Design and Optimization of Vacuum Airships with Currently Available Materials

a project presented to
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Master of Science in Aerospace Engineering

by

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Abstract

This project proposes and designs airships that generate all the lift from air buoyancy. The airship can hover indefinitely for free if leak-free and not failing by other modes. The per-unit cost of the production is modest. The size of the airship is modest. With a radius of 12 m, it can be used as urban eVTOL. The infrastructure requirements are modest, close to none. The vehicle can be used as an air crane to decongest seaports and railway stations, even off-port and off-station. It is easily maneuverable and does not require particular training of the users. It can replace seagoing ships for transportation of goods from inland China to inland United States. It can be used for high-altitude spacecraft launch, which is cheap and controllable. The launch vehicle need not be dedicated. It can be an airship for goods transportation and when needed can be used as launch vehicle. All this with modest costs. Preliminary considerations of urban and economic impact are made.

Acknowledgments

I am greatly indebted to my advisors Professor Periklis Papadopoulos and Nicholas Cramer for all the help throughout my studies for the MS in aerospace engineering. They believed in me, they believed that the idea of vacuum airships stands a chance, and systematically helped me to advance the idea.

I came at the SJSU specifically to work with Professor Papadopoulos in vacuum airships. It was a great and rewarding experience.

Throughout the year 2022 I had weekly meetings with Professor Cramer where we discussed a wide arrange of technical details of the feasibility and advanced the idea.

Professor Nikos Mourtos greatly helped me throughout all the stages of my studies at SJSU.

Being a lifelong university lecturer and professional learner, I have often found myself in the weird situation of being classmates with my students. I have always been amazed by their ingeniuty in the approach of the different aspects of engineering. I have had many rewarding engineering discussions with my classmates/students.

Last but not least, I want to thank Adriana Daudt for her talent, skill, patience in helping me throughout the various procedures at SJSU, both as a student and as a teacher.

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Nomenclature

Table 0.1: List of symbols.

Symbol	Definition	Units
atm	1 atm pressure, 101,325 Pa	atm
δ	Tensile yield strength	Pa
φ	The golden ratio; $\frac{1+\sqrt{5}}{2}$	unitless

Table 0.2: List of subscripts.

Subscript	Meaning
d	regular dodecahedron
i	regular icosahedron
s	spherical. Both “is” and “si” mean “spherical regular icosahedron”

Chapter 1: Historical Perspective and Objective

1.1 Brief history of the art

Archimedes of Syracuse introduced what is now known as Archimedes' principle in circa 246 BC, in his work *On Floating Bodies* comprised of two books. In its English translation [1], page 257 it states

> Any solid lighter than a fluid will, if placed in the fluid, be so far immersed that the weight of the solid will be equal to the weight of the fluid displaced.

For this, Archimedes is widely acknowledged as the father of hydrostatics.

In 1670, Italian Jesuit priest Francesco Lana de Terzi [2, 3] applied the principle of Archimedes to the air and vacuum and hypothesized vacuum airships, also known as vacuum balloons, that generate the entire lift from displacement of air taking place by means of an evacuated structure, rather than by a structure enclosing gases lighter than air, like helium, hydrogen, hot air and the like.

For this work Lana de Terzi is regarded by some as the father of aeronautics. When a working specimen of a vacuum airship will finally be built, Lana de Terzi will prove quite prophetic, a genius more than 352 years ahead of his time. Already at his time the vacuum pump was invented by Otto von Guericke, 1650. All the materials and the technology to produce commercially viable vacuum airships were available. Besides, the compactible airship design later introduced here could have been a really cheap alternative of the vacuum pump. There is no need for a 100% vacuum.

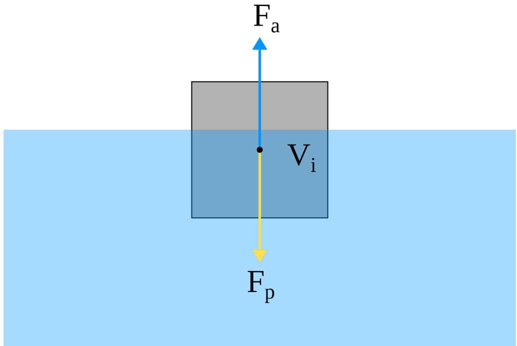

Figure 1.1: The buoyancy F_a and the weight F_p of the object must be equal $F_a = F_p$.

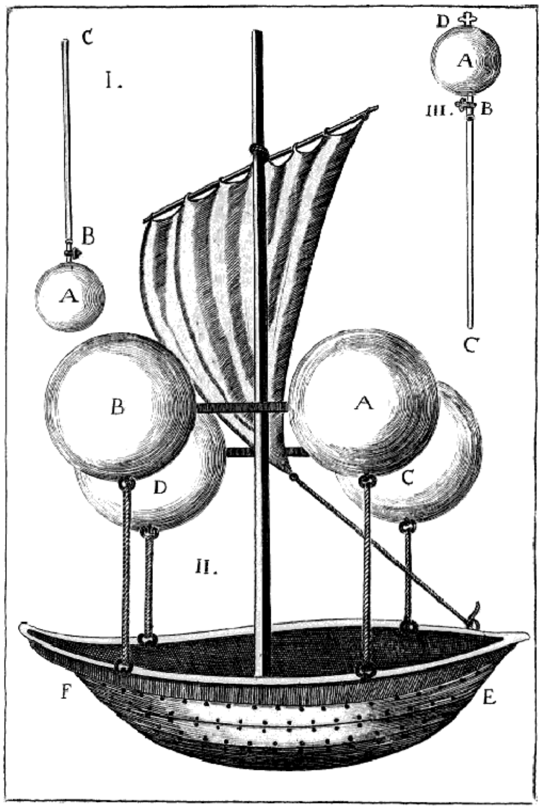

Figure 1.2: Francesco Lana de Terzi's flying boat concept. Public domain.

Figure 1.3: A 1983 Belize postal stamp commemorating the work of Lana de Terzi on the occasion of the 200th anniversary of the first manned flight. Public domain.

Should Lana de Terzi have succeeded centuries ago, it would have overtaken the seagoing ships and there would have never been a “Rule, Britannia! rule the waves” because the waves would have not been worth ruling. Ruling the entire airspace is an entirely different matter.

These airships are low-cost, consume comparably little electricity for thrust by an air fan (propeller, impeller) similarly to a hovercraft. Once lifted, it costs theoretically nothing to float forever. In practice there is air leakage into the vacuum airship, but this can be minimized. Lift can be generated through a vacuum air pump. Little to no infrastructure is needed to run them. The airship can run across land and sea and is VTOL, vertical take off and landing.

There are alternatives to the air pumps, but this is also size-dependent. A second, inner skin, much thinner and more versatile, can be installed inside the first, outer skin. To create vacuum and lift, this skin is partially or totally pulled out. To land, this skin is pulled in. In this way, the vacuum air pump has a much more marginal role to play, lift, and needs not be part of the general design.

Often in the transportation of goods in batches time is not an issue, fuel cost is. In these circumstances, vacuum airships can take advantage of opportune wind currents to cut fuel costs. Wind currents change with altitudes and times of the day and the year. This can make transportation so cheap that transporting freshwater from some places having it in abundance to some places lacking it is several times cheaper than desalination. This is not meant to resolve all freshwater problems for all places and all times, just some freshwater problems for some places and some time, when and where convenient.

Flying vacuum airship cranes can help decongest the ports, railways, also outside of the ports and railway stations. This can be much cheaper than current helicopter cranes that beat the air into submission. Removing the constraints on ports and railways, it allows all sizes of ships outside port constraints to be served in all ports. Ships simply anchor farther outside the port and are served from there.

Another use of vacuum airships would be Venus exploration as reported next in literature review. In fact, airships that float at sea level on Earth are very useful on Venus because at 1 atm pressure and 50 km above datum, conditions on Venus are much Earth-like, except for the fact that the air is mostly carbon dioxide rather than breathable oxygen.

1.2 Project objective

The goal of this project is to establish the feasibility of very useful vacuum airships with currently available cheap materials and of practical sizes. The feasibility of the designs is established in silico, that is with extensive computational simulations, like FEA analysis in Autodesk Inventor Nastran [23] of designs with real-life parameters.

Chapter 2: Literature Review

2.1 Historical approach

Since Lana de Terzi [2, 3] first proposed vacuum airships, research has been occasionally done in the topic but there has not yet been built a functioning vacuum airship. The problem is notoriously interesting, and notoriously hard to tackle. The fact that it has not been resolved in 352 years despite being so interesting, is a testament to its difficulty of treatment. This has resulted in a dearth of academic research, although there is currently happening a minor renaissance of the topic.

In 2000 Illinois historian Howard Lee Scamehorn [4] claimed that Albert Francis Zahm and Octave Chanute publicly denounced and mathematically proved the fallacy of the vacuum airship principle. He does not give his source. Anyway, our views on feasibility are diametrically opposite to Zahm and Chanute, should Scamehorn be correct.

In the years 1886 – 1900 Arthur de Bausset [5] tried in vain to raise funds to build the vacuum airship. There survive no workable designs of de Bausset for vacuum airships.

Armstrong [6] obtained in 1921 a U.S. patent for a composite double wall structure, including honeycomb cellular wall structure. It is our opinion that the double wall structure gives no apparent advantage. Similar structures have never been made to function.

2.2 Modern attempts

In 1983 Noel [7] proposed the geodesic sphere covered with two plastic films filled with air. The inner plastic film borders with vacuum, the outer borders with the atmosphere. There are no known materializations of this idea. While a geodesic sphere can be made to work, it is not the optimal approach. The two plastic films structure should not function.

In 1985 Bliamptis [8] filed for a U.S. patent of an “evacuated balloon” for solar energy collection. No working specimen are known of this patent. The currently prevailing opinion is that the airships of Armstrong, Noel, and Bliamptis would not have been buoyant.

In 2006 Akhmeteli and Gavrilin [9] filed for a patent for a double-layered vacuum airship. A 2021 paper [10] explains the technical details of their double-layered vacuum airship. No working specimen has been reported by the authors or others.

Many authors discuss the employment of new, sometimes futuristic materials. Shikhovtsev [11] and Zornes [12] use graphene in their designs. Materials play a role in the efficient design of vacuum airships. That said, the necessary materials already exist, for centuries. Obviously all improvement is welcome.

Clarke [13] proposed double-layered vacuum airships to be used as a means of transportation on Mars. Given the thinness of Mars atmosphere, all possible designs of vacuum airships are much harder, but possible, on Mars, and may be viable means of transportation.

The ideas of Jenett et al. [14] go along the same lines as above. Double layered lattices with ultra-light, ultra-strong materials are proposed.

Woodley [15] proposes the design of new materials to enable the construction of vacuum airships for Venus exploration. Actually vacuum airships can be built with currently available cheap materials and that they are much more useful on Earth than on Venus, although they can be used on all three planets; Earth, Venus, Mars, and possibly on the gas giants from higher up.

European Space Agency [16] has received many suggestions to use vacuum airships in Venus exploration. Nothing is publicly known about the details, or feasibility, or technological readiness.

Sellers [17] notices that the mass of the air inside a sphere at sea level grows cubically but fails to notice that the atmospheric pressure grows quadratically, like the surface area of the sphere.

Vacuum airships can be used for high altitude spacecraft launch. High-altitude spacecraft launch vehicles need not be dedicated. It can be a cargo airship that is loaned for the brief launch. The high altitude launch has a long list of benefits, like smaller size of spacecraft, cheaper spacecraft, less heat shielding, less fuel needed, less atmospheric drag, etc. The launch window is practically the entire year as the launch altitude can be significant, 55 km or more, and the launch can happen above most relevant weather. These issues are discussed in the abovementioned paper. The authors did not give sufficient details to make the design feasible.

2.3 Current situation

Lighter-than-air vehicles in general are currently undergoing a renaissance, as seen in the peer-reviewed scientific literature and the news [18, 19, 20, 21]. This only emphasizes the dire need for airships in general and vacuum airships in particular.

Vacuum airships are in fact better than helium and hydrogen airships, even if helium and hydrogen came with no strings attached. In fact, the mass of helium and hydrogen enclosed is usually much bigger than the mass of the structure of the vacuum airship. This is again due to the cubicity of the mass of the gas with the radius of the enclosing sphere. This means that times are interesting for the idea of vacuum airship.

No designs of vacuum airships are known to have flown to date based solely on vacuum buoyancy.

Chapter 3: Methodology

3.1 Introduction

Spherical shapes are assumed only for simplicity. Later on other structures are considered that are more optimal than spheres, but not necessarily the most optimal structures. The surface area of a sphere is

$$S = 4\pi R^2 \tag{3.1}$$

Converted to force under the atmospheric pressure at sea level it becomes

$$F_S = 4\pi R^2 \cdot atm \tag{3.2}$$

This is the force that the structure must withstand at sea level.

The volume of the sphere is

$$V = \frac{4}{3}\pi R^3 \tag{3.3}$$

Converted to force at sea level under air buoyancy (complete vacuum) this is

$$F_V = 1.225\frac{4}{3}\pi R^3 g \tag{3.4}$$

This is the theoretically best force generated by the vacuum. To this the force of the mass of the structure under gravity, mg, is subtracted to obtain the force available for useful lift.

The parasitic force from the mass of the structure grows like the surface area of the sphere, that is quadratic. The force of vacuum lift grows cubically, like the volume of the sphere. Eventually the parassitic mass has a smaller and smaller share. Theoretically this is all nice and good. Eventually the vacuum lift overtakes the parasitic force. This fact is illustrated in Figures 3.1 and 3.2. The point is, that must happen within useful ranges of parameters. This is exactly the point made in this entire project.

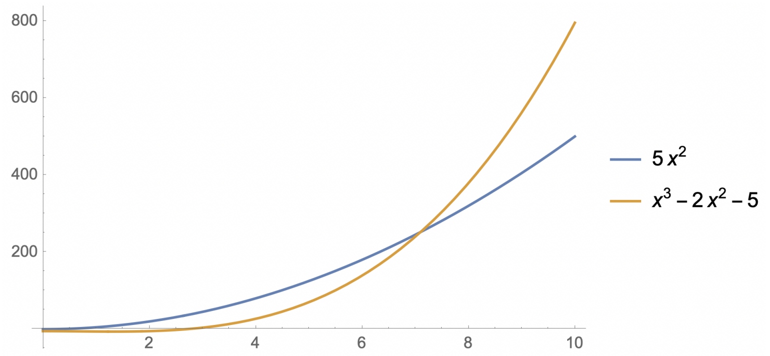

Figure 3.1: At a small scale, the quadratic function can be bigger than the cubic function.

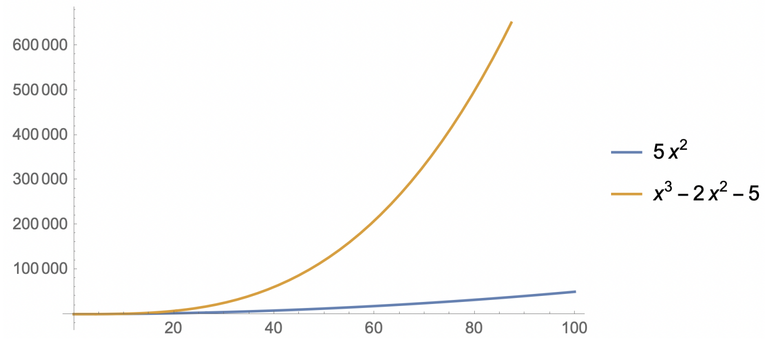

Figure 3.2: As the scale increases, the cubic function takes over the quadratic function more and more wildly.

3.2 Platonic solids: regular dodecahedron and regular icosahedron

The goal of this project is not to provide the most optimal shape of a vacuum airship; just a workable, usefully optimized shape. The geodesic sphere was first considered above. That creates gross problems with the accumulation of the moments at the poles. Even along the meridians forces are pointlessly accumulated. The structure can fail for a vast number of reasons although it is feasible. The goal is to have most of the structure in tension with minor parts in compression.

Pipes may not be the optimal choice for the parts in compression, but they are among the best choices. Then the profile (cross section) of the pipe needs further optimization. Furthermore, the shape and curvature of the pipes matters. The spherical icosahedron is an improvement for the structure.

Eventually the vacuum airships will be built of all shapes. To do useful work they will have a very uneven force distribution, with more forces in the bottom end. This might be optimized in many ways, or by simply making the bottom edges progressively thicker.

There is one more element that makes vacuum airships particularly nice. In tension the vacuum airship skins can be made really thin from steel. Although its mass and weight still grows quadratically, in practice this is not an issue. Furthermore, the only elements that are under compression are the edges. They ought to be reasonably thick. But their mass increases linearly with respect to the radius of the sphere. Their

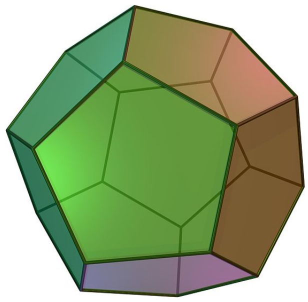

Figure 3.3: The regular dodecahedron.

mass depends on a variety of design choices. This is studied here more in detail for the dodecahedron and icosahedron Platonic solids. This is not a statement that these solids are the optimal design. In this document "regular icosahedron" and "icosahedron" are used interchangeably, as well as "regular dodecahedron" and "dodecahedron".

3.3 The regular dodecahedron

"Dodecahedron" is Greek for "twelve-faced". It has 12 faces, 20 vertices, 30 edges. Its face is a regular pentagon. Denote by $\varphi = (1+\sqrt{5})/2$ the golden ratio for the entirety of this project. Then its vertices are given below up to a multiple. Certainly any other dodecahedron can be obtained by multiplying these vertices by any constant. This is very useful for designs and simulations in Autocad Inventor and FEM, FEA.

The coordinates of the twenty vertices for edge length $a_d = \sqrt{5} - 1 \approx 1.236$ and circumradius (radius of the circumscribed sphere) $R_d = \sqrt{3} \approx 1.732$ are given below. The multiples of the edge give the multiples of the coordinates. Signs vary independently. Twelve of them can be obtained by cyclically rotating anyone of them except for the first.

$$(\pm 1, \pm 1, \pm 1), \qquad \left(0, \pm\varphi, \pm\frac{1}{\varphi}\right), \qquad \left(\pm\frac{1}{\varphi}, 0, \pm\varphi\right), \qquad \left(\pm\varphi, \pm\frac{1}{\varphi}, 0\right) \tag{3.5}$$

If a is its edge, then its surface area, volume, and circumradius are respectively

$$A_d = 3\sqrt{25 + 10\sqrt{5}}a_d^2 \approx 20.645728807a_d^2 \tag{3.6}$$

$$V_d = \frac{1}{4}(15 + 7\sqrt{5})a_d^3 \approx 7.6631189606a_d^3 \tag{3.7}$$

$$R_d = a_d\frac{\sqrt{3}}{4}(1 + \sqrt{5}) \approx 1.401258538a_d \tag{3.8}$$

3.4 The regular icosahedron

"Icosahedron" is Greek for "twenty-faced". Its face is a regular triangle. It has 20 faces, 12 vertices and 30 edges. If a is its edge, then its surface area, volume, and

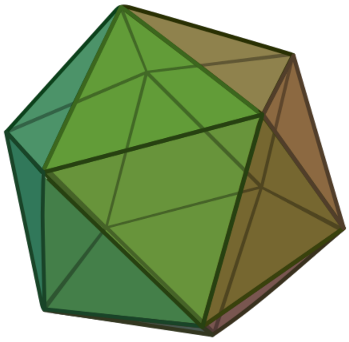

Figure 3.4: The regular icosahedron.

circumradius are respectively

$$A_i = 5\sqrt{3}a_i^2 \approx 8.66025404a_i^2 \tag{3.9}$$

$$V_i = \frac{5}{12}(3+\sqrt{5})a_i^3 \approx 2.18169499a_i^3 \tag{3.10}$$

$$R_i = a_i \sin\frac{2\pi}{5} \approx 0.9510565163a_i \tag{3.11}$$

The coordinates of the vertices of the icosahedron with edge $a_i = 2$ and circumradius $R_i = \sqrt{\varphi^2+1} \approx 1.902$ are given below. The multiples of the edge and circumradius give the multiple of all the other parameters by the equations above. The new coordinates are the multiples of the coordinates below. They all can be obtained by cyclically rotating anyone of them. Signs vary independently.

$$(0, \pm 1, \pm\varphi) \qquad (\pm 1, \pm\varphi, 0) \qquad (\pm\varphi, 0, \pm 1) \tag{3.12}$$

3.5 Discussion

No claim is made that the optimal choice is icosahedron or dodecahedron or anything else. They might be, but the optimal choice might be to be discovered. Besides, other design considerations ought to be kept in mind that outweigh the optimal choice for withstanding atmospheric pressure.

To find out which of the two is better, the volume of the vacuum is fixed, then the sum of all edges and the area for each case are calculated. Even this is not sufficient optimization. For a well optimized design, edges and facets are lighter if they are to sustain lighter loads.

It is obvious that our skeletal structure deforms under stress. This must be kept into account in the design of the sheets. Sheets must be sufficiently larger to not be torn by the structural strain of the frame. This in turn increases the surface area exposed to the atmosphere, therefore it increases the force to be borne by the frame. There are options to this design. This is a design where the sheets are affixed to the edges. Alternatively, all the faces together can be free of the edges. Now there is no problem with the tearing of the covers under frame stress, and a new problem appears. That is the problem of asymmetric dimples in the vacuum airship. This should not be a big issue. Generally speaking, dimples create some turbulence that serves as a lubricant for the vacuum airship and brings down damping from air friction.

One thing is clear from considering only regular dodecahedron and icosahedron. In all other cases the situation is similar. The length of the frame increases linearly with the radius. The mass of the frame increases quadratically with the length of the radius because for bigger structures as thicker cross sections of the beams are needed. But this linear part that multiplies the length is comparably tiny and limited. Properly considered, the cross section of the pipes grows linearly with the radius.

The surface and mass of the covering sheets increases quadratically. The lift generated from the vacuum increases cubically. These are all good news for the design. The worse parts of the design grow quadratically, the best part (lift from the evacuated volume) grows cubically.

It is possible to have vacuum airships entirely under compression, even in spherical shape. Simply this design is not optimal.

3.6 Impact of the altitude

Until now sea level or thereabout considerations were made, where most activity would take place. There is important activity taking place at higher altitudes. Avoiding mountains, climbing up to take advantage of good winds, launching spacecraft from as high as affordable, weather balloons with completely different life spans, doing human activity in the mountains. This is a shortlist of activities taking place at higher altitudes. There is a problem with increased altitude, the fact that air becomes exponentially less dense. The density ratio [22] falls with altitude, as shown in Figure 3.5. With respect to a datum it is given by the equation

$$\rho = \rho_b \left[\frac{T_b}{T_b + (h - h_b) L_b} \right]^{\left(1 + \frac{g_0 M}{R L_b}\right)} \tag{3.13}$$

where

1. $R = 8.31446261815324\ N \cdot m/(mol \cdot K)$ exactly is the universal gas constant,
2. $M = 0.0289644\ kg/mol$ is the molar mass of Earth's air,
3. h is the height above sea level in geopotential meters,
4. ρ is the density in kg/m^3,
5. T_b is the standard temperature in K,
6. L is the standard temperature lapse rate in K/m,
7. $g_0 = 9.80665\ m/s^2$ is the gravitational acceleration of Earth.

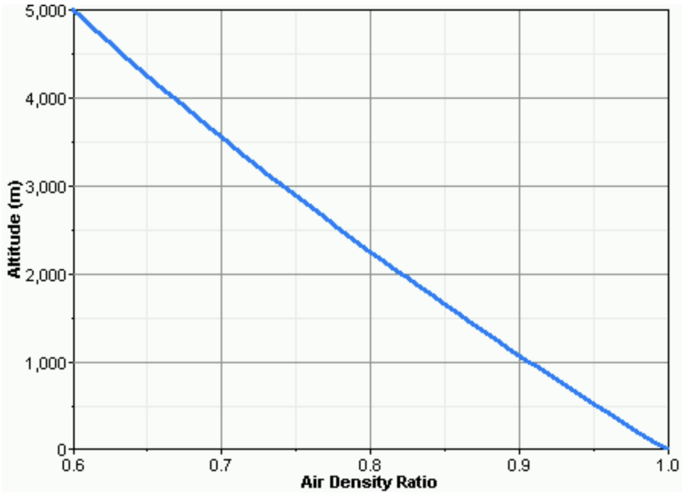

Figure 3.5: Air density drop with altitude for the first 5 km.

Lapse rate is the rate at which a parameter falls with altitude. Geopotential height or altitude is an adjustment to Earth's mean sea level accounting for variations of gravity with altitude and latitude. It is a gravity-adjusted height. The datum most usually is standard sea level. This fall of air density penalizes all types of flying devices. At 5 km altitude, about 60% of sea level air is left. It is accounted for by providing for sufficiently large lift for the given task.

Chapter 4: Firm and Compactible Designs

4.1 The main firm design

The process of designing any useful product is iterative and a process of refinement. Considerations to be kept into account are listed, then in the refining process they are specified more clearly. The more complex the product, the truer this is. Energy efficiency, structure mass, aerodynamic behavior are some of the most important considerations. The choices made also depend on the materials available and many other considerations.

For the purpose of this project, round bodies are assumed and other simplifying assumptions are made. Examples are the frames in figures 4.2 and 4.2. Their edges are arcs. They are the radial projections of the edges of the regular dodecahedron into the circumscribing sphere. This design has the advantage that some more forces partially cancel each other. The outward arc structure is an unstable equilibrium, but this is a very well studied structure in many other applications.

In Figure 4.5, the spherical icosahedron has been so rotated that the x axis passes through two diametrically opposed vertices. The spherical icosahedron has been stretched by a desired factor to yield the vacuum dirigible.

In Figure 4.8 joining rims can be made airtight by applying, for example, silicon along the outer contact rim. The skin itself can be rolled with the edge inward. This limits the sites of possible air inflow.

In Figure 4.7, the two points in the interior are situated away from the plane. One leftmost and one rightmost edge are situated in the plane, as are the endpoints of the two edges cut in half.

The gondola in Figure 4.8 is designed to carry 2 – 4 people. The radius of the airship is about 12 m. The gondola is about the size of the habitacle of a car.

Unless otherwise stated, all parts are designed by the author in Autodesk Inventor [23].

4.2 Compactible designs

Umbrella-shaped structures have important aerospace engineering applications, like vacuum airships for Venus exploration for example. It can take many shapes. Here are two examples.

One configuration is this. The skin and the frame are compacted into one stick vaguely resembling an umbrella. A steel cable runs inside, through the extremities of

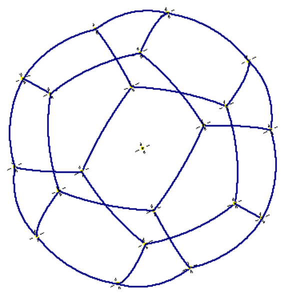

Figure 4.1: Spherical dodecahedron.

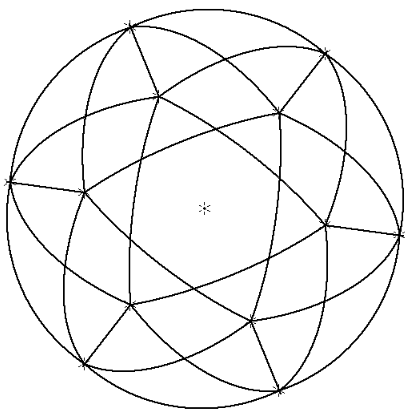

Figure 4.2: Spherical icosahedron.

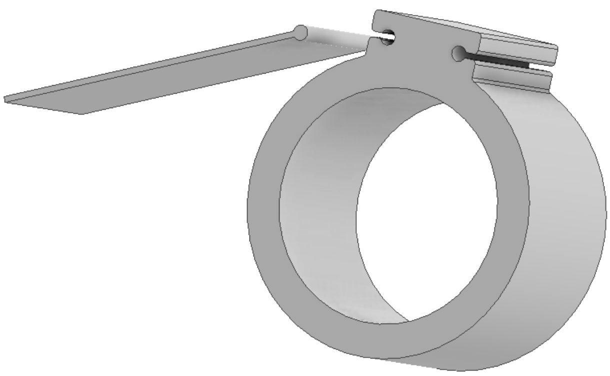

Figure 4.3: An example of how skin and frame can be joined together.

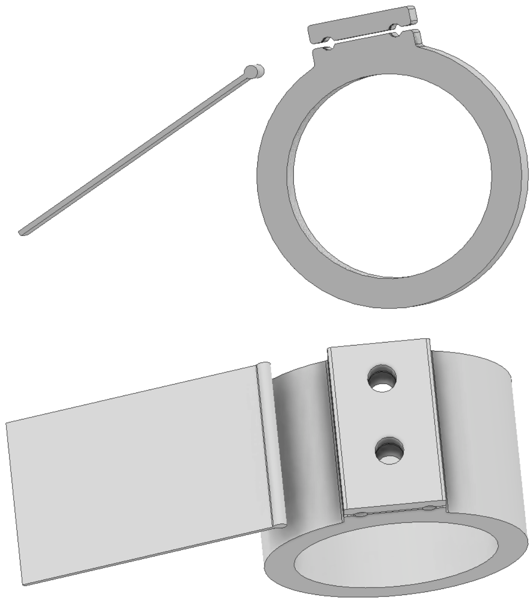

Figure 4.4: Two views of the cross section of an example of fastening the skin to the ribs.

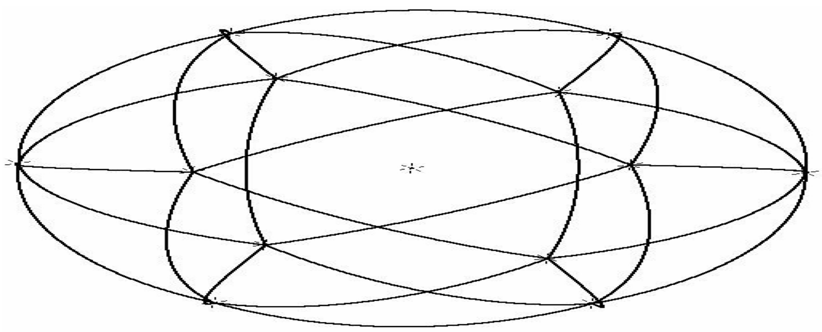

Figure 4.5: Aerodynamic considerations may favor other shapes of the vacuum airship, like this vacuum dirigible.

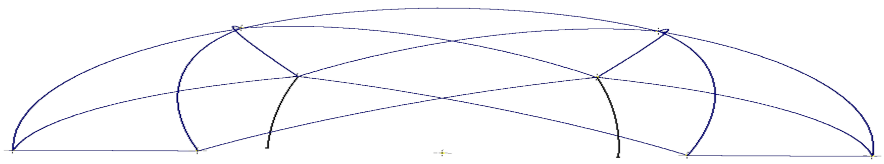

Figure 4.6: A cross section along the xy plane of the vacuum dirigible in Figure 4.5.

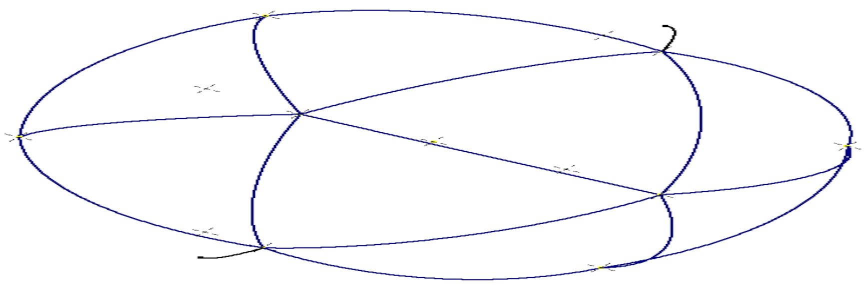

Figure 4.7: An xz cross section of the same dirigible, or otherwise a rotation of the cross section in Figure 4.6.

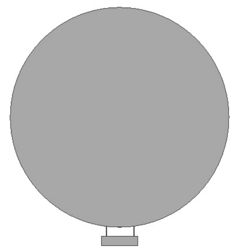

Figure 4.8: A representation to scale of the vacuum airship and the gondola.

the device. When deploying, the cable is collected to some extent in one pole, and the structure takes the spherical shape. Here the shape of the frame is not necessarily icosahedral.

Another configuration is the following. The skin and the frame are squeezed flat and locked. The structure is so built that when unlocked it would become a stick, as above. But a steel cable of appropriate length prevents this, and the structure retains an approximately spherical shape.

All these shapes, squeezed flat or squeezed into a stick, help carrying vacuum balloons in the rockets to Venus where they are deployed to stay for long periods of time at the designed altitude. There is no need to carry a vacuum pump as the deployment happens at an altitude at Venus where at once the vacuum naturally occurs and the gravity of Venus is felt. So the vacuum balloon will naturally descend on Venus. The vacuum balloon itself should be sufficient to guarantee a smooth descent. If this is not the case, a parachute can be attached to the vacuum balloon to further smoothe the descent.

Chapter 5: Structural Analysis

5.1 Preliminary considerations

Various elements of the vacuum airships have been proposed up to this point. To show their feasibility, the existence of practical choices of parameters that withstand the forces involved must be shown. In all of the shapes like spherical icosahedron, icosa-dirigible the beams are in unstable equilibrium. In exchange, they offer advantages that no other designs offer. A lot of stresses partially cancel each other. This allows for more slender structures. The next best choice are the straight beams. They are the optimal choices if stable equilibrium of the beams is desired. They are not equally good at partially canceling stresses, therefore need to be thicker to withstand more stress.

The optimal cross section of the beams may be something else than a thin pipe and it depends on many design consiredations, but thin pipes are in general close to optimal. Here all beams are assumed to be thin pipes. “Pipe” and “thin pipe” are used interchangeably. The ratio of the inner and outer radii of the pipe is important and receives attention later on in this chapter.

Not all beams of the airship carry the same amount of load. Therefore not all beams need to be equally thick. The distribution of the forces on a beam is important. The goal of this chapter is proving that vacuum airships can actually be built. This means that concerns about load distribution are ignored and assume that the load is equally distributed.

In practice the vacuum airship can be of ovoid shape, or many other shapes. At this level of technology readiness these considerations only complicate matters uselessly and shall be ignored. The main sources of structural load are

1. Air buoyancy on the frame
2. Pressure differential on the skin
3. Gondola and the useful mass that is being transported, on the frame
4. Mass of the frame
5. Mass of the skin
6. Winds

It is impossible to properly order them by magnitude as the share of each of these loads in the overall load greatly varies with the size of the airship. They must add up to 0 to have the airship in equilibrium. Also, their distribution is nonhomogeneous.

The different loads being different at different locations dictates that not all beams have the same thickness. The beams in the “south pole” need to be thicker because they carry the buoyancy and useful mass load in most designs.

Especially winds and control of the device dictate other shapes than the spherical ones considered until now. It could be ovoid or anything else. The device could contain wings and other elements for control. This too dictates a varied distribution of loads.

As a matter of example let us assume that the structure is a regular icosahedron with an edge (beam) of length a_i. Then a beam of length a_i is bound to a canvas in each side. The area of each canvas (face) is at least

$$A_{i,side} = \frac{\sqrt{3}}{4} a_i^2 \tag{5.1}$$

if the face is plane. Most usually it is dimpled, concave. Each face discharges on each beam 1/3 of its stress coming from the atmospheric pressure. Each beam has two such faces. The force of each canvas on each edge (beam) is therefore

$$F_{i,1} = \frac{\sqrt{3}}{12} a_i^2 \cdot atm = \frac{1}{4\sqrt{3}} a_i^2 \cdot atm = 0.1443375672974 a_i^2 \cdot atm \tag{5.2}$$

They are at an angle of

$$\phi_i = \arccos\left(-\frac{\sqrt{5}}{3}\right) \approx 138.189685^o \tag{5.3}$$

For comparison, the dihedral angle of the dodecahedron is

$$\phi_d = \arccos\left(-\frac{1}{\sqrt{5}}\right) \approx 116.56505^o \tag{5.4}$$

Therefore there is a bigger cancellation of forces in the icosahedron than in the dodecahedron. This is one argument in favor of the icosahedron.

The same considerations for the regular dodecahedron with edge of length a_d yield the following. The face is a regular pentagon. The area is at least

$$A_{d,side} = \frac{1}{4}\sqrt{5(5+2\sqrt{5})} a_d^2 \approx 1.7204774 a_d^2 \tag{5.5}$$

Only 1/5th of the force is discharged on a given edge, that is

$$F_{d,1} = \frac{1}{20}\sqrt{5(5+2\sqrt{5})} a_d^2 atm \approx 0.34409548 a_d^2 atm \tag{5.6}$$

Another argument in favor of the icosahedron is the load distribution along the beams. The dodecahedron has sharper loads in the center of the beams, greatly contributing to bigger moments of inertia. For tubes and rods in general this is a fourth degree polynomial of the radius, and for the thin-walled pipes a third degree polynomial.

A third argument is that the faces of the icosahedron are triangles, therefore more stable. Also, having the gondola attached to a vertex of the icosahedron makes the load better distributed faster as each vertex gathers five beams. These beams each touch five more beams, some in common.

The resultant force on a beam of the icosahedron is the shorter diagonal of the rhombus that the forces form. This is due to the obtuse angle between the forces. So,

$$F_{i,2} = F_{i,1}\sqrt{2 \pm 2\cos\phi_i} = F_{i,1}\sqrt{2 \pm 2\frac{\sqrt{5}}{3}} = \sqrt{\frac{6-2\sqrt{5}}{3}} \cdot \frac{\sqrt{3}}{12} a_i^2 \cdot atm = \tag{5.7}$$

$$\frac{a_d^2}{12}\sqrt{6-2\sqrt{5}} \cdot atm \approx 0.10300566479164912 a_i^2 \cdot atm \tag{5.8}$$

Therefore $F_{i,2} < F_{i,1}$, the worst-case scenario being $F_{i,2} = 2F_{i,1}$. The cancellation of forces is considerable. Only about 35.68% of the worst-case scenario force remains.

The same considerations for the regular dodecahedron yield

$$F_{d,2} = F_{d,1}\sqrt{2 \pm 2\cos\phi_d} = F_{d,1}\sqrt{2 \pm 2\frac{1}{\sqrt{5}}} = \tag{5.9}$$

$$\sqrt{\frac{2\sqrt{5}-2}{\sqrt{5}}} \cdot \frac{1}{20}\sqrt{5(5+2\sqrt{5})} a_d^2 \cdot atm = \tag{5.10}$$

$$\approx 0.361803398874989 47 a_d^2 \cdot atm \tag{5.11}$$

As expected, only about 52.57% of the theoretical maximum force remains. This is worse than the icosahedron but still very desirable. The icosahedron design again shows its superiority. It cancels forces better than the dodecahedron design.

There are 30 such edges in either the icosahedron or the dodecahedron, each contributing 1/30 to the buoyancy lift. That is, the volume per beam for the icosahedron is

$$V_{i,1} = \frac{1}{30} \cdot \frac{5}{12}(3+\sqrt{5}) a_i^3 = \frac{1}{72}(3+\sqrt{5}) a_i^3 \approx 0.072723166354 a_i^3 \tag{5.12}$$

For the dodecahedron

$$V_{d,1} = \frac{1}{30} \cdot \frac{1}{4}(15+7\sqrt{5}) a_d^3 \approx 0.2554372986874877 a_d^3 \tag{5.13}$$

A first-order comparison, for the same edge length, the dodecahedron creates about

$$\frac{0.2554372986874877}{0.072723166354} = 3.5124611797498115 \tag{5.14}$$

times more lift while sustaining about

$$\frac{0.36180339887498947}{0.10300566479164912} = 3.5124611797498115 \tag{5.15}$$

times more stress. That is exactly the same number. From here the advantages of the icosahedron are the stability of the triangle and the fact that the stress load is better spread out along the beam. This creates more tolerable moments of inertiae. Besides, the area of the pentagon is about 3.97 times bigger than the area of the triangle. This means that the dodecahedron must be covered with a thicker canvas. A better comparison is this. For the same lift generated, that is volume enclosed, with the icosahedron the same number of beams is needed, but they must be 3.5 times longer than for the dodecahedron. The per-beam stress sustained is slightly smaller for the icosahedron.

Yet another comparison is this. The volumes of the icosahedron and dodecahedron are respectively

$$V_i = \frac{5}{12}(3+\sqrt{5})a_i^3 \qquad V_d = \frac{1}{4}(15+7\sqrt{5})a_d^3 \tag{5.16}$$

For the same volume,

$$\frac{5}{3}(3+\sqrt{5})a_i^3 = (15+7\sqrt{5})a_d^3 \tag{5.17}$$

$$a_i = \sqrt[3]{\frac{3(5+3\sqrt{5})}{10}}a_d \tag{5.18}$$

The surface areas are respectively

$$A_i = 5\sqrt{3}a_i^2 = 5\sqrt{3}\left(\sqrt[3]{\frac{3(5+3\sqrt{5})}{10}}\right)^2 a_d^2 \qquad A_d = 3\sqrt{25+10\sqrt{5}}a_d^2 \tag{5.19}$$

Their ratio is

$$\frac{A_i}{A_d} = \frac{5\sqrt{3}\left(\sqrt[3]{\frac{3(5+3\sqrt{5})}{10}}\right)^2}{3\sqrt{25+10\sqrt{5}}} = \frac{\sqrt[6]{\frac{3}{5}}\left(5+3\sqrt{5}\right)^{2/3}}{2^{2/3}\sqrt{5+2\sqrt{5}}} = 0.9692625554191894 \tag{5.20}$$

The icosahedron wins this comparison too, having a surface area of about 3.07% smaller than the dodecahedron for the same lift generated. This translates to a slightly smaller atmospheric pressure needed to withstand. This combines very well with the fact that there is a much greater cancellation of forces in the icosahedron.

The per-beam contribution to the buoyancy force is obtained by multiplying by air density at sea level, 1.225 kg/m^3 and per gravity constant g. The advantage of longer beams is clear, as the useful lift grows cubically. These two forces do not compare in the sense that one has to be bigger than the other. They are all forces absorbed by the beams. For small lengths of the beams the mass of the beams is less than or equal to the mass of the displaced air. After that there is useful net lift. The considerations of this paragraph are valid at sea level. At higher levels, like 40 km up, the density of the air and buoyancy are different.

The force generated by the useful lift is in tension: gondola and cargo pending on the structure, for example on a vertex of the icosahedron. At the five beams of the vertex it is split by five, and the calculations continue so on. That is, there is one vertex in contact with the load, five in contact with it, five in contact with them, and one vertex in contact with the last five vertices. This is easy in silico and could be given as an interesting undergraduate Statics class homework problem.

From an engineering viewpoint, tension is much easier to deal with than compression. The fact that the load is in tension simplifies the design. In fact, cables can be employed in addition to beams to significantly decrease the mass of the structure.

The goal is to prove in silico that the design is feasible and in fact very efficient. The structure only lifts itself and will be kept from escaping by a thread. This does not generate any loads to be kept into account. For any bigger radius it generates useful lift. Therefore the mass of the structure and skin must be less than the mass of the enclosed air.

5.2 Load analysis of the beams

In this section all the beams are assumed straight thin-walled tubes. Let r be the outer radius of a beam. Then the inner radius is $0.9r$. Then the surface area of the ring which is the cross section of the thin pipe is

$$A_{ring} = \pi(r^2 - 0.81r^2) = 0.19\pi r^2 \tag{5.21}$$

The volume of the beam of length a is

$$V_{beam} = 0.19\pi r^2 a \tag{5.22}$$

The mass of the beam made of a material of density ρ is

$$m_{beam} = 0.19\pi r^2 a\rho \tag{5.23}$$

For the cases considered here, the load distribution over the beam is isosceles triangular with the base being the entire beam. The beam is fixed on both ends.

5.3 Compressive strength of the frame

Compression (aka compressive, compressive Young's) modulus E of an elastic material is the ratio of the applied stress to the resulting strain

$$E = \frac{\sigma}{\varepsilon} \tag{5.24}$$

where E is the compression modulus, σ is the applied compressive stress, ε is the strain, that is (compressed length)/(original length). It is also called bulk modulus.

Compressive strength, CS, is the maximum compressive stress that, under a gradually applied load, a given solid material can sustain without fracture

$$CS = \frac{F}{A} \tag{5.25}$$

where F is the applied force and A is the area of the cross section of the material.

There is evidence through private communications that 3D printing with metal powders produces materials of superior mechanical properties and fewer defects.

Shear strength is the maximum amount of compressive stress a component can withstand when subjected to two opposite forces that act on two different, tangential areas [24]. The strain produced due to the shear stress is referred to as shear strain. There is no shear stress or strain worth noting in our designs.

Some aluminum alloys have a compressive strength of 280 MPa [24]. The density of the alloy is approximately that of the aluminum, 2.7 g/cm^3. There are steels that are much better than that, but aluminum wins in specific compressive strength, that is (compressive strentgh)/density, which matters the most. The density of the steel in general can be assumed 8 g/cm^3. There exist other materials with better specific compressive strength, but they are prohibitively expensive. Throughout this document, other considerations, like unconsidered failure modes, prices, etc. can override our choices. The goal of this project is to prove the feasibility and usefulness of the vacuum airships, not to descend into the finest details of fine-tuning the design of an efficient vacuum airship.

Compressive yield strength is the stress measured at the point of permanent yield, zero slope, on the stress-strain curve [25]. Most of the information for the rest of this section is taken from the same source.

Glass fiber has a density of about 2.5 g/cm^3. Some plastics mixed with glass fiber at different proportions offer excellent mechanical properties in compression and tension as well. Having small densities in general, this furthermore emphasizes their specific compressive yield strength, that is (compressive yield strength)/density. ABS (Acrylonitrile butadiene styrene, density 0.9 $g/cm^3 - 1.53$ g/cm^3) with 30% glass fiber has a compressive yield strength of 120 MPa. POM (polyoxymethylene, density 1.4 g/cm^3) copolymer with 30% glass fiber has a compressive yield strength of 100 MPa. POM is reported as acetal in [25].

Some PAI (polyamide-imide, density 1.48 g/cm^3) have a compressive yield strength of 130 MPa. Please notice that plastic materials bundled together under the same name can differ by length and branching of the polymer chains, functional groups, mechanical properties and more. Some PI (polyimide, density 1.42 g/cm^3) have a compressive strength of 150 MPa. PI with glass fiber stands at 220 MPa and compressive modulus of 12 GPa. While the percentage of glass fiber is not stated in the source, it is assumed about 30%. It is therefore assumed that the density of this material is 1.7 g/cm^3. All the calculations of feasibility are done with this material in mind. In fact, mild steel water pipes from Home Depot are sufficient for a proof of concept of the device.

5.4 Tensile strength of the skin

The tensile stress and strain issue is considered the easier of the two problems (tension, compression) to solve, which is why the design is made largely in tension. Tensile strength is the maximum amount of pulling that a material can withstand without being permanently damaged [24]. As always, specific tensile strength rather than tensile strength is of interest to us. That is, (tensile strength)/density. There are in fact many more considerations ought to be made over the material choice for the skin and the frame for the matter. Creep resistance is one of them. The airtightness of the material is not an issue. Any material can be coated on the outside by a thin layer of plastic and be made airtight.

Aluminum 6061-T6 has a tensile strength of 310 MPa [24]. In specific tensile strength it is better than steel and titanium. The density is 2720 kg/m^3. Graphene has a Young's modulus of 1 TPa and a density of 2.267 g/cm^3, close to diamond [26]. It has not yet been produced in reasonable amounts, sizes, and prices to assume using it. The same goes for single-walled carbon nanotubes. Silicon carbide (SiC, carborundum) has a Young's modulus of 450 GPa, a tensile yield strength $\delta = 3.44\ GPa$, and a density of $\rho = 3.16\ g/cm^3$. Again, the best specific tensile yield strength δ/ρ is desirable. Kevlar has a tensile strength of about 3.62 GPa and a density of 1.44 g/cm^3.

The size of the frame can be assumed to grow linearly with the size of the vacuum airship, but in fact it grows linearly with the atmospheric pressure that it has to withstand, and with the payload, whichever greater. The lesser of the two is not kept into account. Generally the mass of the frame is manageable.

The size of the skin grows quadratically with the size of the vacuum airship. The bigger the size of one patch of the skin corresponding to a face of the frame, the thicker it needs to be to withstand a greater force from the atmospheric pressure.

These considerations alone make sure that vacuum airships exist, even if they are built homogeneously thick, entirely in compression. The problem is, the size and cost would be impractical. This is why the holy grail of this project is making the vacuum airship mostly in tension, except for the frame that is in compression.

Most materials are generally about one to two orders of magnitude better in tension than in compression. The holy grail of this project is making the vacuum airship mostly in tension, except for the frame that is in compression. For these reasons, the mass of the skin shall be omitted from further considerations of the vacuum airship structural analyses.

New materials are being made of graphene that are 10 times stronger than steel and more lightweight than carbon [27]. They are 2D assemblies of graphene that fill the 3D space. These futuristic materials are not relied upon in this project, as welcome as they are. In fact, vacuum airships can be built right now, and they will be an economic miracle: cheap to make, modest infrastructure and energy requirements, very useful.

5.5 Force magnitude and distribution along the beam

Now there are left to consider only the frame and the atmospheric pressure that is acting as if the frame were covered and evacuated. While not entirely accurate, it may be assumed that the beam is fixed at both ends. The beam is a thin pipe, which is straight or a circular segment defined by two adjacent vertices and the center of the icosahedron. In either case the vertex angle of the formed isosceles triangle is

$$\alpha_i = \arccos \frac{\varphi}{1+\varphi^2} \approx 63.4349488^o \tag{5.26}$$

The triangle so defined is almost equilateral, as suggested by Equation (3.11) where the radius is almost equal to the edge.

By comparison, for the dodecahedron

$$\alpha_d = \arccos \frac{1+\varphi}{\sqrt{3(1+\varphi^2)}} \approx 37.37736814^o \tag{5.27}$$

This is compatible with Equation (3.8).

The spherical icosahedron has the advantage that even more forces cancel each other. The disadvantage is that it is in unstable equilibrium, unlike the regular icosahedron. In real life neither of them has a planar face. The optimal face of the spherical icosahedron is furthermore complicated.

In the regular icosahedron and dodecahedron, force distribution along the beam is isosceles triangular. Let h be the height of such a triangle. In the regular spherical icosahedron and dodecahedron it is not, but misses by not much and for simplicity can be assumed to be so. Let the overall force over the beam be F and the distribution function be f over the beam of length a. Then

$$F = \int_0^a f ds = \frac{1}{2} a h \tag{5.28}$$

From here,

$$h = \frac{2F}{a} \tag{5.29}$$

This equation turns useful when placing loads on beams during simulations. The load is an isosceles triangle of height h.

Chapter 6: Examples

No modal analysis (the study of the natural frequency modes) is performed, only static analysis. This is not the case with the real-life vacuum airships that need to withstand engine vibrations and wind frequencies without entering in resonance with their natural frequencies.

The thin-walled pipes assumption was made to keep the moment of inertia a cubic function rather than a quartic function. The thickness of the walls of the pipes must then be 10% or less of the external radius [28]. This is not a limiting assumption in vacuum airships.

6.1 Personal VTOL vacuum airship

Let us build an icosahedral vacuum airship with edge $a_i = 12\ m$. Then the area is $A_i = 5\sqrt{3} \cdot 12^2\ m^2 = 720\sqrt{3}\ m^2 \approx 1247.0765814495917\ m^2$ and the volume is

$$V_i = \frac{5}{12}(3+\sqrt{5})a_i^3 = 720(3+\sqrt{5})\ m^3 \tag{6.1}$$

The mass lifted at sea level is

$$m_i = 720(3+\sqrt{5}) \cdot 1.225 = 4618\ kg \tag{6.2}$$

Per Equation 5.8, the force sustained by each beam is

$$F_{i,2} \approx 0.10300566479164912 a_i^2 \cdot atm = 1.503\ MN \tag{6.3}$$

This is the force that the beam has to withstand. This is the load placed on the beam. The load distribution is isosceles triangular with peak given by Equation 5.29

$$h = \frac{2F}{a} = 250,489\ N/m \tag{6.4}$$

There are many ways to park these VTOLs. One is the following. There are steel cables in the parking lot. They can be on the ground, or still better kept upright by a small vacuum airship. A person lands in the parking lot then lifts the VTOL up someplace in the cable where he anchors it. To come down, the ship is released then lowered to the ground. Such a cheap and trivial design allows for many-story storage of the VTOLs.

Each beam need not be uniformly thick. It is whatever suggested by the load distribution analysis. Usually the airship has the gondola in a vertex here called south. In the icosahedron and spherical icosahedron that vertex has six other non-adjacent vertices. Thin steel cables can connect these six vertices to the south pole, in sight tension. This contributes negatively to the overall mass of the structure, and helps better distribute the weight of the gondola in the structure.

6.2 A cheap Mach 120 rocket

Consider launching a vacuum airship from the depths of the ocean. The water buoyancy can give it 120 Mach velocity, or about 40 km/s. This is:

1. low in the technology readiness scale.

2. an interesting thought experiment that could see the light of the day.

3. a first-order calculation, therefore grossly inaccurate. The behavior of the water, cavitation, supercavitation, friction, viscosity, mixed-phase fluids, properties of the materials, etc. are not kept into account.

At these velocities it is quite possible that new, unknown aerodynamic and hydrodynamic phenomena will appear. All the better. I am personally curious to see the behavior of heat transfer in such big amounts of heat in such tiny fractions of time. Will heat evaporate a layer of the material without having time to go deeper? Heat dissipation in space can happen through evaporation, liquefaction, and radiation. It goes without saying that all the known properties will wildly deviate from their expected behavior. Nobody will launch a 120-Mach vacuum balloon before trying enough of 3-, 10-, 20-, 30-, ... 110-Mach vacuum balloons.

How to descend the vacuum balloon to those depths? Well, for sure this is not a free meal or a perpetum mobile. It is just at shred costs as compared to the currently available alternatives. Some simple infrastructure is necessary. At the bottom of the ocean ought to be installed some simple structure made of blocks of concrete and stones that can hold down such an empty vacuum balloon. Here is a possible procedure.

1. The vacuum balloon is of a hydrodynamically suitable shape. It has attached to it, inside or outside, the useful load that can be a load to be slingshot to Mars, to the Moon, to the Earth orbit, or a rocket to hit a target on the Moon, on the Earth orbit, or on Earth. The acceleration endured by the structure is of such enormity that no life can survive in it, even for the smallest interval of time. This can be useful nonetheless.

2. A regular ship brings the vacuum balloon to the desired ocean location. The mass of the vacuum balloon is not prohibitive. It can be made lighter by evacuating the air. This same ship brings a water pump, fuel to be converted to electricity, a sufficiently long power cable that can also lower and lift the water pump, as clarified later in the following.

3. While being lowered from the ship to the depth of the ocean, the vacuum balloon is filled with seawater, at least partially, sufficiently to slowly sink it without problems.
4. The filled, descended vacuum balloon is hooked to the undersea structure.
5. A water pump evacuates the seawater from th vacuum balloon. The electricity for the pump is provided by the ship on the surface that converts gasoline to electricity, or something similar. The ship and the pump are connected through a cable that is capable of lifting the ship and provides the electricity. It is wise that the ship does not stay straight above the vacuum balloon during the water evacuation and launch.
6. The water pump is lifted to the ship, the ship moves away from the site.
7. The vacuum balloon is launched from the seabed.
8. As soon as it reaches the ocean surface, the vacuum balloon opens (if the cargo is inside) and the useful load launches itself forward by inertia. If the useful cargo is outside in the tip of the vacuum balloon, it could be so designed that just the air resistance over the vacuum balloon leaves the vacuum balloon behind while the useful load continues forward by inertia.

The vacuum balloon used in this launch better be reusable. This would favor vacuum balloons that do not open in contact with the air, just unhinge the useful cargo and drop back in the ocean where they float.

The depth is not the more the better. In fact, the water pressure grows linearly with depth, and so grows the mass of the vacuum balloon of fixed surface area. The final velocity, starting from the 0 velocity is found as follows. F is the water buoyancy force minus the gravity force. The a is the resulting acceleration on the comprehensive mass m. The s is the ocean depth.

$$F = am \rightarrow a = \frac{F}{m} \tag{6.5}$$

$$dv = adt \rightarrow \Delta v = \int_0^t adt = at \tag{6.6}$$

$$v = \frac{ds}{dt} \rightarrow s = \frac{1}{2}at^2 \rightarrow t = \sqrt{\frac{2s}{a}} \tag{6.7}$$

$$v = \sqrt{2sa} \tag{6.8}$$

The last equation expresses the final velocity v as a function of the known acceleration a and depth s. It only increases as the square root function of the depth. That is, increasing the depth by a factor of four increases the final velocity by a factor of two. The exact optimal depth can be found jointly with the rest of the specifications, varying on a case by case basis.

Speed of sound therefore definition of Mach change with the conditions. As an example, in Figure 6.1 gives the speed of sound in water at different depths as derived from data from the 2005 World Ocean Atlas [29].

The variations of speed of sound for the air are shown in Figure 6.2 and are derived from NASA [30]. In the calculations speed of sound is assumed 343 m/s in the air and 1,500 m/s in seawater.

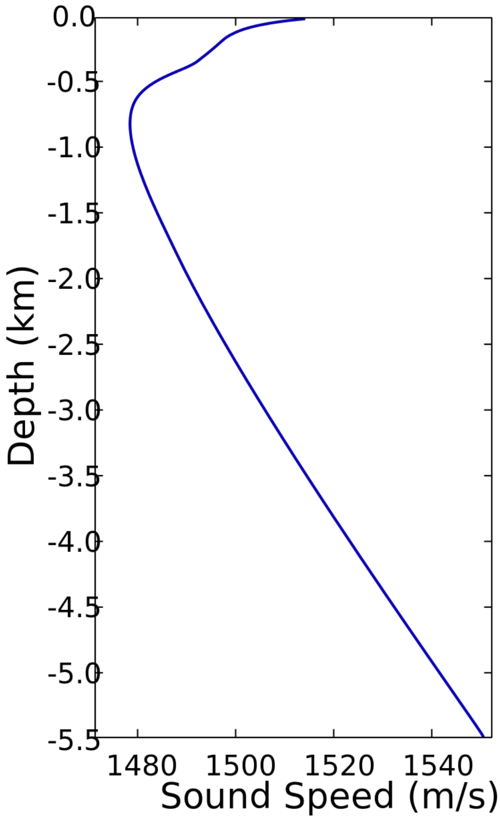

Figure 6.1: Speed of sound as a function of depth at a position north of Hawaii in the Pacific Ocean. Credits NOAA.

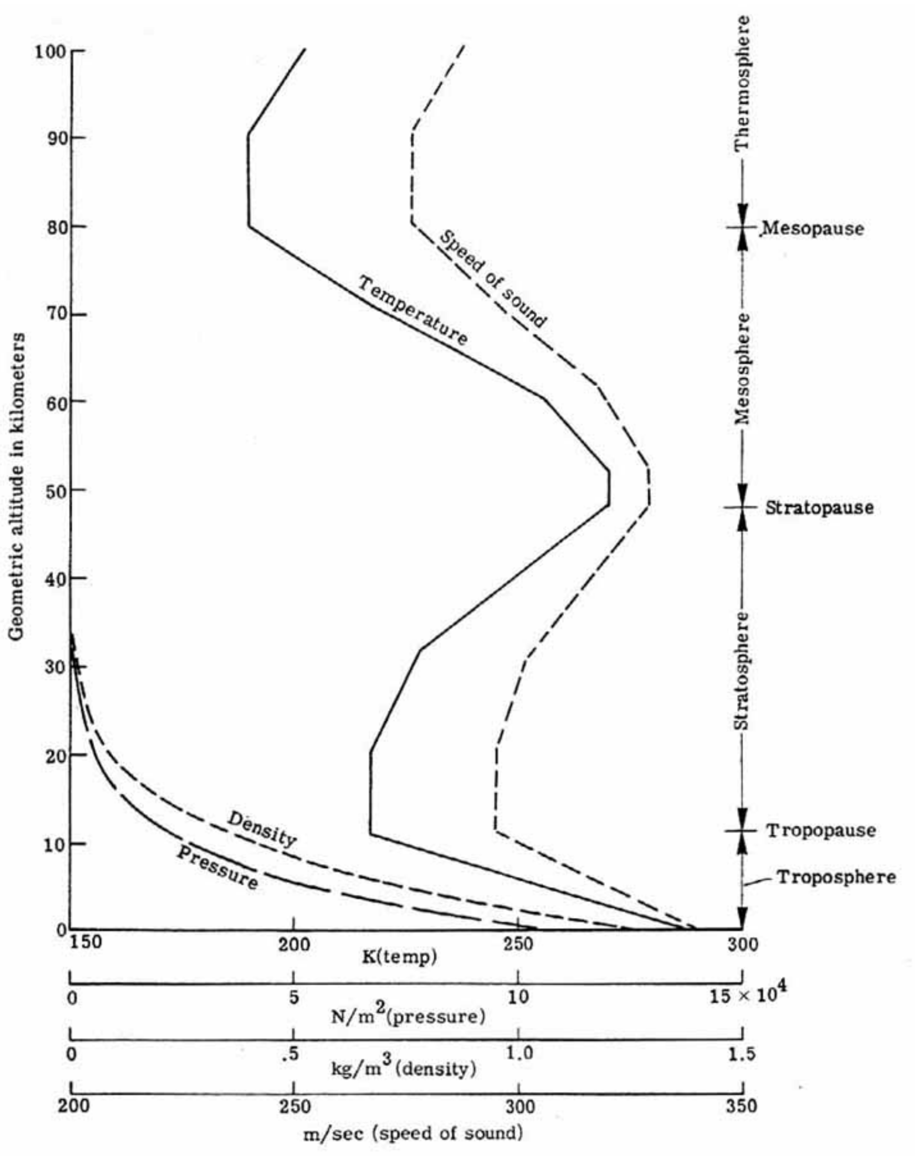

Figure 6.2: Geometric altitude vs. temperature, pressure, density, and the speed of sound derived from the 1962 U.S. Standard Atmosphere. Credits NASA.

It is possible to design smaller vehicles for small accelerations suitable for humans and life in general. This would not be sufficient for a shot to space, but can be thought of as one more stage of spacecraft launch. No comparisons are made between manned launches from ocean depths and from high altitudes. For the unmanned launches, the ocean depths offer unmatched velocities at unmatched low prices, and some unique challenges that with time can be matched.

6.3 Vacuum airship for high altitude spacecraft launch

The main design here is very different from the other designs. The beams and the skin are not designed to withstand full vacuum. They are designed to withstand full vacuum at a very high altitude. That is, as the airship is evacuated, it rises high to lower pressure. The structure need only support the pressure difference, which is easy to calculate: enough buoyancy for the useful mass and the structure. This continues all the way to the designed altitude. One final boost of altitude can be given to the airship by parachuting down everything non-essential, that is the vacuum pump, engines and anything else but the balloon itself and the spacecraft to be launched.

There is yet another method of launching a spacecraft from a vacuum airship. This is similar in many ways to the vacuum balloon in the previous section. The vacuum airship and the spacecraft are tied to the ground. The airship is vacuumed, totally or partially. It is then slingshot. It would have the tendency to reach a much higher altitude than the first design in this section. The biggest altitude is reached with the first round up. At that point the airship is detached from the spacecraft, which then continues to space. Obviously this structure needs to be much more robust than the first structure presented earlier in this section. The acceleration can be adjusted to be tolerable by the humans. This can be achieved by partial vacuum.

6.4 Vacuum airship crane for ship and train containers

A standard container for ships and trains has a maximum laden mass of about 30.481 metric tons. Laden mass is the mass of the container itself, plus the mass of its content. This is the mass that a vacuum flying crane must lift.

Chapter 7: Impact

No ad hoc study was undertaken. The impact considerations are extrapolated from the available similar studies and situations.

7.1 The big picture

The state of development of a country or a region can be quickly and accurately assessed with a glimpse on its infrastructure. Infrastructure is the one defining and limiting parameter of development. On the other hand it is one of the biggest drains of resources in the history of the mankind. It is costly to build and maintain, it has its own limitations to use. The situation becomes more exasperate in sparsely populated countries with particularly hostile natural environment like Texas, Alaska, Canada, Russia, Africa, Central Asia. Canada and Norway feel the pinch less due to the fact that all (Norway) or much of their territory is accessible by sea navigation, which is the cheapest means of transportation currently available.

There are vast known natural resources that make no economic sense because the cost of the necessary infrastructure would outweigh their profitability. There are other vast number of cases that the infrastructure is in place and being used, but it still exacts a heavy toll on our resources.

The importance of the infrastructure becomes obvious with a glance at its prominence in the international affairs. China has made the headlines since 2013 with what it now calls the Belt and Road Initiative (BRI), a global infrastructure development strategy currently involving three continents out of six and nearly 150 out of 195 countries of the world. BRI is likely to increase world GDP by \$7.1 trillion by 2040 and will cost \$4 – \$8 trillion to build. It is politically so important that it has been countered by various initiatives of various countries, including the US initiative to spend hundreds of billions of dollars in domestic infrastructure improvements, and to spend considerable amounts of money in the development of alternative international infrastructure. Similar initiatives have been advanced by several other countries that do not want to be left out of this game.

7.2 The long haul

The long range infrastructure is particularly taxing to build and maintain and with comparably low returns. It is often built out of political rather than economic considerations. Vacuum airships would render that completely irrelevant. The hundreds of billions of dollars earmarked for infrastructure can be redirected anywhere else where needed.

Vacuum airships can replace or relieve the long range infrastructure in its totality. Vast resources suddenly become accessible and economically viable.

For more than a century now, the management of anything in human activities has been modeled with graphs (graph theory, not to be confused with the common usage of the word graph, or graphic). This emphasizes that in actuality humans do not even live in a 2D world, humans live in dots on a 2D surface. This is what our cities, villages, human settlements, factories, mines are: dots on a 2D surface embedded in a 3D space, far from the full colonization of a 2D surface. With the vacuum airships this changes. Not only that. The new space that becomes available is even more suitable for vacuum airships than the centers of our megalopoleis.

All of the sudden, building a home on the top of a mountain becomes a privilege accessible to everybody. This is also desirable because it relieves our cities, costs much less to build than multistory buildings, and uses land that otherwise has low value. This means that it spares the fields for other uses. Where accessible, mountains are usually praized lots for suburban development. Now they are everywhere accessible. Transportation of people, goods and trash from and to can be done with vacuum airships, without need of road infrastructure. Part of the other needs can be covered with networks of electricity, water, sewage. There is a good overlap between needs covered by vacuum airship and other means. It is decided on a case by case basis which one is preferable in which case.

Vacuum airships outstrip seagoing ships in versatility and all the other parameters. Vacuum airships can go to different altitudes and take advantage of air currents to bring down the cost of transportation. Unlike seagoing ships, vacuum airships can go from any point to any point by the optimal (fastest or cheapest 3D path, or any combination, as dictated by the constraints and the desired outcome) path. They are not as much subject to weather as seagoing ships and do not fear underwater rocks. The infrastructure associaded with large vacuum airships is close to null. No seaports, no lighthouses, no floating cranes.

There are too many differences between current airplanes and vacuum airships. Airplanes are faster. This is their only advantage over vacuum airships. Vacuum airships require no airports. They are cheaper to produce and run. They access the entirety of the 2D surface of the planet, from a 3D approach. They are maneuverable at a level unthinkable for airplanes and only comparable to cars. The cost to make and run is incomparably low, several orders of magnitude.

There is no use building new long range roads. Vacuum airships outstrip cars in almost every direction.

The advantages of vacuum airships over ships are gross and clearly visible in the international scene. The travel paths are remarkably shorter. They are not dictated by bodies of water, depth of water. Airships have no limitations dictated by natural or artificial constraints like Panamax, Suezmax, Bosphorus, locks, depth of ports and sea lanes, etc. No strategically important chokepoints like Gibraltar, Panama, Suez, Bosphorus, Malaccas, South China Sea, the island chains around China.

Access to the sea and development are powerfully correlated, which is why countries have fought wars for access to the sea. Bolivia, Austria, Hungary and Serbia bitterly decry their loss of access to the sea. Serbia, Austria, Hungary maintain limited access to the sea through Danube.

Kazakhstan repeatedly proposes to Russia the construction of the 700-km-long

Eurasia Canal in the Kuma-Manych Depression to link the Caspian and Black seas. If built, this will be Russia's own private Bosphorus. It will be the chokepoint where Kazakhstan, Turkmenistan, Azerbaijan and partially Iran have to pass to have access to cheap shipping. Uzbekistan would become singly-landlocked and leave Liechtenstein as the only doubly-landlocked country in the world. If vacuum airships receive proper attention, the Eurasian Canal point becomes moot, alongside with all its political and economic implications.

Part of the aggressive behavior of Russia stems from its self-perception of being a practically landlocked country. Its access to the Mediterranean can be subject to the political will of Türkiye. Its access through the Baltic Sea can be blocked by Norway and Denmark, all three NATO countries. The northern shipping lanes are becoming more and more viable with the global warming, but still Russia's access to the world sealanes is severely limited. Its access to the resources inside its own country is severely limited by the accessibility of its own territory, and this has enormous impact on its economic development, similar to Africa discussed below. All of these points will become moot with the advent of the vacuum airships.

A prominent far-right Russian "philosopher" influential within the Russian elites, one Alexander Dugin, has even coined two neologisms; thalassocracy and tellurocracy, respectively meaning civilization built by the sea and on the mainland. Etymologically the words mean respectively sea-power and land-power. If possible, some among the Russian elites would lock the world out and build for themselves the tellurocratic civilization of their hearts' desire. Vacuum airships grant them their wish. Hope they find with themselves the peace that they deserve and leave the rest of us alone. In a hundred years they will need to find out why tellurocracy did not work out well for Russia and why selenocracy[1] will work.

China routinely harasses free international navigation in what they call South China Sea. Keeping those sea lanes free of charge and unimpeded costs precious resources to the United States. Should vacuum airships receive proper attention, there will be nothing for China to harass because those shipping lanes will lose their economic allure. As a bonus, China would never get the hoped return of investment, nor the hoped international political clout from BRI, its cherished and expensive toy.

African countries without easy access to the sea are remarkably less developed than their maritime and seafaring peers. The history and shapes of Congo Kinshasa and Angola (and Slovenia, Bosnia and many other countries) further illustrate the importance of the sea. The geography of the African interior is currently particularly non-conductive to economic advancement. It is totally useless to build roads in sand deserts (as opposed to firm deserts) because they are harder to build and require very high maintenance. The situation is similar in the Russian and Canadian taiga. Already building long roads is in itself very inefficient, as discussed above.

The geography of Africa is otherwise marred with vast deserts, marshlands, forests, mountain ranges, non-navigable rivers and other disruptive geographical features, all standing in the way of the economic advancement; diseases only compounding the problems. The advent of vacuum airships removes all of these obstacles to economic advancement (except for the diseases) overnight, at no cost, by magic.

[1]Alternately meaning Moon-power and lunatic-power, also a pun on tellurium and selenium.

The advent of the vacuum balloons launched from the bottom of the ocean will give an unimaginable thrust to the space age. Launching goods to LEO, Moon, Mars, Venus and other planets will become a cheap routine. This will facilitate space colonization and mining. Launching humans will become much cheaper as well. Humans and other fragile cargo can be launched to LEO, where they meet the rest of their material requirements to proceed to Mars or other space destination. Already humans can be easily lifted to very high altitudes by means of vacuum airships, almost halfway there.

Launch of satellites will become cheaper, if not largely moot because of their replacement by cheap vacuum airships with the mission of hovering very high for extended periods of time. Besides, these vacuum balloons are recoverable and serviceable, furthermore eroding the price tag and the allure of the satellites.

The vacuum balloons launched from the bottom of the ocean will have important defense implications. The velocities of the rockets and projectiles launched from these vacuum balloons are two orders of magnitude ahead of the electronics development for their perception and neutralization. Furthermore, properly designed, these rockets are also two orders of magnitude down with the price as compared with the currently available rockets.

7.3 The urban setting

One limitation of the vacuum airships is that they start at a relatively big size for a passenger vehicle. A balloon with a diameter of 24 m is still cumbersome for many important applications. Various approaches can mitigate the problem. Compactible balloons are one approach. The balloon does not need to be fully compactible, but it can be. Another approach to mitigate the problem are the oblong balloons, with the long dimension being vertical, or at least becoming vertical in tighter urban environments.

The parking is an issue, but new possibilities suddenly open up. Windows and rooftops of buildings can be used, designed and adapted as parking spaces without essentially adding loads to the buildings. The vacuum airships can be hooked to the buildings while keeping their weight irrelevant through some minimal amount of vacuum always present.

Parking and landing are two different problems. It is possible to land in the road, then lift the vacuum airship to somewhere to park it. In the returning trip, the vacuum airship is approached on the road as desired and possible, it is then un-parked, brought close to the person for use.

Ultimately vacuum airships will not entirely replace the old infrastructure. Roads will remain useful in the cities. Ships will remain useful for fishing as well as for their defense applications. Airplanes will retain their niche of fast transportation among some preset points called airports, as well as their defense applications. Mass transportation will retain its niche, be it by busses, vacuum airships, trains, trams, subways. Some tracts of trains and long haul roads network will retain their usefulness and economic meaning. Other means of transportation besides vacuum airships will appear and claim their own niches.

A large number of bridges and tunnels have been built, designed and envisioned by various engineers at various times and locations.

The bridge of Messina is supposed to connect Sicily with mainland Italy.

The two bridges of the Sakhalin island are supposed to link Sakhalin with Japan and with mainland Russia, effectively turning Japan into a peninsula, like the English Channel Tunnel (aka Chunnel) did with the island of Great Britain. Work on the Russia-Sakhalin bridge started before the Second World War, was interrupted by the war, and never picked up again.

The Bering Strait Crossing is a hypothetical bridge or tunnel or dike linking Alaska with Chukotka, a region of Russia internationally famous for the particular sense of humor of its people. This link would therefore connect by cars and trains North and Central America from Panama to Asia, Japan, Africa, Europe. The strait is 80 km wide at its narrowest and exceptionally shallow. It even contains two islands and other underwater banks at its narrowest. It has been a solid ice bridge for extended geological periods. This enabled the human colonization of the Americas. Dikes have been proposed for other functions than traveling through, including warming up the northern coasts of the North Pacific Ocean thusly making them more economically interesting. No detailed economic, feasibility, and impact studies have been carried out for any of these design choices. From an engineering viewpoint, dikes, bridges and tunnels are all conceptually feasible as the area is low in seismic and volcanic activity. They just make no economic sense currently.

The Helsinki-Tallinn Tunnel is a proposed tunnel that would run undersea in the Gulf of Finland. It would provide a much shorter path from Finland to mainland Europe that does not pass through Russia. In any case it would considerably shorten the travel time between Helsinki and Tallinn.

The Strait of Gibraltar Crossing is a hypothetical bridge or tunnel connecting Morocco with Spain. The Strait of Gibraltar is only 14 km at its narrowest, the sea is particularly shallow but the area is high in seismic activity. In the recent geological past it has been a land bridge as well. Should it be built, my suggestion is that it is built on the sea floor rather than under it. This would make it more resistant to seismic activity and keep the sealanes clear.

A number of canals have been proposed across the globe with the purpose of navigation, like the above-mentioned Eurasia Canal linking Caspian Sea and Black Sea. Other most prominent candidates follow.

The Instanbul Canal links Black Sea with the Marmara Sea, helping decongest the Bosphorus Strait. A stated international political goal of the canal is bypassing the Montreux Convention Regarding the Regime of the Straits. Development of the area around the new canal is another stated internal economic and political goal. Works have started in 2021.

The Nicaragua Canal, an alternative and competitor of the Panama Canal, increasing the revenue and the international political clout for Nicaragua.

Colombia has considered a similar canal competing with the Panama Canal. The Panama Canal itself partially competes for traffic and revenue with the Suez Canal, on the other side of the planet.

A canal linking the port of Thessaloniki, Greece, via the rivers Morava and Axios/Vardar with the Danube therefore shortening the navigation route and reaching central Europe from the Suez without circumnavigating Europe and the Mediterranean sea or entering Danube from the Black Sea is under consideration by China.

All of these objects and many more are wonders of engineering, and a gross drain in the finances of the involved parties. Their very existence further illustrates the importance of the infrastructure. Vacuum airships will render all or most of them useless or almost; certainly unprofitable.

There are various limits placed on skyscrapers. The cost of each floor increases quadratically with the number of floors. The usefulness and the useful floorspace goes down with the number of floors. The taller the skyscraper, the more elevators it needs, although this could be somehow alleviated with the one-way elevators. There are two adjacent elevator lots, both containing many cars. In one lot the cars only go up, in the other only go down. The transfer of cars from one lot to the other is a comparably easy engineering feat.

More elevators necessitates making the surface area at the base of the skyscraper wider and wider to keep the extra floors economically meaningful.

Another limitation is car parking. Both of these problems are alleviated by vacuum airships. People can reach directly to the desired floor rather than use elevators, and park the vacuum airship by the side of the skyscraper, or anywhere else. All these docks for people to move in and out and for vacuum airships to park make skyscrapers less picturesque, but this is a completely different matter. As mentioned before, vacuum airships open up space for building and accessibility of heretofore unused space. This altogether alleviates the need for skyscrapers from a different approach.

The Empire State Building spire was designed as a landing dock for passenger airships. Due to the Hindenburg disaster, this never happened and the spire has been waiting for its patrons since 1931. Vacuum airships can promptly change that.

It is an eerie coincidence that functioning vacuum airpumps were invented two years before Francesco Lana de Terzi even floated the idea of the vacuum airships. Since their conception in 1670, the technology, the materials, and the know-how to build useful, functioning vacuum airships has always been there. If it were done back then, it would have been the pinnacle of the mankind in too many ways to count. Now, more than 352 years later, vacuum airships are long overdue.

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Appendix A: US Patent Application Number US 17/866,472

In the following pages, the original patent application number US 17/866,472 filed with the United States Patent and Trademark Office (USPTO) is attached. Formatting and wording is done in accordance with the USPTO requirements and differs from the rest of this document. The projected publication date is January 18, 2024.

US NON-PROVISIONAL UTILITY PATENT APPLICATION

TITLE:

VACUUM AIRSHIP

INVENTOR(S):

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APPLICANT-ASSIGNEE:

None

CORRESPONDENCE:

Customer Number: 26349
Docket number: IIT-001US

FIELD

[0001] The present technology is in the field of airborne platforms and, more specifically, airships.

BACKGROUND

[0002] A vacuum airship is a hypothetical airship that is evacuated rather than filled with a lighter-than-air gas, such as hydrogen or helium. By eliminating the mass of hydrogen or helium, a vacuum airship has the potential to provide far greater lifting power per volume of air displaced. Therefore, was is needed is a vacuum airship that includes an envelope and a means for controlling a vacuum within an envelope.

SUMMARY

[0003] In accordance with various embodiments and aspects herein, a vacuum airship includes an envelope and means for creating and controlling a vacuum (or vacuum level) within the envelope. The envelope is defined by and includes skin and a frame for supporting the skin, such that the frame is under compression and the skin is in tension during operation of the airship. The frame includes a plurality of rigid tube-like frame elements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] In order to understand the vacuum airship herein more fully, reference is made to the accompanying drawings. The vacuum airship is described in accordance with the aspects and embodiments in the following description with reference to the drawings or figures, in which like numbers represent the same or similar elements. Understanding that these drawings are not to be considered limitations in the claimed scope of the vacuum airship, the presently described aspects and embodiments of the vacuum airship are described with additional detail through use of the accompanying drawings.

[0005] FIG. 1 is an illustration of various components of a vacuum airship, including an envelope, in accordance with the various aspects and embodiments of the invention.

[0006] FIG. 2 is an illustration of a method of operating the vacuum airship of FIG. 1 in accordance with the various aspects and embodiments of the invention.

[0007] FIG. 3 is an illustration of an example of the envelope in accordance with the various aspects and embodiments of the invention.

[0008] FIG. 4 is an illustration of a cross section of the envelope of FIG. 3 in accordance with the various aspects and embodiments of the invention.

[0009] FIG. 5 is an illustration of a structure for binding skin to a frame of the envelope of FIG. 3 in accordance with the various aspects and embodiments of the invention.

[0010] FIG. 6 is an illustration of tensioned skin of the envelope of FIG. 3 in accordance with the various aspects and embodiments of the invention.

[0011] FIG. 7 is an illustration another example of the envelope in accordance with the various aspects and embodiments of the invention.

[0012] FIG. 8 is an illustration of another example of the envelope in accordance with the various aspects and embodiments of the invention.

[0013] FIG. 9 is an illustration of another envelope in accordance with the various aspects and embodiments of the invention.

[0014] FIG. 10 is an illustration of another envelope in accordance with the various aspects and embodiments of the invention.

DETAILED DESCRIPTION

[0015] The following describes various examples of the present technology that illustrate various aspects and embodiments herein. Generally, examples can use the described aspects in any combination. All statements herein reciting principles, aspects, and embodiments as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents and equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure.

[0016] It is noted that, as used herein, the singular forms “a,” “an” and “the” include plural referents unless the context clearly dictates otherwise. Reference throughout this specification to “one embodiment,” “an embodiment,” “certain embodiment,” “various aspects and embodiments,” “various embodiments,” or similar language means that a particular aspect, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment herein. Thus, appearances of the phrases “in one embodiment,” “in at least one embodiment,” “in an aspect and embodiment,” "in certain embodiments," and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment or similar embodiments. Furthermore, aspects and embodiments described herein are merely exemplary, and should not be construed as limiting of the scope or spirit of the claims as appreciated by those of ordinary skill in the art.

[0017] Furthermore, to the extent that the terms "including", "includes”, “having", "has", "with", or variants thereof are used in either the detailed description and the claims, such terms are intended to be inclusive in a similar manner to the term "comprising."

[0018] Referring now to FIG. 1, a vacuum airship 110 includes an envelope 120 and a vacuum pump 130 for creating and controlling a vacuum, vacuum pressure, and/or vacuum level (near-vacuum) within the envelope 120 in accordance with the various aspects and embodiments of the invention. Vacuum (vacuum level or vacuum pressure) is any pressure that is lower than atmospheric pressure in a known volume; atmospheric pressure is the datum point of vacuum as well as the available pressure the vacuum has to offer. Thus, vacuum is a pressure that can be measured. There are pressure measurements specific to vacuum and a defined known volume is used to determine a vacuum state. The volume, defined by the envelop disclosed herein, is a specific space in which vacuum can be considered and measured.

[0019] The envelope 120 may have a substantially outer shape of a Platonic solid. As used herein, a Platonic solid refers to a convex, regular polyhedron in three-dimensional Euclidean space. Faces of the Platonic solid are congruent (identical in shape and size) regular polygons, and the same number of faces meet at each vertex.

[0020] The envelope 120 includes a rigid frame that defines edges of the Platonic solid, and an airtight skin that defines faces of the Platonic solid. The skin is supported by the frame in accordance with the various aspects and embodiments of the invention. The skin surrounds the frame in accordance with the various aspects and embodiments of the invention. Examples of the envelope 120 are described below.

[0021] The vacuum airship 110 may further include a gondola 140 and a propulsion system 150 coupled to the envelope 120. The gondola 140 may be an external equipment or passenger compartment that is attached to the envelope 120.

[0022] The propulsion system 150 may include one or more propulsion engines that are carried in the gondola 140 or placed in separate nacelles. The nacelles may be mounted to the envelope 120. The vacuum airship 110 may also include flight control surfaces (not shown) for adjusting attitude of the vacuum airship 110 during flight.

[0023] The vacuum airship 110 may be configured for any number of applications. Examples include, but are not limited to, an urban vertical takeoff and landing (VTOL) vehicle (e.g., a taxi), an air crane for loading and unloading cargo in seaports and railway stations, a vehicle for moving cargo across land and sea, a truck for moving cargo, a high-altitude spacecraft launch vehicle.

[0024] Reference is made to FIG. 2, which illustrates the basic operation of the vacuum airship 110 in accordance with the various aspects and embodiments of the invention. At block 210, the vacuum pump 130 is operated to create a vacuum in the envelope 120. As used herein, the term vacuum does not refer to a volume that is devoid of air. Rather, a vacuum as used herein refers to air pressure below atmospheric pressure.

[0025] As used herein buoyant force refers to an upward force that at is proportional to the weight of air displaced from the envelope 120. The buoyant force increases as air is removed from the envelope 120. As used herein, lift or lift capability of the airship 100 is equal to the buoyant force minus the weight of the airship 100.

[0026] At block 220, the propulsion system 150 is operated. Force generated by the propulsion system 150, in combination with the buoyant force generated by the envelope 120, moves the vacuum airship 110 in a desired direction.

[0027] At block 230, the vacuum within the envelope 120 is controlled. The vacuum pump 130 may remove air from the envelope 120 to compensate for any air leakage into the envelope 120. During ascent, the vacuum pump 130 may remove additional air from the envelope 120 to increase the buoyant force. During descent, air may be allowed to enter the envelope 120 to reduce the buoyant force. Entry of the air may be allowed by the vacuum pump 130 and/or by one or more valves (not shown).

[0028] Reference is now made to FIG. 3, which illustrates an example of the envelope 120. In this example, the envelope 120 has the outer shape of a dodecahedron. The dodecahedron envelope 120 has twelve faces, twenty vertices, and thirty edges.

[0029] The dodecahedron envelope 120 has a rigid frame 310 and skin 320. The frame 310 defines the edges of the dodecahedron envelope 120. The frame 310 may include a plurality of individual frame elements 330, where each frame element 330 is located at an edge of the dodecahedron envelope 120 and extends between two vertices. The frame 310 is preferably made of a lightweight material that is strong in compression, such as titanium.

[0030] The skin 320 is airtight, and it defines the faces of the dodecahedron envelope 120. The skin is supported by the frame 310.

[0031] Additional reference is made to FIG. 4, which illustrates a cross-section of the dodecahedron envelope 120. The frame elements 330 are tube-like. Cross-section of the frame elements 330 may be circular, rectangular, or other suitable non-cylindrical geometry in accordance with the various aspects and embodiments of the invention. The frame elements 330 may be solid or they may be hollow.

[0032] The skin 320 is made of a thin sheet of a material that is strong in tension. A better ratio of (tensile strength)/density is preferred. For example, thin-gauged steel sheets or sheets of a composite such as Kevlar may be used. If the skin material is not airtight, it can be made airtight with an outer coating of a plastic material.

[0033] In some configurations, the skin 320 is not bound to any of the elements 330 of the frame. In other configurations, the skin 320 may be bound to the frame 310 at a single location, such as where the gondola 140 attaches to the envelope 120.

[0034] Additional reference is made to FIG. 5, which illustrates an example of a structure 510 for binding the skin 320 to a frame element 330 in accordance with the various aspects and embodiments of the invention. This structure 510 may be used In configurations where the skin 320 is bound to the frame 310 at only a single location.

[0035] Additional reference is made to FIG. 6. The skin 320 may be pre-tensioned, for instance by stretching it over the frame 310. The pre-tensioning enables thinner materials for the skin (e.g., steel sheet) to be used.

[0036] During operation of the airship 110, there is a substantial pressure differential between atmospheric pressure (outside the envelope 120) and vacuum pressure (inside the envelope 120). This pressure differential places the frame 310 under compression. It also causes the skin 320 to dimple and to be placed in tension. The dimpling might have the effect of reducing damping from air friction.

[0037] The size of the envelope 120 depends in part on the intended lift requirements. For instance, an envelope 120 in the range of ten (10) to twelve (12) meters would be sufficient for VTOL vehicle carrying four people.

[0038] The vacuum airship 110 is not limited to the examples described above. The geometry of the envelope 120 is not limited to a dodecahedron. For example, the envelope 120 may have the geometry of an icosahedron.

[0039] Reference is now made to FIG. 7, which illustrates an icosahedron envelope 120 in accordance with the various aspects and embodiments of the invention. The icosahedron envelope 120 has twenty faces, twelve vertices, and thirty edges. A frame 710 defines the edges, with each frame element 730 located at an edge 730 of the icosahedron envelope 120 and extending between two vertices. Skin 720 defines the faces of the icosahedron envelope 120.

[0040] Reference is now made to FIG. 8, which illustrates an envelope 120 that is not a Platonic solid in accordance with the various aspects and embodiments of the invention. The envelope 120 of FIG. 8 has the geometry of an icosa-ball. Consider an icosahedron and a circumscribed sphere. As used herein, the term icosa-ball refers to the radial projection of the edges of the icosahedron from its center to the circumscribed sphere The icosa-ball envelope 120 has twenty faces, twelve vertices, and thirty edges. A frame 810 defines the edges. Each element 830 of the frame 810 is arcuate, is located at an edge of the icosa-ball envelope 120, and extends between two vertices. Skin 820 is stretched over the frame 810 to define curved faces of the icosa-ball envelope 120.

[0041] Reference is now made to FIGS. 9 and 10, which illustrate that the envelope 120 is not limited to any particular geometry. FIG. 9 shows the frame 910 of an envelope 120 having the shape of an icosa-dirigible, and FIG. 10 is a transverse cross-sectional view of the frame 910. As used herein, the term icosa-dirigible refers to an icosa-ball that has been stretched along one or more axis. Each element 930 of the frame 910 is arcuate, and skin (not shown) covers the frame 910. Because each frame element 930 is curved, each face of the icosa-dirigible is also curved (as opposed to being flat).

[0042] In each of these examples, the skin is sufficiently large so as not to be torn by the structural strain of the frame. This in turn increases the surface area exposed to the atmosphere and the force borne by the frame.

[0043] In those configurations where the skin is not bound to the frame, there is not a problem of tearing of the skin under frame stress.

[0044] Not all elements of the frame need be equally thick. Thickness will be dictated by the structural loads placed on the frame elements. Main sources of the structural loads include buoyancy, atmospheric pressure, and useful mass that is being transported (for instance, by the gondola 140). Lesser sources of the structural loads include mass of the frame and the skin, and wind. In configurations where the gondola 140 is suspended from the envelope, those frame elements supporting the gondola 140 will be thicker because they carry the buoyancy and useful mass loads.

[0045] Means for creating and controlling a vacuum in the envelope is not limited to the vacuum pump 130. The vacuum pump 130 is but one example. As a second example of such means, a second, inner skin, much thinner and more versatile, may be installed inside the frame to vary the volume of the envelope 120. To increase the vacuum within the envelope 120, this second skin is partially or totally pulled out. To reduce the vacuum, the second skin is pulled in.

[0046] As a third example, an umbrella-like structure can be used instead of the second skin. Closing the umbrella-like structure forces air out of the envelope 120 to decrease the volume to zero, and then opening the umbrella-like structure creates the evacuated envelope 120.

[0047] Certain examples have been described herein and it will be noted that different combinations of different components from different examples may be possible. Salient features are presented to better explain examples; however, it is clear that certain features may be added, modified, and/or omitted without modifying the functional aspects of these examples as described. Practitioners skilled in the art will recognize many modifications and variations. The modifications and variations include any relevant combination of the disclosed features. Descriptions herein reciting principles, aspects, and embodiments encompass both structural and functional equivalents thereof.

[0048] It will be appreciated by those skilled in the art that other various modifications could be made to the device without parting from the spirit and scope of this disclosure (especially various programmable features and architecture). All such modifications and changes fall within the scope of the claims and are intended to be covered thereby.

[0049] The scope of the invention, therefore, is not intended to be limited to the exemplary embodiments and aspects that are shown and described herein. Rather, the scope and spirit of the invention is embodied by the appended claims.

CLAIMS

1. A vacuum airship comprising:

an envelope having a substantially outer shape of a Platonic solid; and

means for creating and controlling a vacuum within the envelope, where the envelope includes:

a rigid frame that defines edges of the Platonic solid; and

an airtight skin that defines faces of the Platonic solid, the skin being supported by the frame.

2. The vacuum airship of claim 1, wherein the skin is stretched over the frame.

3. The vacuum airship of claim 1, wherein the Platonic solid is a dodecahedron.

4. The vacuum airship of claim 1, wherein the Platonic solid is an icosahedron.

5. The vacuum airship of claim 1, wherein elements of the frame are tube-like.

6. The vacuum airship of claim 1, wherein the skin is not bound to the frame.

7. The vacuum airship of claim 1, wherein the skin is bound to the frame at only a single location of the frame.

8. The vacuum airship of claim 1, wherein the means includes an air vacuum.

9. The vacuum airship of claim 1 further comprising a gondola and a propulsion system coupled to the envelope.

10. An envelope for a vacuum airship, the envelope comprising:

a rigid frame that defines edges of a Platonic solid; and

an airtight skin that defines faces of the Platonic solid, the skin surrounding the frame.

11. The envelope of claim 10, wherein the skin is stretched over the frame.

12. The envelope of claim 10, wherein the Platonic solid is a dodecahedron.

13. The envelope of claim 10, wherein the Platonic solid is an icosahedron.

14. The envelope of claim 10, wherein the skin is bound to the frame.

15. The envelope of claim 10, wherein the skin is bound to the frame at only a single location of the frame.

16. A vacuum airship comprising:

an envelope including:

a skin; and

a frame including a plurality of rigid tube-like frame elements,

wherein the frame supports the skin such that the frame is under compression and the skin is in tension during operation of the airship; and

means for controlling vacuum pressure within the envelope.

17. The vacuum airship of claim 16, wherein the envelope has the shape of a dodecahedron and wherein edges of the dodecahedron are defined by the frame, and faces of the dodecahedron are defined by the skin.

18. The vacuum airship of claim 16, wherein the envelope has the shape of an icosahedron and wherein edges of the icosahedron are defined by the frame and faces of the icosahedron are defined by the skin.

19. The vacuum airship of claim 16, wherein the envelope has the shape of an icosa-ball.

20. The vacuum airship of claim 16, wherein the envelope has the shape of an icosa-dirigible.

ABSTRACT

A vacuum airship includes an envelope and means for creating and controlling vacuum pressure within the envelope. The envelope includes skin and a frame for supporting the skin such that the frame is under compression and the skin is in tension during operation of the airship. The frame includes a plurality of rigid tube-like frame elements.

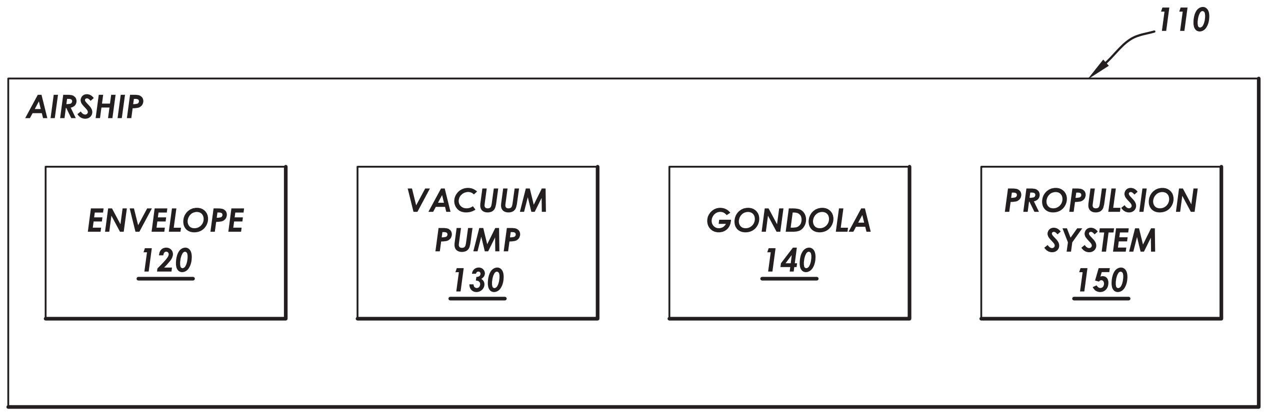

FIG. 1

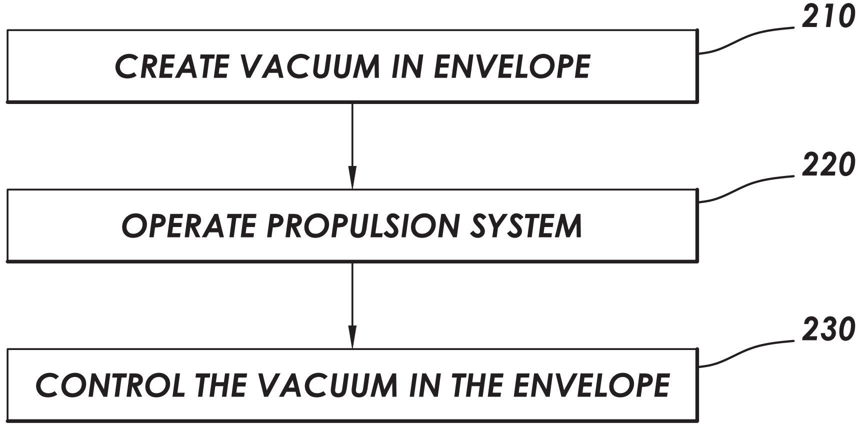

FIG. 2

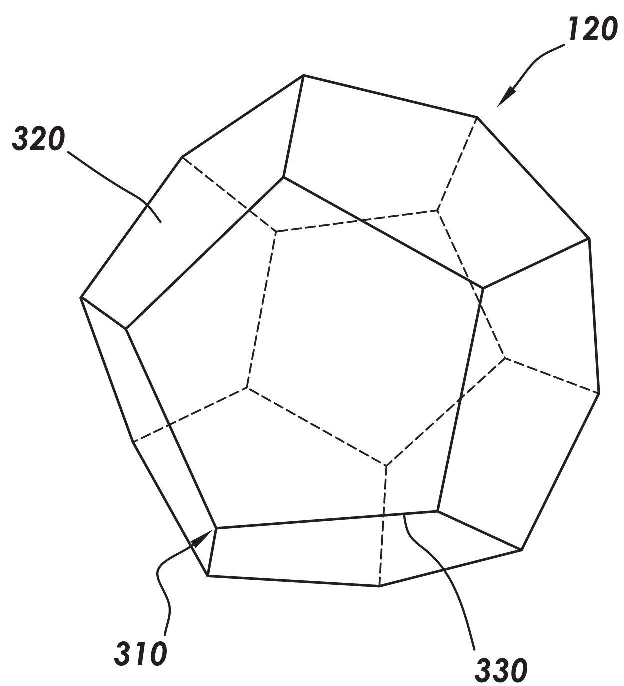

FIG. 3

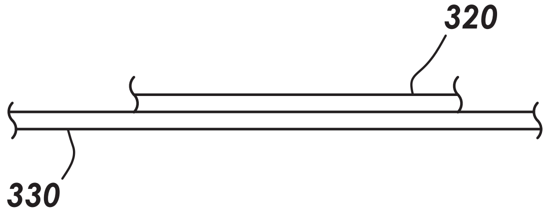

FIG. 4

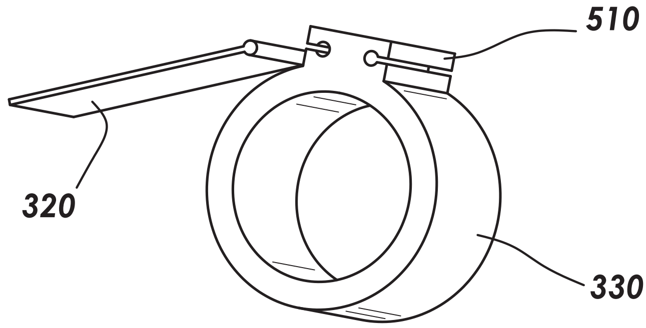

FIG. 5

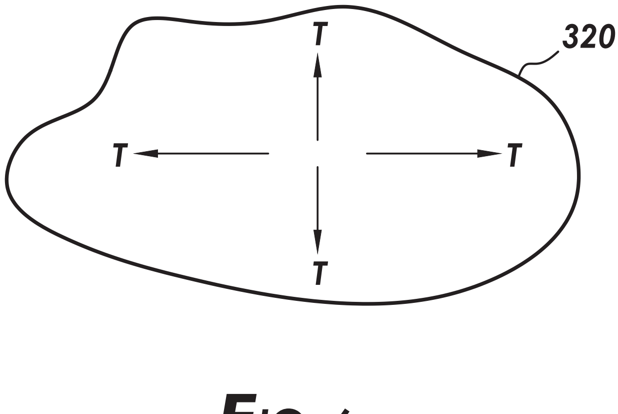

FIG. 6

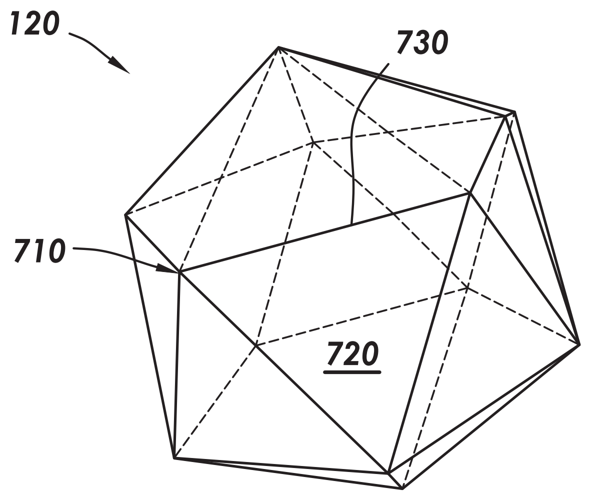

FIG. 7

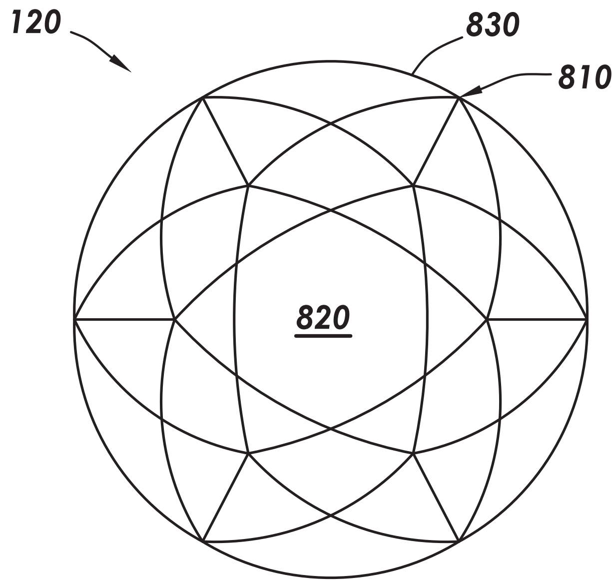

FIG. 8

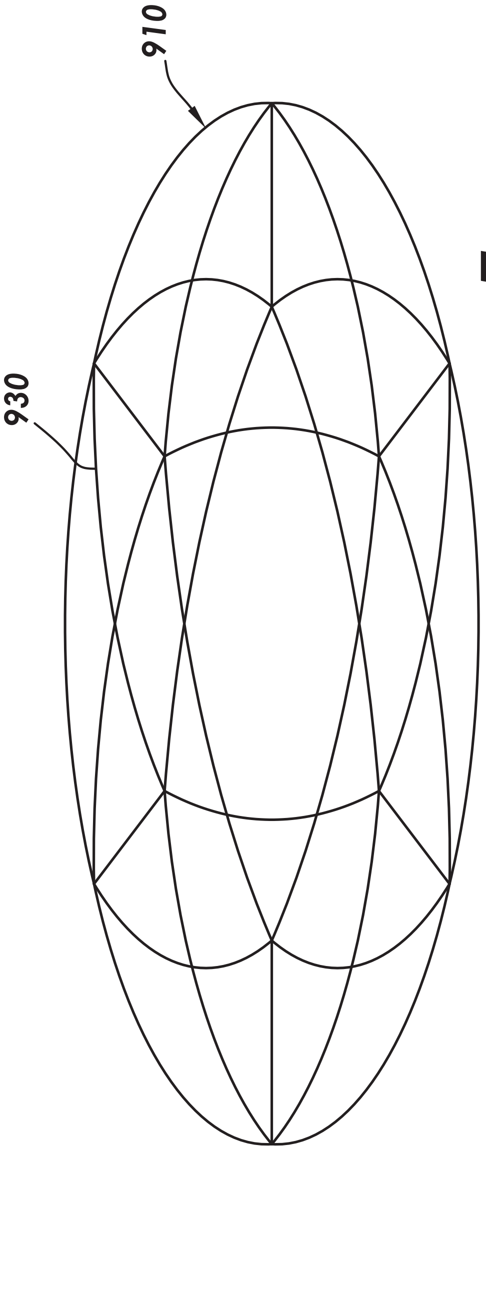

FIG. 9

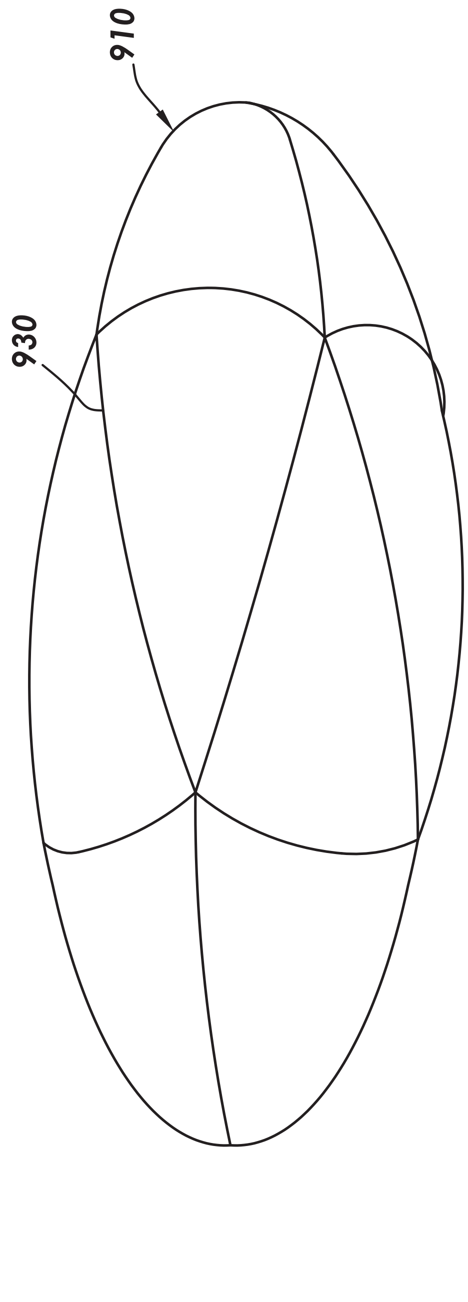

FIG. 10