MULTI-KILOMETER HEIGHT TALL TOWERS

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Multi-Kilometer Height Tall Towers – An Examination

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Abstract

In this age of exponential scientific and industrial growth new technologies are created every single day. The future is bright for hybridized technologies; advancements that occur between fields of discipline. It is this phenomenon that will lead to the realization of many goals and future technologies, which may seem unattainable today. One such endeavor is the construction of increasingly tall structures that could theoretically reach higher than Earth's own atmosphere. The following is an investigation into the possible applications for multi-kilometer high towers. There are several key technologies that are integral to the development of such towers. In light of the fact that few industries could single-handedly benefit from a tower of such height, the magnitude of such an undertaking calls for as many applications from as many different fields as possible. The resultant participation by several individual industries would attenuate the cost and time it would take for the development of multi-kilometer high towers. A heightened demand for the tall tower would bring increased funding for its creation. This paper is also a discussion on the constructability of multi-kilometer high towers and a proposal on different methods to construct them. However, before one discusses "How" to build such a large structure, one must first answer the question "Why should such a thing be built?" The answer to the latter question is a rather detailed and lengthy one that requires many considerations. There are several new technologies as well as several old ones that stand to gain remarkable advantages from the use of a very tall tower. NASA's five strategic enterprises, Earth Science, Space Science, Aerospace Technology, Biological and Physical Research, and Human Exploration and the Development of Space, act as points of departure for the evaluation of uses for a super-tall structure. The first phase of this report is a description of several applications for super-tall towers as well as a discussion on various designs for multi-kilometer high towers. The second phase of the report is a more detailed perspective on a specific tower design with a specific application. The intention of this report is to provide a clear explanation of some of the numerous uses and designs for multi-kilometer high towers.

1. Introduction

A tower is a building or part of a building that is exceptionally high in proportion to its width. It's a tall, slender structure commonly used for observation, signaling, power relay, or pumping. Over the years there has been a great increase in the development of taller structures, primarily because of the many advancements in engineering and man's incessant desire to have bigger and better. Communications technology has had a major impact on the number of towers that exist, because the popularity and appeal of wireless networks has caused the demand for taller towers to increase dramatically. Some of the tallest buildings today are: the CN Tower (553m) in Toronto built in 1973-75; the Petronas Twin Towers (452m) in Kuala Lumpur built in 1998; the Sears Tower (443m) in Chicago built in 1973; and the World Trade Center (415m) in New York built in 1972-73; these among many other skyscrapers that serve as the perfect example of mankind's vision to build structures higher into the sky. The tallest existing structure is a TV antenna, which is 655 meters tall.

Many notable architects and writers have exposed their ideas on constructing buildings as high as our eyes can reach. In 1956, Frank Lloyd Wright designed the Illinois Tower, a skyscraper over one mile high. In 1990 another proposed project intended to be about one kilometer high, was the Tokyo Millennium Tower, a structure that would have taken about ten years and sixteen billion dollars to be built. In 1991 a Japanese architect named Tsui put forth a design for the tallest, most highly populated living establishment of all time. The three and a half kilometer tall Ultima Tower would inhabit as many people as San Francisco and would cost about one hundred-fifty billion dollars to construct. The structure's chief building materials would be high-strength steel and concrete – two of the heaviest building materials that exist. So one can see that if revolutionary building materials and methods of construction were embraced and developed, simpler structures of much greater heights could be constructed.

The idea of super-structures is not in the least a new one. Talk of building beyond the clouds has saturated conference rooms in architectural and engineering firms for decades. Why then, has man not built any of these multi-kilometer tall towers, or MKT's? Seeing that it is an achievable task, only one reason remains: there is an insufficient demand for multi-kilometer height towers. The demand for such structures is so small, in fact, that the idea of a MKT is completely absent from the consciousnesses of industry and society. So the problem faced by an engineer interested in building to new heights is much like the one Galileo faced as he proposed his theory of a sun-centered solar system.

One such "Galilean" scientist was the Russian Yuri Artsutanov who in 1960 proposed the idea of a space elevator that could launch vehicles into space without the use of rockets. His article talks about building a tower thirty-five thousand kilometers high to be the base of the space elevator. The purpose was to connect the Earth's surface with the geostationary Earth orbit level, which is 35,786 km above the Earth's surface, and for the tower to serve as a direct transportation method to space for various applications. Many scientists and engineers dismissed his project as fantastic and theoretically unrealistic.

It should be known, however, that a multi-kilometer height tall tower *is* feasible with today's technology. The scientific advantages that a structure this tall would bring are countless. The tower could serve as a home for high altitude launch platforms, high power communication transmitters and receivers, gravity-bound observatories uninhibited by weather, and several other possible applications. To build such a tall structure, it will be necessary to develop new methods of engineering and construction. The primary purpose of this technical report is to introduce to the scientific community the value and feasibility of constructing a multi-kilometer height tall tower. The introduction is accomplished by presenting applications and future research work to be carried out on towers of extreme heights as well as work to be done on the development of tall structures. Multiple design methods for tall towers are proposed, including materials analysis as well as preliminary structural analysis. Building this type of structure is possible, and innumerable goals can be accomplished if mankind unites its knowledge and dares to imagine the possibilities.

2. Applications

Multi-kilometer height tall towers are a class of structures that have received very little attention from the scientific community. The primary reason for this is that science has failed to realize the great potential of these tall structures. There are hundreds of uses for a super-tall tower that warrant its construction. For the purposes of this discussion, the applications for the tower are viewed through NASA's five strategic enterprises. For the purposes of this section of the report, the reader could assume that a fifteen-kilometer tall structure is already in existence and the following applications are already placed into action.

2.1 Earth Science

Within the realm of Earth Science, many different constraints associated with atmospheric research as well as oceanic and geological studies could be eradicated by use of a multi-kilometer tower. Within the avenue of atmospheric studies alone lay several disciplines that could be completely revolutionized and consequently change the way humanity understands the atmosphere. Some of the disciplines of interest are ozone science, weather science and meteorology.

One of the many applications that would benefit the Earth in a dramatic way is the study of the ozone layer from high altitudes. Ozone is a gas that consists of molecules of three weakly bonded oxygen atoms. The ozone layer shields life on Earth from the harmful effects of the Sun's ultraviolet radiation. The increased amounts of ultraviolet radiation that would reach the Earth's surface because of ozone depletion could increase the incidence of skin cancer and cataracts in humans and animals, harm crops and interfere with marine life. This explains how important the ozone layer is for life on Earth. The ozone layer is located in the stratosphere, the second layer of the Earth's atmosphere, which extends from fifteen to fifty kilometers above sea level. Many methods have been proposed and applied to preserve the ozone layer from destruction. The problem cannot be solved easily but it is possible to find a solution that could minimize the ozone depletion. A fifteen-kilometer high tower would provide some possible methods to stop ozone hole propagation. The ozone hole is expected to be actively increasing for the next fifty years before it will come to it's normal levels. The tower would help raise the ozone levels back to normal in less than 50 years. The ozone tower concept consists of two methods; each method was devised for the purpose of eliminating or reducing the ozone hole.

The first method is centered on destroying chlorofluorocarbons (CFC's), the primary threat to the health of the ozone layer. CFC's are a class of halocarbon compounds consisting of carbon, hydrogen, chlorine, and fluorine that were once used widely as aerosol propellants and refrigerants. High-powered infrared lasers mounted atop the tower at various elevations can be used to destroy the CFC's when they are in the troposphere. The powerful blast would require some moderation, because CFC's molecules need to absorb 30 infrared photons before they are destroyed. A tower with a height of fifteen kilometers would hold several radar detectors to detect the CFC's molecules in the troposphere. Once a high enough concentration of CFC's is detected by the radar, the laser will destroy the harmful molecules, much like radiation treatment is targeted to kill cancerous cells in a human body.

The second method for treating the ozone layer using a fifteen-kilometer high tower is injecting about fifty thousand tons of ethane and/or propane into the Antarctic stratosphere each spring. Through chemical reactions, active ozone depleting molecules containing chlorine would reject their chlorine and create molecules of non-ozone depleting HCL. The tower would release the chemicals into the stratosphere so that they might serve their purpose, this would be done every six to twelve months. The hydrocarbons decompose in about a year, so the process must be repeated annually.

The most obvious solution of manufacturing and transporting ozone to the stratosphere around the depleted areas would be to manually add ozone to the atmosphere, but any ozone that we would artificially add would most likely be destroyed and would not help solve the problem.

Studies show that because ozone is such an unstable molecule, it would most likely decompose to gaseous oxygen (O_2) before it could be of any use to the ozone layer. It must be noted, however, that science has not yet considered manufacturing ozone in the stratosphere itself. Perhaps ozone released into the stratosphere from a high altitude ozone manufacturing facility would in fact survive the short journey to fulfill its purpose. In this manner, having a fifteen-kilometer high tower would provide direct access to studies and research that could revolutionize the understanding of the ozone layer. However, ozone in the troposphere is a harmful pollutant that causes damage to plants and to lung tissue in people and animals, ozone should be manufactured far away from the surface of Earth. Managing the ozone is a very delicate and complex process that hasn't been accomplished in any direct measurement by humans, so it must be handled with extreme caution. A fifteen-kilometer high tower would allow humans to actually see if they can have a direct impact on such large-scale processes as ozone layer depletion, this because of the fact that manufacturing a fifteen-kilometer height tall tower would be quite a large-scale process itself.

2.2 Space Science

Space science is one of the enterprises most heavily influenced by the prospect of a fifteen-kilometer high tower. Within this enterprise, a super-tall tower could impact several avenues of scientific exploration. The two most obvious space research directives that could benefit from the MKT's use are high-altitude instruments and observatories and the systematic collection of interplanetary dust particles present in the Earth's atmosphere.

Imagine a multitude of scientific instruments designed to observe various aspects of outer space: optical and x-ray telescopes for observing distant stars, radio and microwave detectors, and many other instruments. Now imagine that these instruments have a clear view of the sky in every direction at all times. At fifteen-kilometers above sea level, the air is not dense enough to contain the type of clouds that inhibit observation of the heavens. Also, the air is super-cool, and therefore can contain only a fraction of the amount of moisture that the air close to the Earth's surface contains. This means that less of the valuable light and radiation energy from celestial bodies is absorbed on its way to the telescope or other instrument. In turn, more data is made available for scientific observation and analysis. In the world of telescopes for example, the game is in how much light energy a mirror can collect. The High-Energy Replicated Optics (HERO) mission recently obtained data from a binary star system called Cygnus-1 by way of a balloon payload floated to the edge of space. The round trip for the instrument was limited due to constraints associated with balloon observations. If a multi-mirrored hard x-ray collector were stationed fifteen kilometers above sea level, it would have a greater ability to map celestial star systems. Such is the case for optical telescopes as well, not to mention the fact that such telescopes would also be easier to maintain and service.

Another benefit to space science that the MKT would provide is the ability to attach interplanetary dust particle (IDP) collection plates at various heights of the tower. Dust particles from planets other than earth have been known to find their way to Earth's atmosphere. The particles can be suspended in the stratosphere for months before falling to rest on Earth's surface. Early research on specific IDP types collected in the stratosphere established that IDP's could be collected efficiently and in reasonable abundance using flat-plate collectors (Mackinnon 1). Most collection initiatives have been carried out by way of flat plate collectors mounted on high-altitude flight aircrafts. There is actually a successful IDP collection and analysis program in operation today. Much of the research occurs at NASA's Johnson Space Center in Houston, Texas. The improvement of current dust collection methods would allow for a wider variety of samples to be garnered, leading to a more advanced IDP taxonomy, which could lead to several different distinctions within the IDP analysis field. As a matter of fact, a useful classification system is an essential element of any broadly based set of data because it allows for communication between different disciplines. For instance, orbital debris and atmospheric dynamics scientists would be working in a similar context if such a nomenclature were developed (Mackinnon 1). Such a detailed analysis could help to answer many of the questions NASA has set out to answer, including the nature of the origin of the solar system. An IDP collection initiative could compliment other particle collection projects nicely. For example, the data from the IDP collections could be compared to the Genesis mission data to see if any correlations can be made between ancient particles from the sun and those from all nine of the planets. All of the above consideration leaves us closer to answering fundamental questions that we have spent billions of dollars attempting to answer, but to no end.

2.3 Biological and Physical Research

A drop tower is simply a tower used for microgravity experiments and research. It allows scientists and engineers to use a low gravity environment similar to the space environment. Microgravity experimental research is conducted in ground-based facilities such as terrestrial laboratories (both NASA and non-NASA); drop towers, low-g aircraft, and space-based laboratories, primarily the International Space Station. The drop tower will serve as a less expensive method to perform micro gravity experiments. A fifteen kilometer tall tower would give about nine minutes of free fall, very inexpensively, allowing scientists to have other alternatives for space research and also a direct control and accessibility of each experiment from ground. The only other ways to get that much free-fall time are through the Delta-V rocket, or a shuttle launch to the ISS. A drop tower of this height would be an important contribution to microgravity research.

The biosphere is the part of the Earth and its atmosphere in which living organisms exist or that is capable of supporting life. This application would rely on the development of a dome atop the tower to simulate our environment on Earth. With the altitude comes a less dense atmosphere and hence lower pressure environment. Experiments would be performed on organisms and materials alike to observe how they react to different kinds of atmospheric conditions. These experiments will give an opportunity to study the possible reactions of plants and animals as they would occur on other planets. Such information may be extremely valuable in the scope of extraterrestrial colonization.

Nanotechnology is a new field of science based on the manipulation of materials and organisms at the atomic, or "nano" level. Such nano level technology employs atoms and molecules to build extremely pure and uniform materials. It is a developmental fabrication technology in which objects are designed and built with the placement and orientation of individual atoms. The first notable nano-fabrication experiments took place in 1990 in which a sixty-atom carbon molecule, more affectionately known as buckminsterfullerene, was formed. Since then, buckminsterfullerene or the "bucky ball" has been further manipulated into a more useful form of carbon called a bucky tube. A bucky tube is a stretched out molecule of C_{60} that has displayed remarkable properties in the laboratory. It has proven to be a highly effective conductor of heat and electricity. More notably it has been shown to exhibit ultimate strengths

orders of magnitude greater than steel. Carbon nanotubes have the potential to be the strongest material known to man, having the strength of diamond without the brittle fracturing properties associated with the diamond crystal's lattice. Considering that it is also a fraction of the density of steel, it would make for somewhat of an optimal building material. Scientists speculate that a structure made out of a nanotube composite could reach a theoretical maximum height of thousands of kilometers. The use of nanotechnology to build a multi-kilometer tower would be very beneficial, but there is still much research needed in the future of carbon nanotechnology.
Carbon nanotubes are the first high tensile strength electrically and thermally conductive molecules. The carbon nanotubes are a lightweight material, their strength is 100 times stronger than steel, and they offer a high range of advantages to structural applications for all types of existing technology. Today's existing carbon nanotubes are only a few microns in length, which leaves scientists and engineers with extensive research to develop nanotechnology into a viable and productive industry. The construction of a multi-kilometer height tall tower is an opportunity for nanotechnology to prove its worth and extend its capabilities opening up new possibilities for many Space and Earth industries.

2.4 Aerospace Technology

The advantages of a multi-kilometer height tall tower for launch purposes are virtually endless. The tower would serve as a direct launch site for satellites, payloads to the International Space Station and other space missions, as well as a launch assist for orbital experiments. One design for a high-altitude launch system utilizes electromagnetic energy for propulsion. A rail-gun is a propulsion system that uses electromagnetic energy to accelerate a payload from a cannon. It is theoretically possible to accelerate such a payload to escape velocity using the rail-gun, and launching from fifteen kilometers above sea level would require less of an escape velocity. At fifteen kilometers, which elevates the launch platform just above the Earth's troposphere, time and money will be saved for both fuel conservation and the absence of weather delays. Gravity and weather delays will have less adverse effects on the launch process.

At fifteen kilometers high, the launch platform will be above 83% of the Earth's atmosphere, and at this level the atmosphere is less dense so drag forces would also be less significant. The performance of the shuttle launch would greatly increase due to the gains in initial potential energy and loss in aerodynamic drag. The high altitude launch platform would contribute to more than a 60% gain in the efficiency of a payload's launch to orbit. A portion of the energy for the high altitude launch would come from the Earth's rotational energy, thereby conserving even more energy. This makes the development of the technology for a Single Stage to Orbit (SSTO) launch even more attainable.

Today's launch cost of $20,000 per kilogram of payload to LEO is a great concern and quite a setback for space research. Having a high altitude launch platform would provide a significant economic advantage. This offers many opportunities for further space research and accessibility for the government's contractors, which could have more involvement in the space program. It could also provide added flexibility in developing more advanced launch vehicles.

Launching from a fifteen-kilometer tall tower could be one of the first steps towards the use of compression structures for space transportation. Developing even taller towers is possible and it would bring more physical and technological improvements to high altitude launch. In more advanced terms, a tower over 50 km high, which locates the launch platform above 99.7% the Earth's atmosphere, would increase the payload launch to orbit efficiency by well more than

100%. A fifteen-kilometer tower could be the technological breakthrough needed for the future development of launch methods and it will produce numerous advancements in Aerospace Technology.

Another important application is the use of electromagnetic Propulsion. Electromagnetic propulsion is the process of driving or propelling a body using magnetic energy. This application can be used along the tower by an elevator. An electromagnetic elevator would be fairly inexpensive to operate and rather efficient over its life. The fact that the moving body would be levitating over the track would indeed cause less wear on the track itself. An elevator of this constitution would last many years more and require far less maintenance than today's conventional mechanical elevators. The tower would have a rail dedicated to electromagnetic propulsion research and would eventually transport payloads up and down its height using electromagnetic energy. This is an important concept because there is no need for a cable/pulley mechanism that would inevitably deteriorate and require hour upon hour of maintenance. The tower will serve the non-contact transportation infrastructure for the benefit of future technology developments of high-speed electromagnetic propulsion systems. Preliminary testing will be absolutely necessary to provide a well-developed operational design for use in the Space Elevator.

Using MagLev and the MagLift technology, the development and use of an electromagnetic elevator may not be too far ahead. The electromagnetic propulsion of trains in some European countries is happening today. Further research is needed to apply these propulsion systems for launch assist and elevator designs, but it is certainly attainable. The electromagnetic propulsion system will serve primarily as a mass transportation system between sea level and fifteen kilometers up. The tower's height could be anywhere from one kilometer to fifty kilometers for the purpose of electromagnetic propulsion systems research. The two primary systems will be the elevator and the rail gun. The development of these two systems of propulsion would prove to be invaluable in terms of the Space Elevator.

2.5 Human Exploration and Development of Space

The final and most pervasive enterprise NASA has designated as its own is Human Exploration and Development of Space (HEDS). All of the previously mentioned enterprises fit within HEDS; they contribute to HEDS making it quite multi-dimensional. HEDS encapsulates most of the aforementioned applications as well as the ones to follow. A MKT would benefit the HEDS endeavor in several ways. One of the more notable and interesting applications of a MKT in the HEDS domain is in energy conversion.

There are several possibilities for the enhancement of energy conversion practices by using a MKT. One is in solar power; several square meters of solar film and solar energy collection panels could be mounted onto the tower from top to bottom. Such a large structure would have a surface area of more than twenty square kilometers. That is approximately four hundred million square meters of surface area. Just one percent usage of this surface area would allow for a collection zone of four million square meters. That is a significant amount of energy conversion, and the higher up on the tower the collectors are placed, the more energy is collected due to less atmospheric interference. Solar energy conversion could occur during all daylight hours, as weather will no longer be a concern. It should also be noted that solar fuels, or fuels created by the direct use of solar energy, would be perhaps one of the most applicable form of energy conversion in terms of HEDS. One of the most manufactured solar fuels is liquid hydrogen, which is created by the electrolysis of water. Imagine there being a liquid hydrogen conversion plant atop the tower that turned out tons of liquid hydrogen per day using only water and the omnipresent energy of the sun. How convenient would it be to have a way to manufacture rocket fuel on top of the tower for a rocket to be launched from a platform on the tower?

Now a less conventional approach to energy conversion: the Power Tower. The Power Tower is nothing short of an energy conversion dynamo. The Power Tower is a conceptual design for a power plant that utilizes the Earth's internal heat energy as the energy source of choice. The basic idea is that a Rankine cycle is modified to accommodate the ammonia cycle (De Langen 2). The fact that ammonia evaporates at temperatures that are a fraction of water's boiling point and freeze well below zero degrees Celsius is very convenient in nature. In the Power Tower, ammonia is evaporated by a constant enthalpy brought into the closed ammonia loop, from a lake or the warm water of the ocean. As the ammonia evaporates, it travels up into the atmosphere, remaining in the controlled loop, and since ammonia freezes at very low temperatures, freezing will not occur readily as it travels upward into the atmosphere. The Power Tower requires a tower that is anywhere from five to eleven kilometers in height. Somewhere between five and eleven kilometers above sea level, the cold air in the surrounding atmosphere is employed to easily cool and condense the ammonia until it is in liquid form again.

The only difference between this liquid ammonia, and the initial liquid ammonia is that this liquid ammonia now has about GMm/r times the amount of energy that the ammonia at sea level has. By Newton's law of gravitation, one can calculate how much energy the hydroelectric plant (at the base of the tube down which the condensed ammonia falls) will generate from converting the ammonia's kinetic energy into electric energy. The potential energy gained by the condensed ammonia at the top of the tower is converted to kinetic energy by the time it reaches the base of the tower. The ammonia would then re-circulate while being warmed by the water surrounding the reservoir at the base of the tower. Such a set up could be capable of generating seven thousand mega-watts of power, that is, almost twice as much power as Britain's most robust power plant. This technology alone could account for all of the energy used to run the electromagnetic elevator, or the rail gun, or the myriad scientific instruments on deck, or the robots that continue to construct the tower up to three hundred kilometers. This Power Tower proposal coupled with advances in automated construction and a simplified/modularized tall tower architecture could lead to a tower that is virtually building itself around the clock, up to the edge of space. The cost of construction after that point would be next to nothing, as human labor would not be employed, and energy costs would be completely marginalized.

Another aspect of HEDS that stands to gain from a MKT is the development of a more advanced grounded deep space communication network. A fifteen-kilometer tall tower would act as quite a lighthouse in the tumultuous and unforgiving cold environment in space. A radio transmitter/receiver fifteen kilometers tall could generate a rather powerful signal that could travel further into space and be received by human spacecrafts much more efficiently. A powerful receiver might also contribute to the search for signals sent by extraterrestrial life forms. Such a communication system would be a prototype for lunar and Martian models, which when set up, could relay data at limitless rates; this advanced communication infrastructure would be an integral part of colonizing the moon and Mars.

Space tourism is a very important industry in the scope of a MKT as a well-developed public awareness of the benefits and applicability of Space in everyday life will pave the way for more industry involvement in space development. The greater the amount of people who dream about space development, in general, the quicker it will occur. A higher demand for space development could bring with it, the trillions of dollars and then some that will be required for space colonization. A healthier public interest in space will come when safe and reliable ways for people to experience space first hand are delivered. One possible way to include space tourism in the construction of the tower is building high altitude resorts at which it is possible to witness first-hand, the curvature of the Earth and the darkness of space during the day. Resorts would come after simple tours using a pressurized elevator to travel to the top of the stratosphere. Perhaps another intermediate step to the upper-stratospheric resort would be a pressurized balloon ride from a platform located on top of the fifteen-kilometer high tower above the troposphere. The balloon could rather inexpensively and safely transport twenty people on a half-day tour of the stratosphere. Once the people return and talk about their space experience, people will start to realize the incredible beauty of space development. This will be one of the primary vehicles to space colonization: a heavy trust in the ability of man to transform outer space from the coldest barest wasteland into a form of amusement. People, being naturally inquisitive, will begin to feed their innate hunger for the knowledge of where man came from and where man is going. They will begin to feel part of the space revolution slowly working humanity into a space culture. Space will become entangled into culture and advancements in space travel will be looked at as humanity looks at advancements in aircraft travel today. This is the primary benefit of opening up the MKT to space tourism.

The final application for the MKT within HEDS is one of the most important and yet one of the more succinct of them. The use of a MKT as the base of a large-scale space transportation infrastructure will be the most appropriate allocation of its potential. This is a more eventual application, however. It will be simply invaluable to the colonization of space, as it will provide the cheapest proposed way to commit a payload to geosynchronous orbit. Payload launch costs to Low-Earth Orbit are presently twenty thousand dollars per kilogram; the presence of a space elevator in today's economy would make that figure somewhere closer to two dollars per kilogram. For more information on the space elevator, please consult "Space Elevators – An Advanced Earth-Space Infrastructure for the New Millennium" a conference publication compiled by Space Elevator expert, David Smitherman, Jr.

3. Designs

The two main general designs for the multi-kilometer height tall tower are the fractal truss design and the pressurized shell designs. Both designs are completely independent of each other yet have some similarities. For both designs there are two common conditions: the ideal height range and the height-to-base ratio. The ideal height range is fifteen kilometers tall, which locates the top of the tower just above the troposphere, and the height-to-base ratio is 1:20. This means that for every kilometer at the base in width, there will be twenty kilometers in height. Before going into the design process there are some building problems to be discussed. Engineering problems and environmental hazards are prevalent in the consideration of a design. Some engineering problems are buckling, ultimate strength of the primary structural material, and dynamic stability. The environmental hazards that are going to affect the tower are strong wind loads, icing and lighting.

3.1 Fractal Truss Design

The fractal truss design consists of the main columns made up of smaller trusses, which in turn are made of smaller trusses. The fractal approach minimizes wind loads, provides reasonable component sizes, and would lend itself to a robotic assembly method. It also optimizes material strength usage. The fractal tower would be a truss structure composed of high stiffness composite struts, and precision joints. The members' diameters, along with the material properties and cross sectional areas of the longitudinal and diagonal members can be optimized to meet the structural requirements such as natural frequency, bending strength and thermal twist stability. The cross-section of the primary members of the truss would be rectangular or trapezoidal tubes, which would be simpler to fabricate and rather easy to assemble. It is shown that rectangular members are stronger than round ones, and they would have a considerable thickness to resist buckling. The tube maximizes material efficiency to make a strong, rigid member. The principal concept is to get the material as far from the neutral axis as possible, which in this case runs through the centroid of the tube. This construction resists torsion and bending because tension and compression are far apart, providing a large moment. A tube is the ideal shape for a compression member or strut. If the tube members are too large they will need internal circular flanges, and longitudinal flanges for stiffening.

The construction method that most aptly meets the requirements of such a Herculean construction feat is robotic assembly. The chief assemblers are precise robotic machines that will be able, once programmed, to build the tower by sections in a completely automated fashion. Such assemblage could take place round the clock, twenty-four hours a day. One advantage of the use of a truss system is that it can be assembled in a convenient position and moved into place as a complete unit, also the trusses can be constructed by parts.

A truss can be built as a complete unit and then lifted into place. The joints would be riveted or bolted together so that the joints contribute additional stiffness to the structure. The use of automation and robotics involves a residually low cost construction, which makes it a great deal more attractive. Armies of assemblers can construct tower components at any speed desired. The length of the tower requires a system for materials processing, fabrication and assembly that is as autonomous as possible. Human construction will be very dangerous and workers could experience dizziness, or respiratory problems if they were to participate in the tower's construction at high altitudes, this is another reason for robotic assembly.

After conducting a brief and simple structural analysis on the main truss design, the results were that the structure is externally stable, indeterminate to the 1^{st} degree; also it is internally stable and indeterminate to the 2^{nd} degree. The greater the degree of indeterminacy the more stable the structure will be, it also means that if one joint fails, there will be another joint to serve as a back up and the structure will not collapse.

The lightest and strongest compressive material available today is the graphite/epoxy composite material. One of the compressive properties of this material is that its characteristic length is greater than 100 km, which makes the tower's construction by way of carbon/epoxy a feasible accomplishment. Graphite/epoxy has a strength of 1.7 GPa, a density of 1,610 kg/m^3 and a characteristic length of 107.5 km.

3.2 Pressurized Shells Tower

I. Design Description

The pressurized shells tower concept can be better understood by thinking about a balloon. When a balloon is deflated it can resist great amounts of tension but it cannot resist any compressive forces. By inflating the balloon, it's able to resist compressive forces, an idea which is exploited in the pressurized shell tower. By adding gas pressure, the tensile strength is converted into compressive strength, compressive strength that is needed due to the fact that the tensile materials have greater characteristic lengths than compressive materials do, which, in turn, allows us to build even taller structures. Increased loads toward the bottom of the tower can be supported by increasing the gas pressure in the lower sections or by increasing the cross sectional area of the gas. The amount of pressure will depend on the amount of external and internal forces acting on the structure. The type of active stabilization system between the shells that are threaded together much like a screw and connected as well by bolts. This is to reduce the stress area while keeping the shells together. Also, the pressurized shells will require internal pressure bulkheads to keep the pressurizing gas from moving to the bottom of the tower. The pressurized shells, which comprise the vertical tower members, will be made of a tight weave of PBO fibers, inside a very thin graphite/epoxy cylinder. The cylinder serves as a protective restraining layer. To stabilize the pressurized shells horizontally, the members will be connected with horizontal rods made of rectangular graphite/epoxy tubes. To control the wind loads, several rectangular graphite/epoxy tubes will be connected to the shells as diagonal members. To control the gas inside the shells every single shell will be connected to a gas line that will run along every shell of the tower and be controlled from the ground. Air is one possible candidate for the pressure gas, however, the use of a lighter and non-combustible gas like helium could provide actual buoyancy to the tower, and therefore act as an active stabilizer.

The construction methods for the pressurized shell tower will also use robotic assembly as a building process. The pressurized shells will be pressurized before bolting them together, this will be a ground operating process. The structural analysis results showed that the structure is externally and internally stable, indeterminate to the 1st degree. As mentioned before, the pressurized shells will be made of PBO fibers, which are currently the best tensile material available, a high strength polyaramid fiber with a strength of 5.8 GPa and a density of 1,580 kg/m^3. This material allows us to make the tower up to 373.3 km high.

3.3 Design Specifications and Motion Control Systems

Both designs have common specifications like the stabilization systems, the location and the foundations. Towers posses low natural damping characteristics. They are expected to withstand high wind oscillations, which could cause catastrophic failure to the structure. The greater the wind speed near the ground the more gradually the wind speed increases with height. Therefore it's important to design a strong system that can minimize wind loads. The most commonly used control systems are the passive control system and the active control system. The tower will need these types of active control systems to control the excessive vibrations caused by wind excitations. Depending on the degree of freedom of the tower the control system will be an active tuned liquid column damper system (ATLCD) or an active passive tuned mass damper system (APTMD). It's found that the wind-induced response of the tower can be reduced substantially by the ATLCD system. This system is the best for a tower with a single degree of freedom. For a tower with multiple degrees of freedom the APTMD is best chosen over the ATLCD, that is, until further investigation and tests are made. These control systems have several potential advantages, which include low cost, easy installation, simple maintenance requirements, non-restriction to non-directional excitation, and multiple uses.

The control systems have different sensors that provide the reduction in structural motion. The different types of sensors are the displacement, velocity, and acceleration sensors. In general, the ATLCD system is preferred because of the potential advantages of the liquid column damper; such as relatively low cost, multiple uses and less platform displacements. We will use this ATLCD for the tower, as long as it satisfies every structural stability requirement. Also the tower will have a built-in dampening type of system necessary to survive earthquakes, built into the building's foundation.

The foundation is very important to the stability of the tower. The foundation depth will depend on where the tower is located, due to the tower's high altitude; the foundation will go down several meters into bedrock. For the foundation's construction high strength grade concrete will be used. The system will have friction piles (structures narrower than piers), and reinforced by grout (a sand and cement mixture), and it will also have barrette piles that will increase the safety margin.

The tower can be located in any place on Earth, but preferably in the Equatorial region. The Equatorial region is favorable because of mild weather conditions; there are no hurricanes or high wind loads along the Equator. The lowest few kilometers of the tower would feel strong wind loads but the suggested equatorial location avoids the trade winds and the jet streams. The equator experiences very low average wind speeds, the jet streams are limited to temperature latitudes, and hurricanes never occur at less than 5°latitude. Locating the tower in the ocean to include the Power Tower design as well as oceanography applications would be favorable. Also, as a note, it would be extremely important to place the tower in international territories such as in the ocean off the coast of South America to avoid any political problems. Another beneficial location is the Indian Ocean because it's the most stable gravitational location for the tower.

4. Conclusions

To conclude this examination of multi kilometer tall towers, it is possible to construct a multi-kilometer height tall tower with today's engineering materials and technology. A fifteen-kilometer tall tower will bring many advantages to scientific research and will spark the development of the tall structures needed for the Space Elevator. Improvements will occur in launch performance, communication coverage, meteorological research and development of experiments in high altitude systems. NASA's five strategic enterprises, Earth Science, Space Science, Aerospace Technology, Biological and Physical Research, and Human Exploration and Development of Space, would all be profoundly impacted by the existence of a super-tall tower. The research and development of today's construction methods will lead fast-track 24-hour construction. It can also be concluded that the construction of a multi-kilometer height tall towers today would have a direct impact on the likelihood of the Space Elevator being created in the near future.

To make the multi-kilometer height tall tower feasible there is quite a bit of future research to be commenced. More detailed structural analyses and structural testing on the multiple designs is needed to prove their stability. Also, testing composite materials is necessary in order to confirm their high-strength properties. Research and development in future building materials such as carbon nanotubes could be a great accomplishment and a breakthrough in the world of construction materials. There must be an improvement of all applications as well as the construction and design methods. This research is the best way to prove to the world market the feasibility and value of taller structures. Last, but not least, space tourism must be manifested through the tower, and this will need to inject the value and beauty of space into the minds and hearts of the billions of people that inhabit Earth. A complete understanding and realization of the Universe's beautiful and eloquent mysteries shall be the multi-kilometers towers crowning moment as humankind comes to fully grasp the very nature of nature itself.

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Appendix

This section includes charts and drawings to give a better explanation of the many concepts and applications of the multi-kilometer height tall tower.

A.1 Materials Data Table

Materials	**Strength (GPa)**	**Density (kg/m^3)**	**Lc (Km)**	**Lc* (Km)**
A. Compression Materials				
Graphite/Epoxy	1.7	1610	107.5	53.8
Boron/Epoxy	2.43	2020.6	122.5	66.3
Carbon-Nanotubes	5.3	1400	386.3	-
B. Tensile Materials				
Steel	4.2	7800	54.8	43.8
Kevlar 149	3.5	1470	242	121
Aluminum	0.55	3958	14.2	11.4
PBO	5.8	1580	373.3	186.9
Carbon-Nanotubes	30	1400	2186.6	-

Lc* is with safety factor

A.1 This chart shows the materials data table, which describes the properties of the most common compression and tensile materials, as well as the carbon nanotubes.

Formulas for Lc:

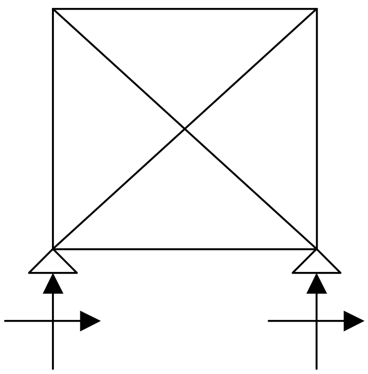
Compression materials:
$Lc=\sigma/\rho g$

Tensile materials:
$Lc= \sigma/2\rho g$

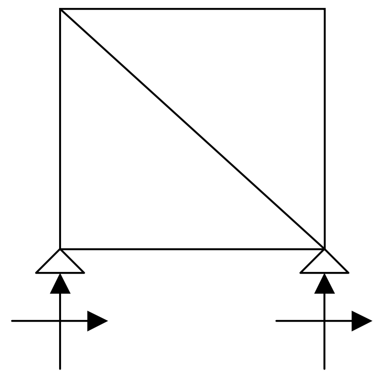
Lc=Characteristic length
σ=Ultimate strength
ρ=Density

A.2 Brief structural analysis:

Fractal Truss Design



Pressurized Shells Design



I. External Analysis:
Formulae:

R-3*(**N**)=**X**

R=number of external reactions
N=number of segments
X=degree of indeterminacy

II. Internal Analysis:
Formulae:

E= (**M**)*(**I**) + **R**
J=**P***(**Q**)
E - **J**=**X**

R=external reactions
E=number of elements
I=1 (internal forces in a truss)
M=number of members
J=number of joints
P=number of joints in the truss
Q=2 (number of equilibrium equations available)

For this truss (Fractal Truss Design):

I. **R**=4 **N**=1
X=1° degree of indeterminacy
Externally Stable

II. **R**=4 **M**=8
P=5
E= 12
J=10
X=2° degrees of indeterminacy
Internally Stable

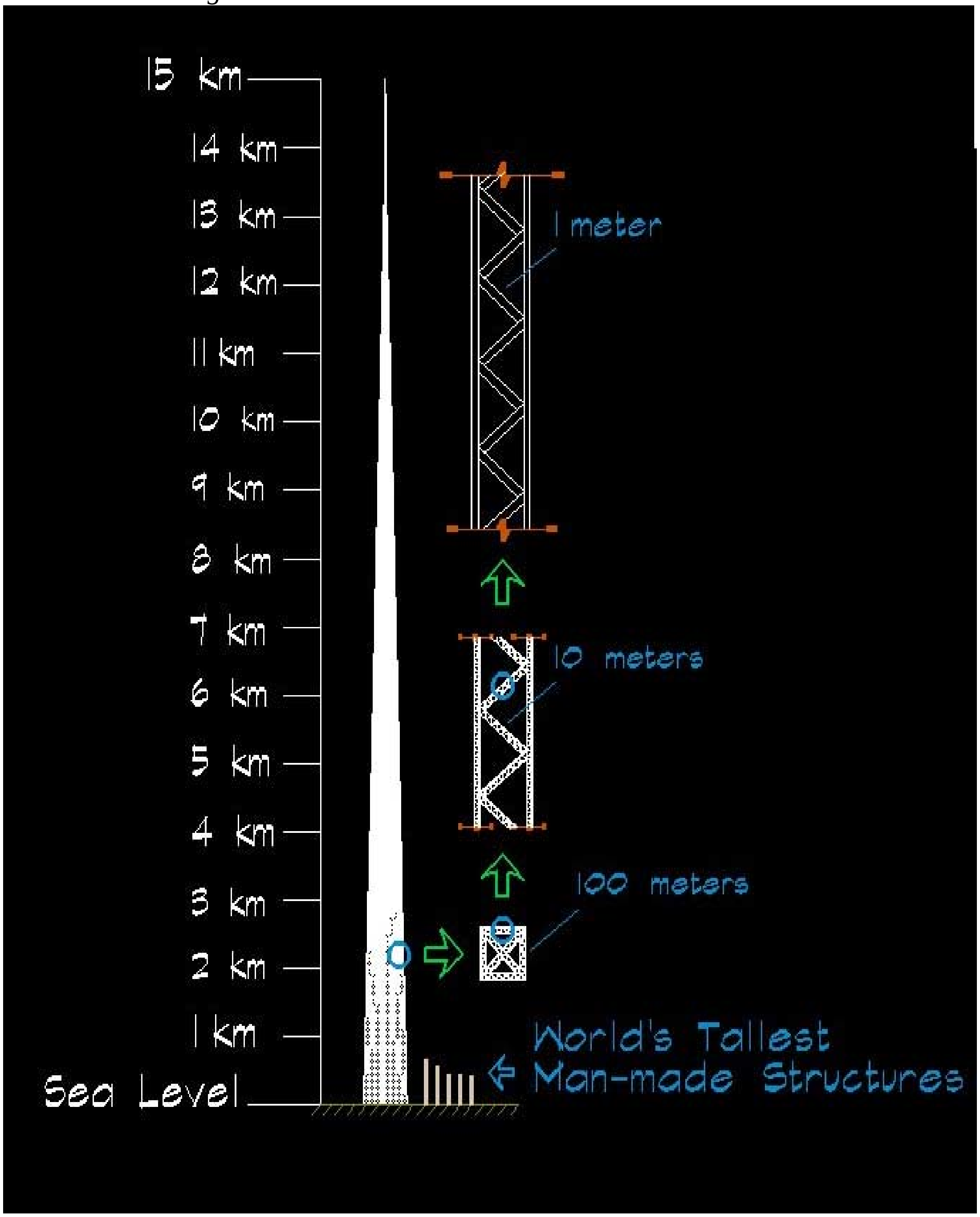
For this truss (Pressurized Shells Design):

I. **R**=4 **N**=1
X=1° degree of indeterminacy
Externally Stable

II. **R**=4 **M**=5
P=4
E=9
J=8
X=1° degree of indeterminacy
Internally Stable

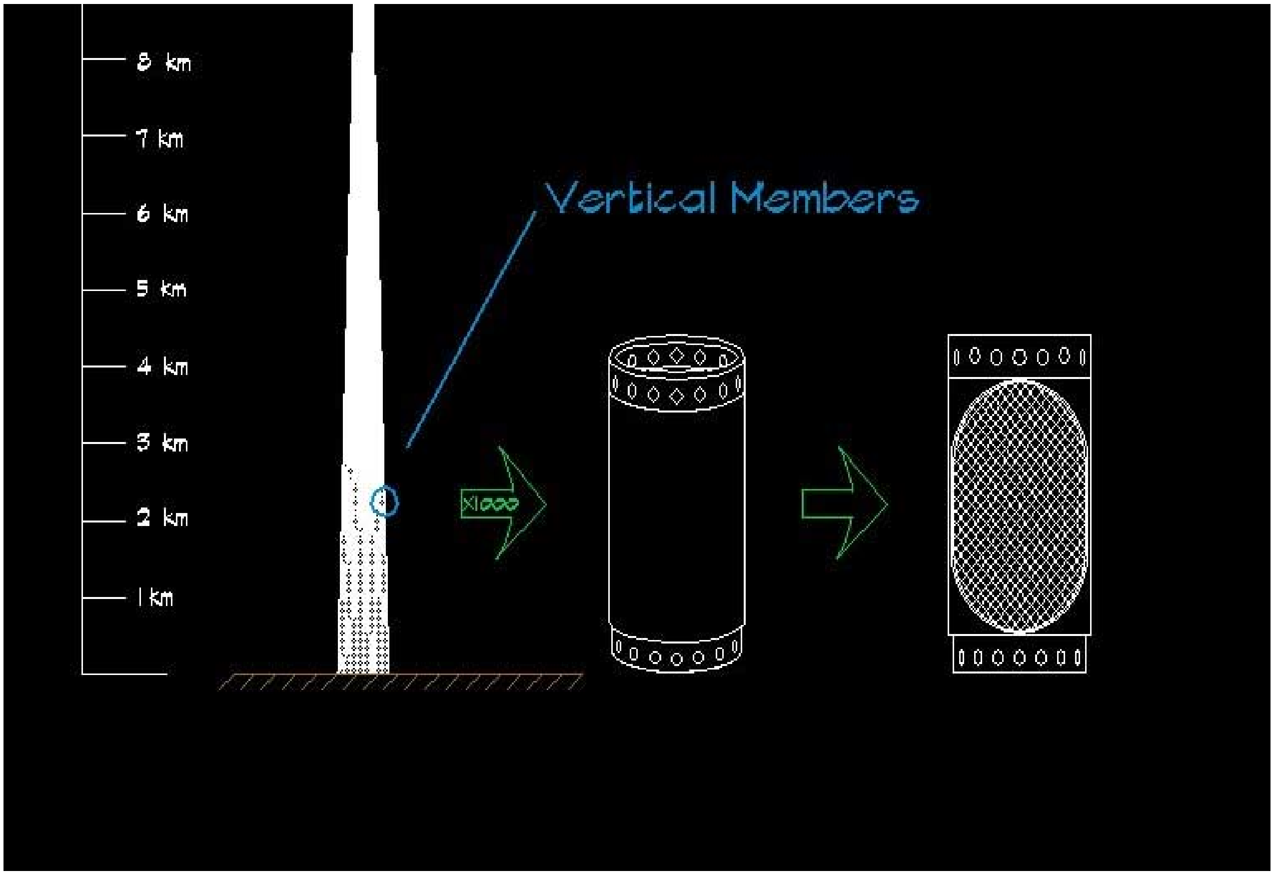
A.3 Tall Tower Designs

A. Fractal Truss Design



A.3A: Design of fifteen kilometer tower with fractal truss design; includes comparison of world's tallest man-made structures.

B. *Pressurized Shells Design*



A.3B: Pressurized shell design magnified one thousand times with cross section included.

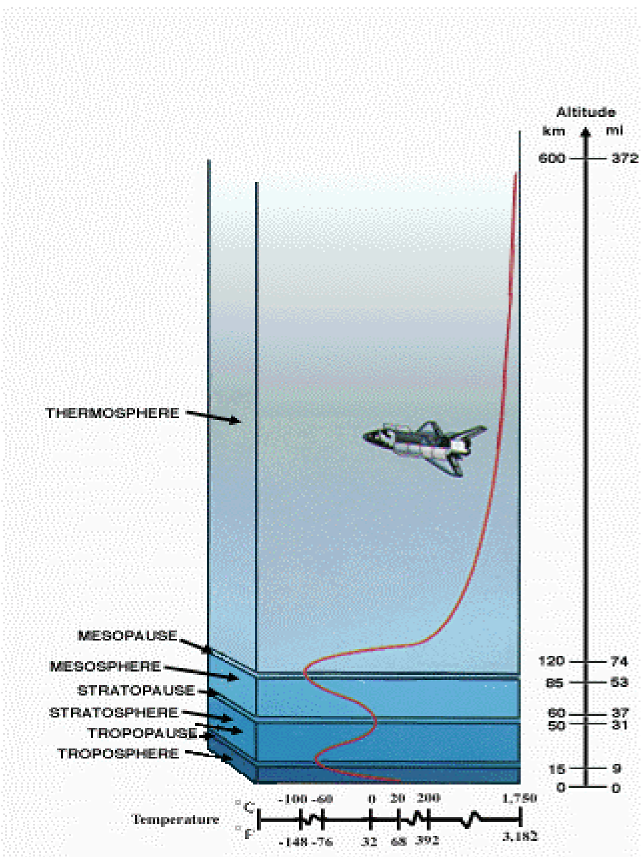
A.4 Atmospheric Layers

This provides a better understanding of the Earth's atmosphere and where the tower is located with respect of the atmosphere. The atmosphere reaches over 560 km from the surface of the Earth and is divided into different layers:

- Troposphere: The lowest layer of the atmosphere, extends from 0 to 14.5 km, and is the densest part of the atmosphere, almost all the weather happens in this region.

- Stratosphere: Starts just above the troposphere and extends to 50 km high. It's dry and less dense and contains the ozone layer.

- Mesosphere and Thermosphere: These extend from 50 to 600 km in altitude. Most chemical reactions occur faster in these layers than in the surface of the Earth due to the absorption of the Sun's energy.



Earth's Atmosphere Distribution