790.00 **Tensegrity Structures**

[790.10-795.11 Tensegrity Scenario]

790.10 **Definition**

790.11 Everyone thinks he knows the meaning of the word structure. We point to a stone wall or a bridge or a barn and say, "That's a structure." What is common to a steel bridge, a wooden barn, a jumbo jet, an iceberg, a starfish, a star, a fern, a diamond jewel, an elephant, a cloud, and a human baby? They are all structures. Some are more versatile than others; some last longer than others. Why? Why do the stone or wood or steel cohere at all? If we understood a little more about structure, it could lead to a better understanding of the political and economic dilemmas of our time. Political and economic systems are structures—often so ill-conceived as to require constant local patching and mending. Even structural engineering has as yet failed to comprehend adequately or to define and cope with structure.

790.12 We all have experiences of *pushing* and *pulling*, and we think of them as 180-degree experiences directly away from us or toward us. But (as we shall soon discover) pushing and pulling both produce 90-degree resultants, which we mistakenly call "side effects." Our side effects are nature's primary effects, and vice versa. Pushing is outwardly explosive from a center of effort: that is why a ping pong ball can ride on the parting outward and downward of the waters of an only-vertically-aimed fountain nozzle. Gravity and magnetism are embracingly contractive around—and radially inward toward—a center of gravity. With gases, *pull* is a partial vacuum whereas *push* is an explosion: attraction vs propulsion, tension vs compression.

790.13 Tension and compression always and only coexist and covary inversely. We experience tension and compression continuously as they interaccommodate the eternally intertransforming and eternally regenerative interplay of the gravitational and radiational forces of Universe.

790.14 The gravitational or omnidirectional tension totality in Universe is quantitatively equal to the totality of the radiational or explosive compression of Universe, but the sum total of tensional coherence is more effectively arranged than the sum total of explosively disintegrative forces. This is why Universe is finite. (See Sec. 231.)

790.15 **Barrel:** A barrel as the sum total of its staves and its encircling hoop bands illustrates the cosmic gravity-vs-radiation balance. (See Figs. 705.01-.02.) The staves are wedges—each stave is wedged between two other truncated-triangle wooden staves. When seen in cross-section, each stave is the outer-arc-chord-truncation segment of a long, thin, isosceles triangle whose inner, sharply pointed section-truncated and dispensed with—would have had its apex at the central axis of the barrel. Each stave's outer chord is always a little wider than its inner chord, wherefore the staves cannot fall inward of one another but could very readily move outwardly and apart, were it not for the tension bands that go completely around the barrel and close back on themselves as a finite integrated system.

790.16 The staves are separate, disassociative, inherently disintegrative, and self-differentiating, while the barrel's external ring-bands are self-integrating: though separate, the two groups of members are operating complementarily to produce union. It is the embracing tension that successfully maintains the integrity of the barrel despite the disintegrative tendencies of the individual staves. The push-pull components are more effective associatively than they are separately. The disintegrative explosive force is embracingly cohered by the gravitational. So it is with Universe.

790.17 Push and pull, disassociative and associative in omnidirectional balance, characterize the essence of structure.

790.18 **Column:** If you load the top center of a thin column, it tends to bend like a banana-its radius of curvature in the bending area gets smaller and smaller. (See Fig. 640.20.) A tensed line tends to get straighter and straighter, though never absolutely straight. Physics has not found any straight lines. Physics has found only waves—the superficially straighter waves being of ever higher frequency and ever shorter wavelength, and always locally and discontinuously particled.

790.19 Compression tends to break a slender one-wavelength column into two columns of two wavelengths, thus tending to focus the ever smaller radius between them into one point, which increases the leverage of either half to consummate the breakage. (See Fig. 640.20G.)

790.20 By contracting their girth, tensed lines of tension tend to pull their fibers together ever more tightly so that the atoms get nearer to one another—their mass interattractiveness increases as the second power of the decrease in the distance between the atoms. (See Fig. 641.01B.) Tensional strength increases initially, and therewith lies its capability to cope with loading; when the girth contraction rate is exceeded by the elongation of the tension member, the atoms recede from one another and coherence decreases rapidly.

790.21 Ropes can be pulled around corners. Neither stiff poles nor flexible ropes can be pushed around corners. Tension has a greater distance range of capability than has compression: witness the compression masts and the only-tensionally-suspended long center spans of the great suspension bridges. Tensional capabilities are always more versatile and energetically effective than are compressional capabilities. The variable live loads of suspension bridges are applied directly only to its cables, which distribute the loads evenly. In the same way the tensed tubes of automobile tires receive the shock loads locally and distribute them evenly.

790.22 The taller a column is in proportion to its mid-girth cross-section dimension, the less the load it will bear before it tends to buckle, which means to bend twistingly outward in one direction, and—if further loaded—ultimately to break into two columns. In principle, tension members of structures have no limit ratio of cross-section-to-length. With materials of higher and higher tensile strength it is possible to make longer and longer and thinner and thinner tension cables-approaching a condition of very great length and no cross-section at all. (See Figs. 641.01C-D.) With better and better alloys it is possible to make longer and longer, thinner and thinner, clear-span suspension bridges. People tend erroneously to think of those cables as "solid"—and of the steel as solid—but they are not solid: the atoms are not touching one another. The distances between the nuclei of the atoms and their orbiting electrons-as measured in diameters of their nuclei—are approximately the same proportionally as the distance between our star Sun and its planets. The individual atoms are in sufficiently critical proximity to be sustainingly attracted to one another as are the Earth and Moon, which obviously are not touching each other. In aeronautical terms they are all in dynamic "flying formation." As the Earth and the Moon co-orbit the Sun, and as the Sun and its planets together are in flight formation in our galactic system's merry-go-round, and as the billions of galaxies omnirecede from one another, they are all intersecured by comprehensive mass attraction. The mutual interpull force between Sun, Earth, and Moon is manifest rotationally around opposite sides of the Earth by the twice-a-day tides as quadrillions of tons of water are progressively pulled outward from Earth's surface jointly by the Moon and the Sun-and then are allowed to subside. In the Milky Way periphery of our galaxy the stars do not touch one another: they are in critical proximity. The Universe itself is held together by tension-invisible, substanceless tension that allows for local motions and transformations.

790.23 The same structural laws of Universe operate at both macro- and microlevels: they are the structural laws of our planet Earth.

790.24 Architecture on our planet Earth is the design process of building macrostructures out of microstructures, the building of visible structures out of invisible structures.

791.00 **Cosmic Structuring**

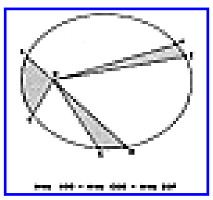
Fig. 791.01

791.01 With the advent of mathematical calculating capability into the public domain only 500 years ago, we had the beginnings of mathematically derived knowledge of cosmic structuring principles. To understand the significance of these principles we begin with Isaac Newton. Newton was inspired by the prior discoveries of Kepler, Galileo, and Copernicus, and he derived his laws of motion from consideration of their basic concepts, as follows:

1. Kepler discovered that all of the Sun's then known six planets orbit the Sun in elliptical paths.
2. The planets are of different sizes, each going around the Sun at different rates and at vastly different distances from the Sun.
3. In a given amount of time all of the planets "sweep out" equal areas. For instance, in a period of 21 days each planet describes a relatively short elliptical arc of travel around the Sun. If we connect the two ends of those arcs by the shortest radial lines to the Sun, and if we make proportionally accurate diagrams of each of the six pie-shaped pieces of sky enclosed by the respective arc-and-radii-bound areas, and if we use Kepler's carefully measured dimensions of those arcs and radii, we will find that the several triangular pieces of pie are very different in shape—ranging from very thin and long to very short and wide-but when calculated for area, they are all

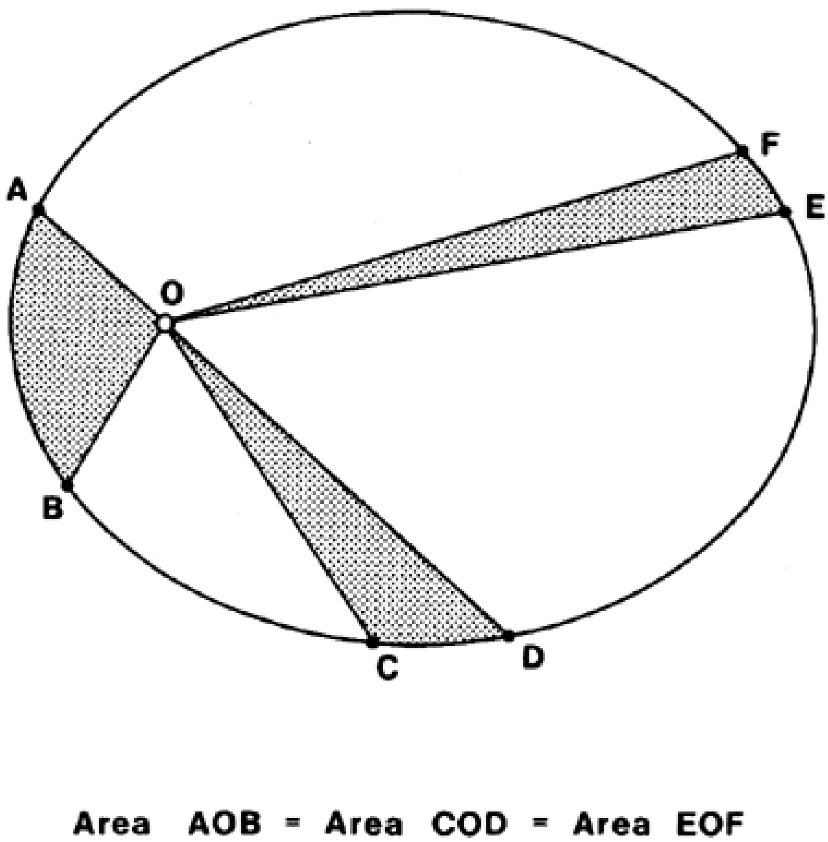

Fig. 791.01(3) Diagram of Equal Area Planetary Sweepouts: Each of the irregular pie-shaped pieces of sky enclose identical areas.

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found to be of exactly identical areas. (Compare Sec. 646.11.)

4. The coordination of these planetary motions was found to be exquisitely accurate but hidden invisibly in disparate observational data. Considered separately, each planet had unique behavioral characteristics that could not be explained by any mechanics of physical contact such as that of a train of teeth- meshed gears. The planets and the Sun are vast distances apart. Kepler must have noted that a weight on the end of a string hand-swung by a human around the head will—when released into orbit—travel tangentially and horizontally away from the human, while being progressively diverted toward Earth by the gravitational pull. Thus Kepler concluded that invisible tensile forces were intercohering the orbiting planets with the Sun and, to a lesser extent, with each other.
5. Galileo's measurement of the accelerating acceleration in the rate of bodies falling freely toward Earth indicated that each time the distance between the falling body and the Earth was halved, the speed of falling increased fourfold.
6. Newton was also impressed by the enormous magnitude of the tidal pulling of the Earth's waters by the Moon and the Sun.
7. The astronomers and navigators had established information governing the seemingly "fixed" interpositions of certain celestial star patterns at any given moment of the year as viewed from any given position on Earth. Of course, much of the celestial sphere patterning is obscured from any human observer on Earth's surface by the vast bulk of our planet. But Newton knew from personal experience that the position (as calculated by spherical geometry) of any one of the viewable stars as measured in angular height above the observer's horizon in any given compass direction at any chronometer- recorded moment of time on any given annual calendar day will permit the observer to make accurate calculation of his position on Earth.

791.02 In consideration of all the foregoing seven concepts—and much other information—Isaac Newton concluded that the relative magnitude of interpull forces of planetary coordination was proportional to the masses of the bodies involved. He concluded that the interpull between two apples would be so insignificant in proportion to the pull of massive Earth upon both apples that the two apples near one another on the table would be so powerfully pulled against the table as to manifest no measurable pull toward each other. Apparently the extraordinary interpulling of Universe could only be manifested in free space; thus it had never been noticed by humans in their preoccupation with Earthian affairs.

791.03 Newton reasoned from Kepler's work that if he swung a weight around his head and then let go of it, it would start off in a horizontal line but become overpowered by gravity and swiftly veer away 90 degrees vertically toward Earth. Thus Newton formulated his first law of motion, that all bodies will persist in a state of rest or in a line of motion *except* as affected by other bodies.

791.04 Newton reasoned that if Earth were to be annihilated, it would relinquish its pull on the Moon, and then the Moon would be free to fly off tangentially on an approximately linear course. He chose a night of full Moon at a given moment of clock time to observe the Moon—well above the horizon—predictably positioned against the celestial pattern of the "fixed" stars. He then calculated the line of tangential direction along which a released Moon would travel as traced against the sky pattern. Newton then observed and calculated the rate at which the Moon would travel away from the theoretical trajectory of release and "fall" toward the Earth as they both orbited the Sun at 60,000 miles per hour.

791.05 As a result of this observation and calculation Newton found that the path of the Moon's "fall" agreed exactly with the falling body data of (Galileo. Wherefore Newton concluded it was celestially manifest that

1. relative to all known bodies, the magnitude of mutual interattraction between any two bodies is proportional to the product of their paired and intermultiplied masses; and
2. whenever the distance between two bodies is halved, the force of their interattraction increases fourfold, which is to say that the interattraction varies exponentially at a second-power rate as the distance between the considered bodies varies at only an arithmetical rate.

791.06 For millennia humans had endeavored to explain the apparently random independence, the seemingly uncoordinated individual motions, of the five planetary bodies visible from Earth, orderly interpositioned against the background of the vast myriads of "fixed" stars of the celestial sphere. What Newton had discovered is relevant to our comprehension of the universal nature of structures. He had discovered a pair of integral characteristics of two bodies, with one interrelationship varying at an exponential rate and the other interrelationship covarying arithmetically. Kepler and Newton had found synergetic behaviors of whole systems that were unpredicted by the behaviors or the integral characteristics of any parts of the system considered separately. Kepler and Newton had found synergy.

791.07 If you were a contemporary of Kepler or Newton and were to have asked them what the mass interattraction called "gravity" *is,* they would have told you that they had no way of knowing. And there is as yet no way to explain the interrelationship behaviors found experimentally to exist "between" and not "of " any two objects in Universe. The relationships they discovered are elegantly reliable, but they are also an absolute a priori mystery.

791.08 Humanity has inherited an inventory of generalized laws of Universe from the Copernicus-Kepler-Galileo-Newton discoveries, which they in turn inherited from their Greek, Mesopotamian, Egyptian, Indian, and Chinese predecessors. There is no information to suggest that the inventory has been completed. All of the generalized laws can be expressed in mathematical terms. They are all eternally operative and interaccommodative. Together, the thus-far-discovered generalized laws guarantee the integrity of nonsimultaneous, only partially overlapping, Scenario Universe.

792.00 **Design**

792.01 The word *design* is used in contradistinction to random happenstance. Design is intellectually deliberate. Design means that all the components of the composition are interconsiderately arranged. In a design the component behaviors, proclivities, and mathematical behaviors are interaccommodative. The family of generalized principles constitutes an eternal cosmic design whose interrelationships are expressible only in abstract mathematical terms.

792.02 Speaking in terms of generalized law, *structure* is always and only the consequence of a complex of six energy events—three dominantly tensive and three dominantly compressive—with each set interacting in complement to produce a self- regeneratively stabilized pattern.

792.03 Contrary to common opinion (even that of engineers), structures are always dynamic and never static. All structural realizations are special case. Structural realizations have specific longevities; they are entropic; they give off energy. The energies are often syntropically replaceable in the consequence of structural transformations.

792.04 Any and all of what humans identify as substances are structural systems. Any and all structure consists entirely of atoms. Atoms are not things: they are energy events occurring in pure principle. Each and every experimentally evidenced atom is a complex of unique structural-system interrelationships—both internal and external—that manifest generalized pattern integrities in special case scenario continuities.

792.10 **Universe:** Universe is synergetic. Universe is synergetically consequent to all the generalized principles, known or unknown. Universe is not a structure. Universe embraces all structures and more. While a plurality of generalizations governs all structures, *realized* structuring is always special case. Structures are synergetic consequences of the intimate interaction of a complex of special case factors. Superficially, the overall limits of the manifold omniintertransformability of structures are unitarily conceptual.

792.20 *Scenario Universe:* Scenario Universe embraces all the nonsimultaneous, only-local-in-time-and-place structurings, destructurings, unstructurings, and restructurings. All the somethingnesses are structures. All the nothingness is unstructure. All the somethingnesses are special case. All the nothingness is generalized.

792.30 **Tension and Compression:** Everything we call structure is synergetic and exists only as a consequence of interactions between divergent compressional forces and convergent tension forces.

792.31 I take a piece of rope and tense it. As I purposely tense it, I inadvertently make it more taut. But I was not tensing the rope for the purpose of making it taut; my brain was only trying to elongate the rope. As I do so, however, the girth is inadvertently contracting and the rope is inadvertently getting harder. In getting harder the cross-section of the rope is contracting radially in a plane at 90 degrees to the axis of my purposeful tensing, thus inadvertently producing the always and only coexisting action-reaction-and- resultant complementations of myopic preoccupation.

792.32 Next I purposely produce compression. I take tempered steel rods, each three feet long and one-eighth of an inch in diameter. The rods bend flexively. We find that two rods cannot get closer to one another than in parallel tangency of their circular cross- sections. A third rod cannot get closer to the other two than by nestling in the parallel valley between them. With each of the three rods in parallel tangency, the centers of their three circular cross-sections form an equilateral triangle.

792.33 Hexagons consist of six equiangular triangles. Hexagons have six circumferential points and a center point—seven in all—all equidistant from their neighbors. Six rods now huddle in closest-packed tangency around the original rod. (See Fig. 412.01.) And 12 more rods may be huddled around the first seven to complete an additional hexagonal perimeter. Successive perimeters aggregate, each time with six more rods than those of the previous ring. The outermost rods will be tangentially closest packed in triangular stabilization with their neighbors; the rod at the center is at the symmetrical nucleus of the aggregate. We note in nature that the rodlike Earthward trajectories of closely falling, inter-mass-attracted raindrops passing through freezing temperatures nucleate in hexagonal snowflake arrays under just such hexagonal close- packing laws.

792.34 The Greek architects found experientially that when the height of a stone column exceeded its girth by 18 diameters, it tended to fail by buckling out of the central stone cylinder section. The length-to-diameter ratio of a compressional column is called its *slenderness ratio.* Continuous steel columns are more stable than stone columns and may be used structurally with slenderness ratios as high as 30 to 1—these are long columns. Short columns-with a slenderness ratio of 12 to 1—tend to fail by crushing rather than by buckling.

792.35 For our further experiment in *purposeful compression* we assemble a column 36 inches high with a minimum girth diameter of three inches. It requires 547 of our 36- inch-long, one-eighth-inch-diameter rods to produce this 12-to-1 short column. Each individual rod is slender and highly buckleable, but bound circumferentially together for its full length by tightly wound steel wire. The rods will close-pack symmetrically in a hexagonal set of 13 concentric rings around a nuclear rod: the maximum diameter will be three and three-eighths inches. We can then add forged steel caps over the hexagonal ends of this integrated short column.

792.36 We may next insert the column perpendicularly between the upper and lower jaws of a hydraulic press and load the composite column in vertical compression. We know from our earlier trial that each rod taken by itself can bend when end-loaded. Being close-packed together, they cannot bend further inwardly toward the center rod: they can only bend outwardly, straining the binding wire wrapped around the rods and causing them ultimately to yield to the severe outward force at the column's mid-girth. The bunched ends are held together by the hexagonal steel caps as the force of the hydraulic press increases. This results in the whole column twisting mildly and bulging out to become cigar-shaped as seen in vertical profile. If loaded sufficiently, the bundle approaches sphericity.

792.37 This experiment indicates that our purposeful loading of the column in compression inadvertently results in its girth increasing in diameter, which brings about *tension* in the horizontally bound wires. An inadvertent tension occurs in a plane at 90 degrees to the axis of compression.

792.40 **Tidal Complementarities:** By two visibly different experiments—one with rope and the other with steel rods—we have demonstrated experimentally that tension and compression always and only coexist. One can be at *high tide* of visibility and the other coincidentally at *low tide,* or vice versa. These tidal covariables are typical complementarities: they are not mirror images of one another, but must always balance one another complexedly in physical equations. Both demonstrate 90-degree inadvertent resultants. In engineering this behavior is known as the *Poisson effect,* and in physics it is known as *precession.*

792.50 **Spherical Islands:** Short columns loaded on their neutral axes tend to bulge toward sphericity of conformation. In the spherical form-and only in the spherical-we find that the system has no unique axis. Any diametric loading in the sphere is in effect a neutral axis. In coping with compressive loads, spheres act most effectively regardless of which is the loaded axis. Since spheres have the greatest volume with the least surface, loads are evenly distributed radially from the center to all of the enclosing mass. Thus ball bearings constitute the most effective of universal load-bearing designs for compressional functioning.

792.51 We find nature preferentially investing her compressionally assigned energy tasks in sphericals—whether stars, planets, asteroids, oranges, or atoms. Universe isolates all her major compression functions in spherical islands that are vastly remote from one another and that are intercohered only by Kepler's and Newton's invisible tension: gravity. The star Sun gravitationally precesses its compressionally islanded planets to orbit around it; the atomic nucleus gravitationally precesses its islanded electrons to orbit around it. Nature's cosmic structuring strategy employs only discontinuous islanded compression and only omni-everywhere continuous tension, *gravity.* Paradoxically, Earthian engineers as yet design their structures only as compressional continuities, sometimes tied together by tension rods and reinforcements. Humans still use a primarily direct-compressional Stone Age logic, using tension only as a secondary reinforcement. Nature—both macrocosmically and microcosmically—uses a primary tensional logic, with compression as a secondary islanded back-up.

792.52 The Stone Age logic said that the wider and heavier the walls, the more happily secure would be the inhabitants. The advent of metal alloys in the 20th century has brought an abrupt change from the advantage of structural ponderousness to the advantage of structural lightness. This is at the heart of all ephemeralization: that is the dymaxion principle of doing ever more with ever less weight, time, and ergs per each given level of functional performance. With an average recycling rate for all metals of 22 years, and with comparable design improvements in performance per pound, ephemeralization means that ever more people are being served at ever higher standards with the same old materials.

Next Section: 793.00

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