A SPACE "NECKLACE" ABOUT THE EARTH

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A SPACE "NECKLACE" ABOUT THE EARTH

G. Polyakov*

The resources of our planet are by no means unlimited and the rapidly growing population will certainly migrate to the nearest heavenly bodies and artificially created asteroids. However, sicentists have no single opinion as to how and at what time this "great migration of humanity" will occur. Can the space transport ships of a future time cope with mass migration? And then, in addition to humans, one must also transport a huge amount of various materials, equipment, and other things necessary to build space habitations. /41**

Since the "astro-humans" must work somewhere, there must be industries in space. These must primarily be technological processes which can survive the presence of factors such as high vacuum, weightlessness, and intense radiation. Andthere will be high-power solar and thermonuclear power stations to supply energy to the extra-terrestrial factors and cities. And again, all of these require transportation.

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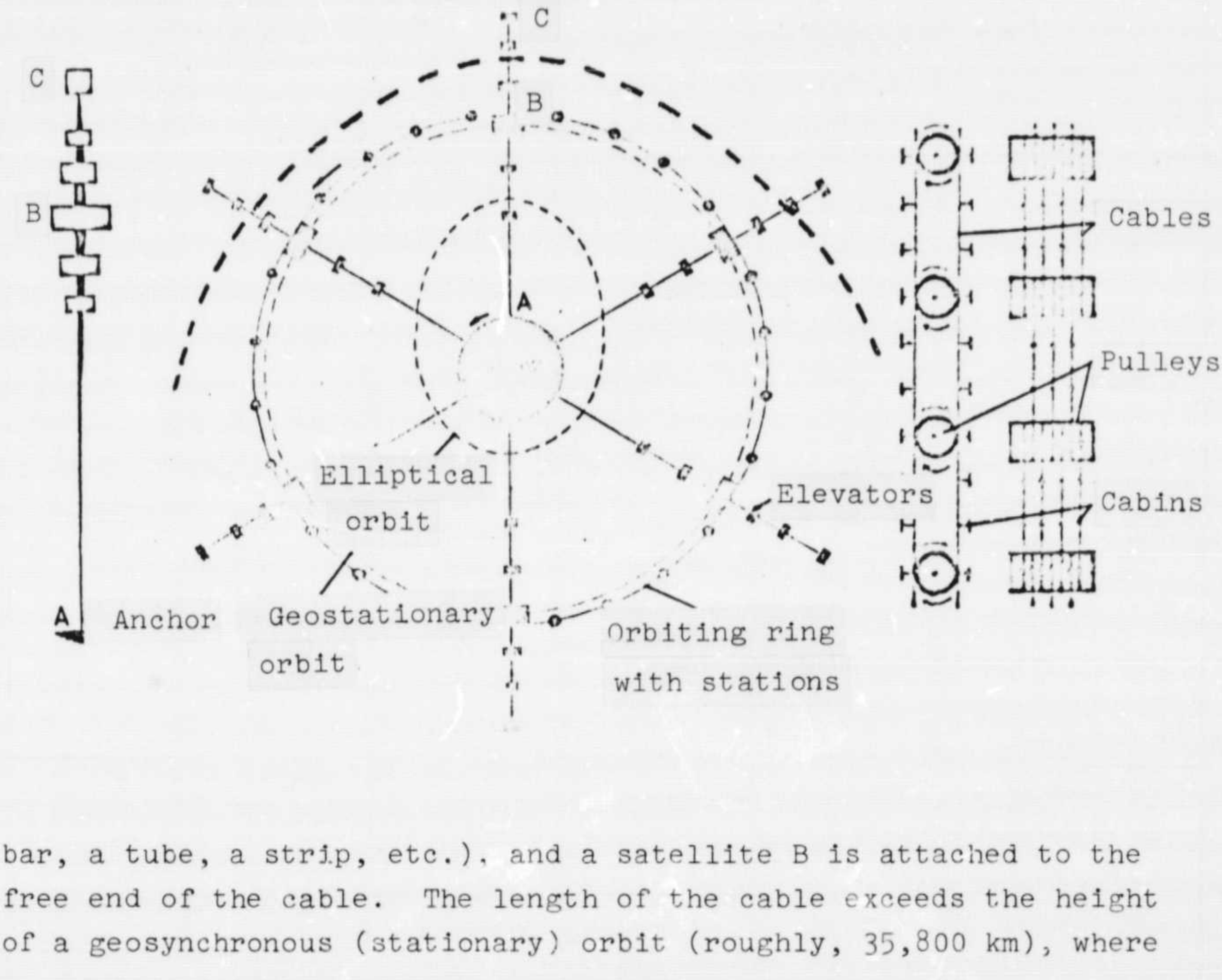
In our opinion, the transport problem can be solved by the space elevator; it supplements rockets as the railway supplements aircraft.

Tsiolkovskiy mentioned the possibility of a structure like this in 1896 in his article "Daydreams About the Earth and the Heavens". But this idea has attracted fresh interest 64 years later, when the Leningrad engineer Yu. Artsutanov put it in an advanced form and explained its rationale in Komsomol'skaya Pravda. The present paper describes further development of this very unusual project.

At first sight the space elevator seems to be simply a curiosity. Referring to the figure (below, left): a cable is attached at the Earth's equator (at the point A; the cable can be replaced by a



bar, a tube, a strip, etc.), and a satellite B is attached to the free end of the cable. The length of the cable exceeds the height of a geosynchronous (stationary) orbit (roughly, 35,800 km), where a body has a rotation period of 24 hours (more correctly, 23 hours, 56 minutes), i.e., the same as the Earth. (In other words, it hangs motionless above the surface of the planet.) The elevator is acted on by two opposing forces: gravitational and centrifugal, due to gravity and the daily rotation of the Earth. At the point B, located at the stationary orbit, these forces are balanced. The gravitational force predominates in the section AB, and the centrifugal dominates in the section BC.

The elevator will be in a stable equilibrium only when the centrifugal force dominates over the gravitational. (This is why the satellite flies above the stationary orbit.) In this condition, the cable is taut and the force on the base A is equal to the difference between these forces.

Naturally, the material of the elevator must possess unique properties: high strength against rupture, and simultaneously low mass. It is enough to say that the ratio of the rupture stress to the density (σ/ρ) must be at least a factor of 50 greater than for steel. It would be wrong to think that the production of such materials is a matter for the remote future. A search in this direction has begun, and now various composite materials have been obtained, foam steel, beryllium alloys, crystal whiskers, ... In principle, these already meet the requirements demanded of the elevators. /42

However, not all of the cable must be made of crystal fibers. Calculations show that the quantity σ/ρ is inversely proportional to the quantity $\alpha = S_B/S_A$, the ratio of the cable cross sectional area at the points B and A. This means that it is appropriate to thin down the cable away from the point B, where the thickness is a maximum, towards the ends. It is true that the mass of the elevator rapidly increases, and that α cannot apparently exceed 10. Since the stress is greatest at the point B and falls monotonically towards the end of the cable, it is likely that the ordinary super-strength materials will be suitable for the peripheral parts of the elevator.

Finally, an actual space elevator will be a more complex structure than described here. It will include stations for operational servicing, scientific laboratories, living and production quarters, stations, and many other features. These modules will be located symmetrically relative to the point B, so that a complex elevator may well consist of a number of simple units with sequentially diminishing lengths. Each is a self-balancing system, and the stability of the whole structure derives from only one of them, that which reaches the Earth.

We frequently mention the point B, with good reason: here the main base is located. Since it is in a state of weightlessness, its dimensions can be very large (from several tens of meters to 10 km in diameter). However, it is not pleasant to live constantly under weightless conditions. At the base it is necessary to create an artificial gravity, supplied by rotation. Certainly, then the elevator, rotating along with the Earth, will experience a gyroscopic moment which will tend to deviate it toward one of the poles. To counteract this effect, it is desirable to make the base of two identical disks, rotating in opposite direction with equal angular rates. As a result of symmetry, the gyroscopic moment goes to zero.

In regard to the other nodes, the gravity question does not arise: this is because of the difference between the gravitational and centrifugal forces. For stations located below the point B, the gravity is directed downwards, and for the stations above B it is upward. The further the node is from this point, the greater is the gravity.

The length of the elevator (roughly 4 Earth diameters) has been chosen such that a spacecraft separating from the top of the cable would fly out into open space because of inertia. In other words, at the point C there will be a launch point for interplanetary spacecraft. This can take the form of several distinct stages, each, because of its own speed in space, designed to launch toward a particular planet, thereby providing a minimum correction to the trajectory of a spacecraft released from it. Further, a spaceship returning from a flight would first go into a geosynchronous orbit, and then be sent down by elevator to the base region.

If an emergency arises, and some station becomes separated from the elevator, it begins to rotate around the Earth in an elliptical orbit (the figure, center). The point of separation becomes either /43 the perigee of the orbit (the station lies above the base), or the apogee (below the base). The lowest of the large stations is located at a height such that if it becomes separated the perigee of the orbit should be beyond the atmosphere. Naturally, stations finding themselves isolated will call for fast assistance from space tugs.

From the construction viewpoint, the space elevator takes the form of two parallel tubes or columns of rectangular section, whose wall thickness varies according to a specific law. Along one of these, the cabins move upward, and in the other — downward. Of course, there is no impediment to constructing several such pairs.

The tube can be simple, and composed of a great many parallel cables, whose position is fixed by a series of transverse rectangular frames. This would facilitate erection and repair of the elevator.

The elevator cabins are simply surfaces which are moved by individual electric motors. These carry cargo or living modules (the journey in the elevator will take a week or more).

The main junctions are located at the points A, B, and C, and are joined by several transport lines. In order for the elevator to remain vertical, the motion of the cabins with cargo must be congruent. It is interesting that the centrifugal force makes it easy to raise the cabins. And in the section BC they will move upward by themselves.

To economize energy one might create the system shown in the figure on the right. It consists of a series of pulleys through which endless cables move with cabins suspended on the cables, and is reminiscent of a cable-chair system. The axes of the pulleys, where electric motors are mounted, are fastened to the elevator supports. Here the weight of ascending and descending cabins are balanced and, therefore, the only energy expended is that to overcome friction.

The "sky escalator" has two main purposes: to serve as a transport trunkline to near space and as a means of acquiring cosmic speeds without using rockets. However, it will undoubtedly find a multitude of other applications. For example, from the stations one can study the Earth and heavenly bodies, radio transmission, etc., and with wires carried along the elevator one could transmit energy to the Earth from orbiting solar and thermonuclear power stations. The technical state of the equipment will be monitored continuously (via a network of sensors) by a special electronic system.

The actual construction begins with the creation of a large long-lived orbiting station in geosynchronous orbit. From the station to the Earth and from the Earth we draw out two cables strictly in congruent manner, and a small spacecraft is attached to the free end of the top one. At first, the motion of the cables is directed by control jet motors, and later by gravitational and inertial forces. The stability of the entire system (until the lower cable reaches the surface of the planet) is also managed by rocket jet motors.

Then the other cables are drawn out parallel to the main cable. It is possible that these will be drawn out from the melt directly at the orbiting station, since it is more convenient to obtain super-strength materials in weightless and vacuum conditions.

Taking account of predictions of the growth of the Earth's population, one can calculate that the migration via a space elevator will appear somewhere in the first quarter of the 21st century. Equipment like this will also be set up on other heavenly bodies of the solar system, whose mass is less than that of the Earth and which rotate fast enough (Mars, individual satellites of planets, and large asteroids). Extraterrestrial elevators will be much smaller and will experience comparatively small limiting stresses. For example, an equipment on Mars experiences a load that is less by a factor of 5 than on Earth and, in addition, its length is less by a factor of 2.

Nowadays one reads much about astro-cities, for which Tsiolkovskiy proposed the first plans. Where should these be located in outer space? Some specialists consider that they should be at the so-called Lagrange points, where the attractive forces of the Earth and the Moon are balanced. But these sections are quite far from us. It is clearly desirable to choose the same geosynchronous orbit. It is already becoming rapidly populated by satellites.

These sections would soon be linked up with dozens of solar electric power stations. We note that the well-known American scientist K. Ehricke has proposed the positioning of a row of huge mirrors along a geosynchronous orbit, with a total area of up to 66,000 km^2. On some regions of the Earth this creates illumination comparable with sunlight.

These and other promising technical proposals support the prediction that in the lifetime of people alive today the geosynchronous orbit will become densely populated by spacecraft of very diverse kinds and purposes. And since these will be all nearly motionless relative to the Earth, it will be very attractive to link them to the Earth and to each other by means of space elevators and an annular transport trunkline.

Thus we arrive at the idea of a space "necklace" around the Earth (see the figure, center, and also the front cover of the journal). It consists of radially positioned equatorial elevators, and a huge ring extending somewhat above the geosynchronous orbit, to which a multitude of space stations is moored.

If the ring is located exactly in geosynchronous orbit, it will be in unstable equilibrium. To avoid this, the radius of the ring is increased a little to place it somewhat above geosynchronous orbit, so that the excess centrifugal force stretches the necklace. The ring is in a near weightless state, it is not subject to any special stresses, and it is much simpler to build than the space elevator.

The necklace serves as a unique cable (or track) railway between astral cities and also gives them stable equilibrium in geosynchronous orbit. Certainly, without the ring the stations would gradually spread apart under the action of perturbing forces. This would severely limit their number, and rocket engines would be required to compensate for perturbations, entailing a large fuel use and causing pollution of the environment.

In addition to the living quarters, e.g., O'Neil-type cylinders (TM, 1976, No. 4), the ring also includes stations for industrial, agricultural, and power production. The technical processes in these enterprises will undoubtedly be based on closed and fully automated cycles.

Since the length of the necklace is very great (260 thousand km), it can carry a great many stations. If the habitations are, say, 100 km apart, there could be 2600. If each dwelling station housed 10 thousand poeple, the total number in the ring would be 26 million. If the size and number of these astro-cities were both increased appreciably, the number of people would increase greatly.

The creation of this space necklace around the Earth is possibly the practical embodiment of one facet of Tsiolkovskiy's plan for the conquest of world space, where he speaks of "building vast settlements around the Earth".