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Air Cable Transport System

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Currently, aircraft are used to move payloads and passengers from one place to other. This method is expensive because aircraft use expensive fuel and have high capital costs. New method for less expensive delivery of payload and people from one city to other city (similar to airlines), or across streams, river, canyons, and mountains, is proposed. The method uses a closed-loop cable path with the propulsion system located on the ground. The system can utilize any inexpensive energy source and air vehicles or cheaper wing containers without expensive electronic equipment. This method is particularly effective for providing an air bridge across straits or mountains. It is less expensive then conventional air transport systems. The analysis provides computations for two projects: airline travel from New York to Washington and an air bridge across Gibraltar. The closed results are for English Channel. The proposed systems can also transfer large amounts of mechanical energy from one place to an earth's surface to another with high efficiency.

Nomenclature

C_f	=	friction cable drag coefficient
D	=	drag of cable, n
D_f	=	cable friction drag, n
D_L	=	air laminar drag, n
D_T	=	air turbulent friction drag, n
d	=	diameter of the cable, m
E	=	energy, J
g	=	9.81 m/s^2, gravity coefficient
K	=	$10^{-7}\sigma/\gamma$, stress coefficient
K_1	=	ratio of a lift force to a drag force of the wing container ($K_1 = 10$–17)
K_2	=	ratio of a lift force to a drag force of the support cable wing ($K_2 = 15 - 25$)
L	=	distance between power stations, m
m	=	mass of apparatus, kg
n	=	overload, g
q	=	$\rho V^2/2$, dynamic pressure, n
S	=	cross-section area of a start cable, m^2
S_0	=	cross-section area of transport cable supported by wing, m^2
V	=	cable speed, m/s
W	=	cable weight, kg
W_0	=	weight of cable supported by wing, kg
γ	=	specific density of cable, kg/m^3
σ	=	tensile stress of cable, n/m^2
μ	=	air viscosity, $1.79/10^5$ kg/s · m at altitude 0 km and $1.527/10^5$ kg/s · m at altitude 8 km
ρ	=	air density, 1.225 kg/m^3 at altitude 0 km and 0.5258 kg/m^3 at altitude 8 km

Introduction

CURRENTLY, aircraft, cars, trucks, trains, and ships are used to move payloads from one place to other. This method is expensive and requires good highway systems and expensive vehicles, which limits the feasibility of delivering many types of freight. Aircraft use expensive fuel and have high capital costs. The author offers a new, revolutionary method and installations for cheaper delivery of payloads and people 1) from one place to another; 2) across streams, rivers, canyons, mountains, etc.; 3) accelerating vehicles to desired velocity; and 4) cheaper vehicles, which do not require their own engine. The method uses a closed-loop cable path with the propulsion system located on the ground; the concept includes airlines.

There are cable systems used to transport people (ski lifts, tram cars) or to cable launch systems for gliders. However, the suggested system has a principal, very important distinction from them. Our support cable system is located at atmosphere at high altitude (up to 12 km) and supported by moved WINGS connected with moved cable. Our system does not need supported columns and can have a very long length (up to thousands of kilometers). It allows the air vehicles to fly at high altitude with high speed (up to supersonic speed) and makes the offered transport system inexpensive. The proposed system is unique with no references found for similar systems in the literature or patents.

At the present time all vehicles (cars, trucks, buses, trains, aircraft, airships, dirigibles, sea ships) use engines located on the vehicle. Their engines require expensive fuel. The vehicle must carry both the engine and the fuel, which reduces the payload capacity. For example, for aircraft flying long distances the fuel weight can reach 30 to 40% of the takeoff weight; the engine weight is about 10% of the full weight of the vehicle. As a result, the payload is decreased to only 10–20% of the vehicle takeoff weight.

The proposed method maximizes the payload (no engine, no fuel in the vehicle) and allows use of the cheapest form of energy (such as liquid fuel, natural gas, wind-, or hydropower stations) and cheaper vehicles.

The basic idea is simple (Fig. 1): to connect the vehicle to an engine located on the ground by a strong light cable. Loss of flexibility is not a large problem because travel routes with the most traffic for civilian airlines are fixed. The problems appear when we want to cover a long distance (from one mile up to hundreds or thousands of miles) across a stream, river, sea, ocean, or heavily congested area, especially the suspension of a cable in the air at high altitudes (5–12 km). It is another problem. For highways, the connection and disconnection of the vehicle (auto, car, truck, bus) at required locations along the route of a permanently moving cable is also a problem. For city transport systems (large numbers of routes and stops) the changing of lines and directions and the organization of the delivery of a huge flow of different vehicles to many points also must be addressed.

These main problems are solved in the proposed innovation.[1] The important feature of this invention is the possibility of using existing

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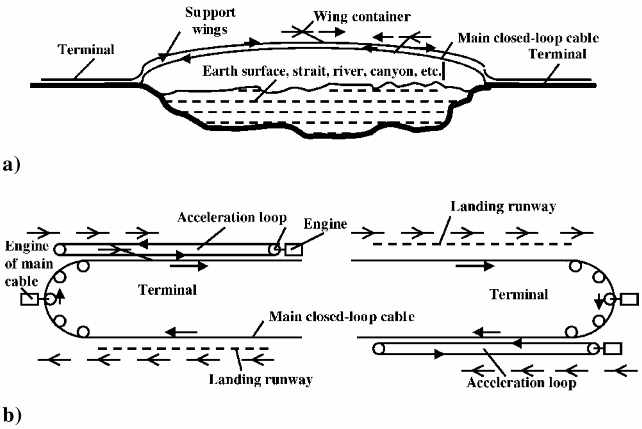

Fig. 1 Airline or air bridge when main cable supported by cable wings: a) side view and b) top view.

aircraft and automobiles (trucks or buses) for the suggested system after connection–disconnection devices are added to them.

Computations show that a strong and light cable (rope) for a long-distance movement (delivery, transportation) system (some hundreds and thousands miles) is required. Currently, industry is producing cheap fibers, which have the required properties. We also have fibers, whiskers, and experimental nanotubes, which have the required properties for application to the proposed ideas.

For distances more than 100 km, the light, strong cable (rope) requires a ratio of tensile strength/specific weight, of more than 200 km.

The objective of this innovation is to provide cheap delivery of payloads and people from one place to another. That can include airlines from one city to another and air bridge over straits such as Gibraltar or English Channel. Moreover the suggested transportation system can transfer large amounts of mechanical energy from one place to another on Earth with high efficiency. The other applications that use these ideas are presented in Refs. 2–11.

Short Description of Installation

An example installation is shown on Fig. 1a (side view). This is an airline, an air bridge over a sea strait, stream, or channel, for example, the Straits of Gibraltar (16 km) or English Channel (40 km). The installation includes the terminals (departure and arrival), a light, strong closed-loop (main) cable over the surface, strait, mountain, or water (in both directions), winged containers for payload and people, and a wing support system.

Figure 1b shows the terminal (departure and arrival ports). The departure terminal (port) has a starting acceleration system, takeoff runway, arrival (braking) station (system), starting (acceleration) closed-loop cable, starting rollers, starting engine (engine of the starting system), starting connection–disconnection sliding device (connected to a starting cable and to the wing container), main connection–disconnection sliding devices (connected to the main cable and to the wing container), landing runway, platform for arriving wing containers (unloading station), and platform for departing wing containers (loading station). The terminals also have the rollers for the main cable and an engine (drive) station of the main cable. The engine drive station includes engines, storage of energy (energy storage system, for example, inertial flywheel), transmission, clutches, brake, control system, and an energy transfer system.

This installation works in the following way (see Fig. 1b). The acceleration engine moves the closed-loop starting cable and the main engine moves the primary closed-loop main cable. The payload (cars and trucks) and people arrive to port. They are loaded to the platform and rolled to winged containers. The wing container is connected to the starting cable via the connection device, and the starting engine system accelerates the wing container to a velocity when the wing can keep the container in air. At the end of the takeoff segment of the flight, the container is disconnected from the starting cable and transfers connection of the container by device to the main cable. The container flies over the surface (strait and water) and lands at the arriving port. Here it is disconnected from the main cable and brakes on the landing runway. It moves to the arrived platform, where it is unloaded and is moved to the departure platform for the next loading and flight. The delivery in the opposite direction is the same.

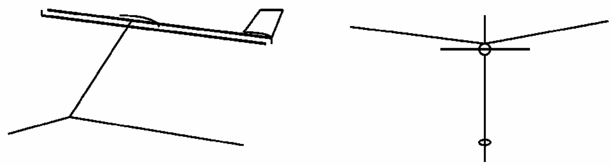

Fig. 2 Support wings of main transport cable.

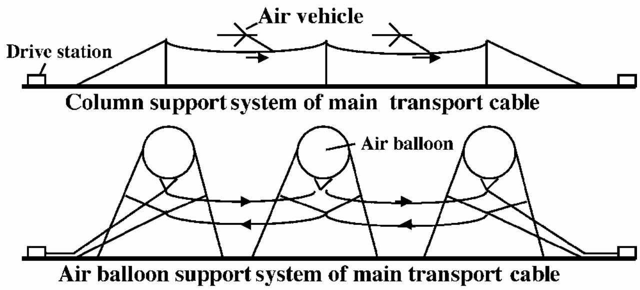

Fig. 3 Column or air balloon support system of main transport cable.

Figure 2 shows the cable wing for support main transport cable. Figure 3 shows the short support system, which uses columns or air balloons.

The suggested movement system has large advantages in comparison with the current systems of airlines, bridges, underground tunnels, and delivery by conventional cars and trucks:

1) Aircraft are very expensive. The suggested airline system does not use conventional aircraft. They use a cheap wing container or cabin without engines and expensive electronic equipment for navigation and communication.

2) Aviation fuel is expensive. The proposed airline system can use any sort of cheapest energy such as wind, water, nuclear or fuels such as natural gas, coal, peat, etc., because the engine is located on the Earth's surface. The old airplanes (without engines and electronic equipment) can be used as wing containers.

3) It is not necessary to have a highly qualified personal such as pilots with their high salaries.

4) The fare for the flight will be much lower.

5) Terrorists cannot use this system for damage of important objects.

Formulas for Estimation and Computation

The following formulas were developed or used by the author. These formulas allow you to calculate different variants.

1) Cross-section area and the weight of a starting (acceleration) cable of a constant cross-section area can be found from equality (balance, equilibrium), an inertia force to cable stress

$$S = mng/(\sigma - ng\gamma L), \qquad W = SL\gamma \tag{1}$$

2) Cross-section area and weight of a transportation cable supported by cable wings

$$S_0 = (D + m/K_1)/(\sigma - \gamma L/K_2) \tag{2}$$

$$W_0 = S_0 \gamma L \tag{3}$$

The cable drag is small. Results of computation for cable density $\gamma = 1800$ kg/m^3, airplane mass $m = 100$ tons, $K_1 = 12$, $K_2 = 20$, and $D = 0$, presented on Figs. 4–7.

Maximum cable distance L supported by wings for $D = 0$ is

$$L = KK_2 \tag{4}$$

Results of computation are presented on Fig. 8.

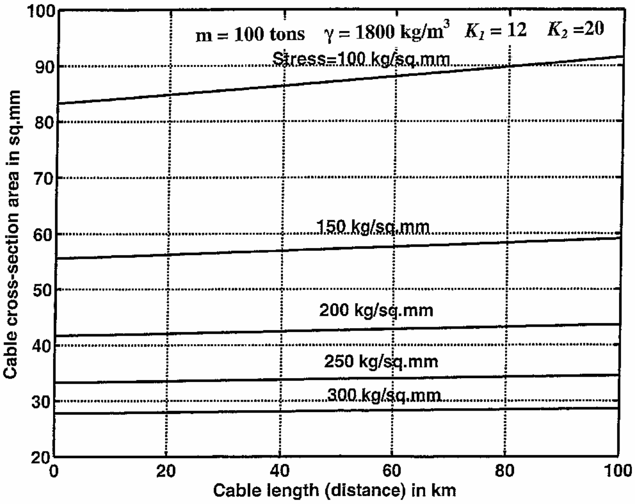

Fig. 4 Cable cross-section area vs distance 0–100 km for admissible tensile stress 100–300 kg/mm^2.

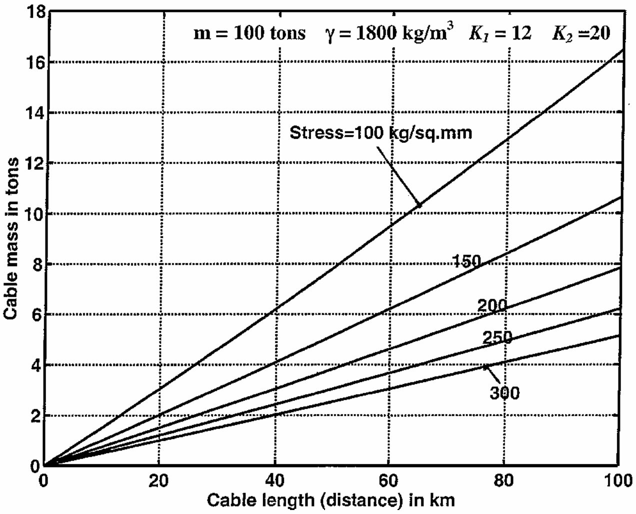

Fig. 5 Cable mass vs distance 0–100 km for admissible cable tensile stress 100–300 kg/mm^2.

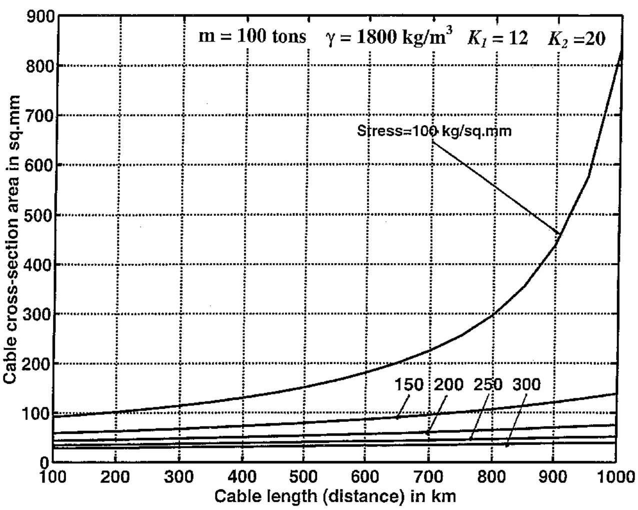

Fig. 6 Cable cross-section area vs distance 100–1000 km for admissible tensile stress 100–300 kg/mm^2.

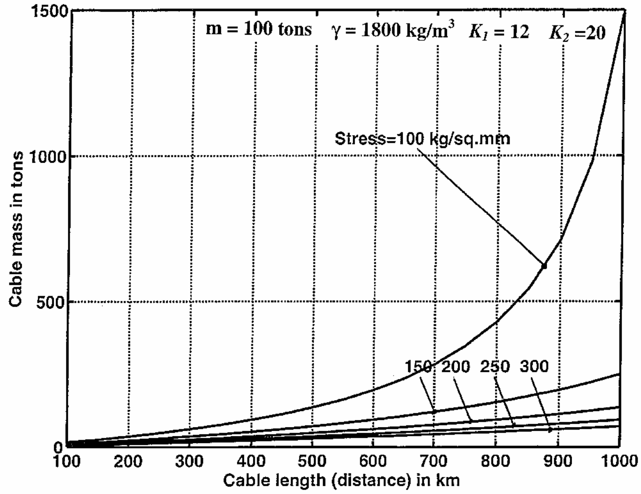

Fig. 7 Cable mass vs distance 100–1000 km for admissible cable tensile stress 100–300 kg/mm^2.

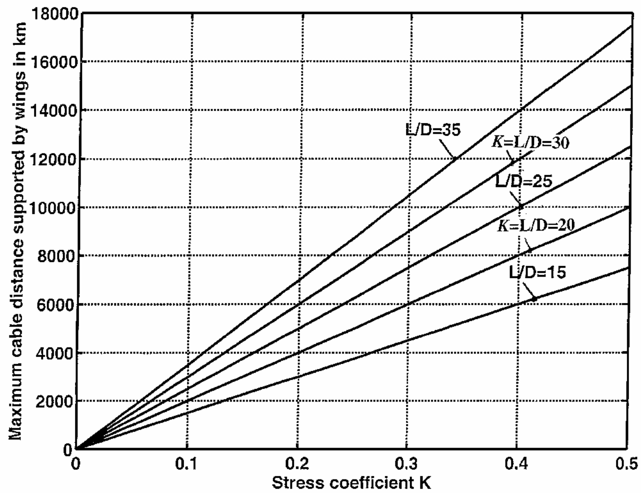

Fig. 8 Maximum cable distance supported by wings vs stress coefficient for lift/drag ratio 15, 20, 25, 30, 35.

If $D \neq 0$, the formula (4) is

$$L = \sigma S/(\gamma S/K_2 + C_f q \pi d) \tag{4'}$$

The others methods of the cable support such as balloons or columns do not have this constriction. They can be computed by Eq. (4′) if $K_2 = \infty$.

3) Energy storage by a rotary flywheel per 1 kg cable (J/kg) can be found from the known equation of the kinetic energy

$$E = 2\sigma/\gamma \tag{5}$$

4) Estimation of cable friction caused by the air is difficult because no experimental data for air friction of an infinity thin cable exist. The well-known equation for air friction (drag) of a flat plate is used to estimate this effect. This friction (drag) can be turbulent or laminar. Their values are different. The plate has two sides. It means for the cable that the cable drag must be decreased in two times. For subsonic speed and a flat plate the equation of turbulent and laminar drags is

$$D_T = 0.0573\rho^{0.8}\mu^{0.2}V^{1.8}L^{0.8}d \tag{6}$$

$$D_L = 1.04\rho^{0.5}\mu^{0.5}V^{1.5}L^{0.5}d \tag{7}$$

It is postulated that the cable surface has a half-laminar boundary layer because of a small side wind that will blow away the turbulent layer and restore the laminar flow.

$$D_f = 0.5(D_T + D_L) \tag{8}$$

Result of the computation is on Figs. 9 and 10.

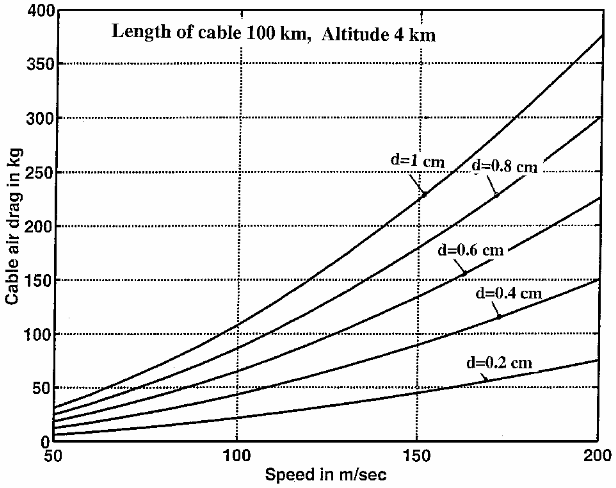

Fig. 9 Cable air drag vs speed for cable diameter 0.2, 0.4, 0.6, 0.8, 1 cm. Cable length is 100 km. Altitude is 4 km.

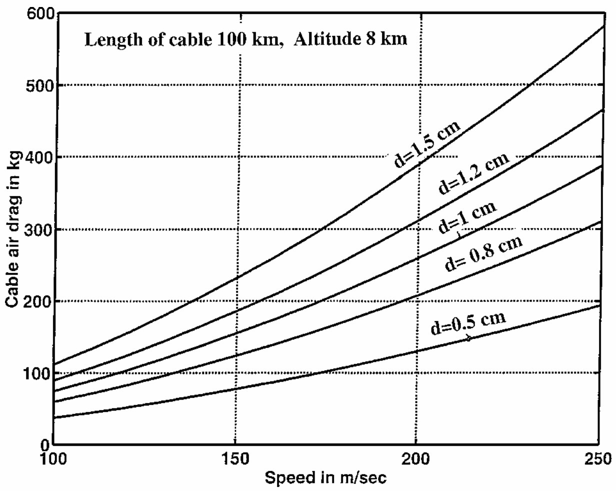

Fig. 10 Cable air drag vs speed for cable diameter 0.5, 0.8, 1, 1.2, 1.5 cm. Cable length is 100 km. Altitude is 8 km.

Cable Characteristics

Most engineers and scientists think it is impossible to develop an inexpensive transportation system using a long cable. Twenty years ago, the mass of the required cable would not allow this proposal to be possible. However, today's industry produces artificial fibers, which have tensile strengths three to five times more than steel and densities four to five times less then steel. There are experimental fibers, which have tensile strengths 30–100 times more than a steel and densities two to five times less than steel. For example, in Ref. 12, p. 158, there is a whisker C_D, which has a tensile strength of $\sigma = 8000$ kg/mm^2 and density of $\gamma = 3.5$ g/cm^3. If we take an estimated strength of 7000 kg/mm^2 ($\sigma = 7 \cdot 10^{10}$ n/m^2, $\gamma = 3500$ kg/m^3), then the ratio is $\gamma/\sigma = 0.05 \cdot 10^{-6}$ or $\sigma/\gamma = 20 \cdot 10^6$ ($K = 10^{-7}\sigma/\gamma = 2$). Although the described (1976) graphite fibers are strong ($\sigma/\gamma = 10 \cdot 10^6$), they are at best still 10 times weaker than theory predicts. The steel fiber has a tensile strength of 5000 MPa (500 kg/sq · mm); and the theoretical limit is 22,000 MPa (1987); the polyethylene fiber has a tensile strength 20,000 MPa, and the theoretical limit is 35,000 MPa (1987).

Apart from unique electronic properties, the mechanical behavior of nanotubes also has provided excitement because nanotubes are seen as the ultimate carbon fiber, which can be used as reinforcements in advanced composite technology. Early theoretical work and recent experiments on individual nanotubes [mostly multi wall nano-tubes (MWNT)] have confirmed that nanotubes are one of the stiffest materials ever made. Whereas carbon-carbon covalent bonds are one of the strongest in nature, a structure based on a perfect arrangement of these bonds oriented along the axis of nanotubes would produce an exceedingly strong material. Traditional carbon fibers show high strength and stiffness, but fall far short of the theoretical, in-plane strength of graphite layers (an order of magnitude lower). Nanotubes come close to being the best fiber that can be made from graphite structure.

For example, whiskers from a carbon nanotube (CNT) have a tensile strength of 200 GPa and a Young's modulus over 1 tera Pa (1999). The theory predicts 1 tera Pa and a Young's modules of 1–5 tera Pa. The hollow structure of nanotubes makes them very light. (The specific density varies from 0.8 g/cc for single wall nano-tubes (SWNT) up to 1.8 g/cc for MWNTs, compared to 2.26 g/cc for graphite or 7.8 g/cc for steel.)

The strength/density ratio is important in the design of our long air transportation system; nanotubes have values at least two orders of magnitude greater than steel. Traditional carbon fibers have a specific strength 40 times that of steel. Because nanotubes are made of graphitic carbon, they have good resistance to chemical attack and have high thermal stability. Oxidation studies have shown that the onset of oxidation shifts by about 100°C to higher temperatures in nanotubes compared to high modulus graphite fibers. In a vacuum, or reducing atmospheres, nanotube structures will be stable to any practical service temperature.

The fibers are cheap. They are widely used in tires. The price of SiC whiskers produced by Carborundum Company with $\sigma = 20{,}690$ MPa (2069 kg/mm^2) and $\gamma = 3.22$ g/cc were \$440/kg in 1989. The market price of nanotubes is also too high presently (~\$200 per gram) (2000). In the last 2–3 years there have been several companies that were set up in the U.S. to produce and market nanotubes. It is hoped in the next few years nanotubes will be available to consumers for less than U.S. \$100/pound.

Following is a brief overview of recent research information regarding the proposed experimental tested fibers. Data that can be used for computation are in Refs. 12–15. Let us consider the following experimental and industrial fibers, whiskers, and tubes:

1) Experimental nanotube CNT has a tensile strength of 200 GPa (20,000 kg/sq · mm), Young's modules are over 1 tera Pa, and specific density $\gamma = 1800$ kg/m^3 (1.8 g/cc)(year 2000). For a safety factor let $n = 2.4$, $\sigma = 8300$ kg/mm$^2 = 8.3 \times 10^{10}$ n/m^2, and $\gamma = 1800$ kg/m^3, $(\sigma/\gamma) = 46 \cdot 10^6$. The nanotube SWNT has a density of 0.8 g/cc, and the nanotube MWNT has a density of 1.8 g/cc. Unfortunately, the nanotube is very expensive at the present time (1994). The United States corporations will produce 300-kg nanotubes in 2002.

2) Whiskers C_D have $\sigma = 8000$ kg/mm^2 and $\gamma = 3500$ kg/m^3 (1989). The computations assume $\sigma = 7000$ kg/mm^2, $\gamma = 3500$ kg/m^3, and $\sigma/\gamma = 20 \times 10^6$.

3) Industrial fibers with $\sigma = 500$–620 kg/mm^2, $\gamma = 1800$ kg/m^3, and $\sigma/\gamma = (2.78 - 0.334) \cdot 10^6 = (2.78 - 0.334)\ K$.

Projects

Project 1: Airline New York–Washington (340 km)

Let us take one wing cabin (container) with a weight of 100 tons. The payload is $\frac{2}{3}$ of the full weight (66 tons ≈ 660 passengers). The flight time with a speed of 200 m/s is 28.3 min ≈ 30 min or about 100 flights per day (in both directions). The total (maximum) number of passengers is 66,000 or 6600 tons of payload per day. Assuming an aerodynamic efficiency of 16 (ratio of lift/drag), the required thrust is 100/16 = 6.2 tons, assuming a thrust of 10 tons for one direction (includes cable drag and drag of support devices). For admissible cable tensile strength $\sigma = 250$ kg/mm^2 the required cable cross-sectional area is 40 mm^2, the cable diameter is 7.2 mm, and the cable weight is 24.5 tons for a cable density of 1.8 g/cc. The air drag of a cable at an altitude of 7 km is 1.08 tons.

Estimation of drag for the support flight devices (cable support wings) assumes the aerodynamic efficiency equals 25. Then the support device drag will be 24.5/25 = 1 ton. The total drag is $6.2 + 1.08 + 1 = 8.28$ tons which is less than the 10 tons of thrust available. The required power is $V \cdot T = 200 \times 10{,}000 \times 10 = 20$ or 40 MgW for both directions. This equals the power of four 10,000-KW turbojet engines.

The wing container has a wing area of 170 m^2 and a wingspan of 42 m.

Production cost of one passenger delivered: Assume the cost of the installation is $20 million and has a service life of 20 years. The system requires 40 employees with an average salary of $50,000 per year, and the fuel cost is $0.25 per liter. The depreciation is $2750 per day, the salary is $5500 per day, and the fuel cost is $64,750 per day. Assuming 66,000 daily passengers, we find that the delivery production cost is less than $1 per passenger (64,750/66,000). If this cost is divided by a loading coefficient of 0.75, the delivery cost is $1.30 per passenger. This is less than a subway fare in New York. If a flight fare of $4.99 is charged, the profit is $173,000 per day or $63 million per year. You can live in New York and work in Washington, D.C. The flight takes about 30 minutes, which is less than the average transit time of the New York subway.

Project 2: Air Bridge

There are a lot of islands in the world, located close to one another or located close to a continent, that have large transportation flows.

An estimation of the main parameters for a Gibraltar air bridge (16 km) are presented; this result is closed for the English Channel or the other large bridges and tunnels [for example: Bering Straits (Russian–America), Sakhalin-Asia, Russia-Japan, etc.].

The main parameters are computed for the following daily load flow (same in both directions): 1) 1000 cars, the weight of each is 1 ton, total is 1000 tons; 2) 1000 trucks, the weight of each is 10 tons, total is 10,000 tons; and 3) 10,000 people, the weight of each is 100 kg, the total is 1000 tons. The total daily load flow in one direction is 12,000 tons for a total load flow of 24,000 tons.

Let us assume the average payload of a wing container is $\frac{2}{3}$ of its maximum payload capability. The total payload capability of the wing container is 300 tons: thus, the average payload is 200 tons for one container. Then we will need (12,000/200) = 60 flights per day in each direction.

Let us assume a flight (cable) speed of 100 m/s. (Speeds up 250 m/s can be used.) The flight takes (16,000/100) 160 s (about 3 minutes) in one direction; the English Channel transit time (40 km) will be 7 minutes with a speed of 100 m/s and 3 minutes with a speed of 250 m/s.

If the loading of the wing container takes 25 minutes, one wing container can make 50 flights per day. For 120 flights we will need three wing containers.

Estimates for the cable assume they are manufactured from fibers that have a tensile strength of $\sigma = 620$ kg/mm^2 and density of 1.8 g/cc (for example, QC-8805). Let use a safety coefficient of 2.4, then an admissible $\sigma = 250$ kg/mm^2. Let us use an aerodynamic efficiency (ratio of lift/drag) of 12 (current airplanes are up to 17 and gliders up 40). Then the drag of the container is (300/12) 25 tons. This is increased to 30 tons (we assume about 2–3% cable air drag plus 1–2% drag from the support flight devices). The cross-sectional area of the cable is (30,000/250) 120 mm^2, and the cable diameter is $D = 12.4$ mm. The weight of two cable branches (32 km) is 6912 kg $\approx$ 7 tons. For aerodynamic efficiency of support flight devices equals 20–30, the additional drag will be 7000/20 = 350 kg or 350/30,000 = 0.012 = 1.2% of the total trust.

The required energy impulse equals $N = 300{,}000$ n $\times$ 100 m/s = 30 MgW over a 160-s period. If we use an inertial accumulator of energy and the flight frequency equals 12 minutes, we will need an engine with a steady-state power output of $N = 30 \times 160/12 \times 60 = 6670$ kW; this is equivalent to one turboengine. The weight of the inertial accumulator of energy (constructed from fibers) equals $30 \times 160/0{,}75 = 6400$ kg = 6.4 tons.

Estimation of acceleration system requirements assumes an acceleration for takeoff and landing of $a = 0.5$ g = 5 m/s^2. Takeoff and landing distance is $L = V^2/2a = 10{,}000/10 = 1000$ m = 1 km. The thrust required for acceleration is $T = Wa/g = 300 \times 5/10 = 150$ tons. The cable has a cross-sectional area of (150,000/250) 600 mm^2, a diameter of 28 mm^2, and a weight of 4320 kg.

Estimation of the support flight devices assumes that one device supports 1-km cable. The weight of 1-km cable with a cross-sectional area of 120 mm^2 is 216 kg. If lift coefficient equals 1, the necessary wing area equals 0.42 m^2, resulting in a wing size of 2×0.2 m.

Data on the flight container assume a wing area of 480 m^2, a wing span of 80 m (80×6 m), the size of the container is $10 \times 5 \times 86$ m, the useful area of the floor is 500 m^2, and the useful volume is 2500 m^3.

For the suggested bridge we need only 11.4 tons of cable, three wing containers, a 6700-kW engine, an inertial accumulator of energy with a disc weight of 6.4 tons, and two simple ports with 1 km of runway length. The bridge system costs $10–30 million and requires six months for construction. The English Channel tunnel cost several billions of dollars, construction took many years, and delivery transit time is more than 0.5 hour. If the tunnel is damaged, the repair will be very expensive and take a long time.

Economic estimation: Let us assume the cost of the air bridge is $15 million (wing containers, engines, flywheels, and departure and arrival stations) and has a service life of 15 years (depreciation is $1 million per year). Employee costs assume 80 men with an average salary of $50,000 per year (maintenance is $5 million per year, $14,000 per day), and fuel costs of $0.25 per liter ($10,850 per day). The total load flow is 24,000 tons per day. The direct operating costs will be less then $2 per ton ($2 per car). If the toll charge for using the bridge is $5 from 1 car (1 ton), the profit will be $13 million per year.

Conclusion

The proposed method and installation for transportation is significantly cheaper then the current methods of flying traditional airlines. It will dramatically decrease the price of flight on conventional airlines, cost and time of construction on long bridges and tunnels and will put in practice huge projects as connections, such as Europe to Africa across Gibraltar, Russia to America across Bering Strait, Russia to Japan across Sakhalin, Taiwan to mainland China, and so on. It will decrease the cost and construction time of gas pipelines to save the environment.

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