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Catapult Transportation*

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Abstract

The current flight passenger-transport and cargo systems have reached the peak of their development. In the last 30 years there has been no increase in speed or reductions in trip costs. The transportation industry needs a revolutionary idea, which allows jumps in speed and delivery capability, and dramatic drops in trip price. The author offers a new idea in transportation in which trip (flight) time practically does not depend on distance, and vehicle load capability doubles and which has a driving engine that is located on the ground and can use any cheap source of energy.

The author develops the theory and provides computations for project contains five subprojects united the common idea: acceleration the air vehicle on ground and continuation of flight by inertia (high speed catapulting). The initial speed is 290 – 6000 m/s, the range is 50 -10000 km (short, average, and long distances). Short transport system has range 50-70 km, for example: city – sub-city, strait and air bridges such as across the Straits of Gibraltar 16 km, the English Channel 40 km, Bering Straits 100 km (Russia–America), Sakhalin–Asia 20 km, Russia–Japan, etc. The long distance has range up 10000 km such as New York-Paris 5838 km, Washington-London 7373 km, San-Francisco – Tokyo 8277 km, San-Francisco – Vladivostok (Russia) 8377 km, New York – Moscow 7519 km, Moscow – Beijing 5800 km, Moscow – Tokyo 7487 km, New York – Berlin 6392 km, and so on.

The offered catapult system having length 400 km can be used as the space launch system which decreases the space launch cost in hundreds times. That also may be used as the new conventional high speed (up 1000 km/h) transport system between cities. That will be significantly cheaper then used MagLev (Magnetic Levitation) systems, because for suspending of the vehicle used the conventional wing.

The offered system may be also used for the mass launch of bombs (projectiles) in war.

Key word: air catapult transport, air kinetic transport, new passenger and cargo transport, catapult aviation, new space launch system, new suspending high speed ground system, cattran, skimplane.

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Introduction

Current takeoff mass of a long distance aircraft is made up of approximately 1/3 aircraft body, 1/3 fuel, and 1/3 payload. The aircraft engine needs expensive aviation fuel. The passenger-transport aircraft cannot exceed the speed of sound. The “Concorde” history shows that the conventional passenger supersonic aircraft is unprofitable. The hypersonic aircraft, which is under development by the USA, will be more unprofitable as a passenger long distance aircraft because it will use very expensive hydrogen fuel, it is very complex and it has a high production cost [1]. The hypersonic engine problems have not been solved in spite of spending tens of millions dollars in research and testing [2]. The space launch by the current rocket space system is very expensive. The current high speed (up to 580 km/h) MagLev (Magnetic Levitation) transport system is also very expensive [3].

Transport, space launch systems and aviation needs new ideas which increase speed, and load capability, and reduce delivery cost. Some of these ideas have been published by the current author [1]–[11].

The initial author's idea is the acceleration (catapulting) of a cargo glider (vehicle), winged cargo box (non-engine aircraft), or space ship to high speed by using a cable engine. It was offered in 2002 [2] – [7], in particularly, it was presented in [1] and published in [8]. Given research is different because it uses a linear electric engine located on the ground. The vehicle will then use its kinetic energy for flight. The computation shows that a catapulted/kinetic aircraft accelerated to subsonic speed of 270–300 m/s can fly up to 60–80 km until its speed decreases to a landing speed of 50–60 m/s. This is far enough for suburban transport or for air bridges across the Straits of Gibraltar, English Channel, Bering Straits (Russia–America), Sakhalin–Asia, Russia–Japan, etc. For acceleration to this speed at a rate this is acceptable to passengers (overload is 3g)[5] the runway length must be 1.5 km (current runways for large aircraft are 1.5–3 km long). For the middle range (200 - 1600 km) the runway must be up to 4 - 67 km. For the long-distance flight (6000–8000 km), the air vehicle must be accelerated to a speed of 4–6 km/s. For acceleration of no more than 3g the required runway length would then be 270 – 400 km[5]. This runway can be also used for a space launch. One author method and design are described in References [5], [8]. Rather than being a conventional runway, it is an air cable acceleration system [5]–[8] for the acceleration of space vehicles and it is located in atmosphere.

The offered method is different from conventional MagLev because for suspending of vehicle one uses the conventional wing (no magnetic levitation!). That is significantly cheaper. The offered system has also small finance risk because it is used conventional technologies and in any case one may be used as conventional ground high-speed transport system between big cities.

Brief description of the innovation

The system for catapult/kinetic vehicles (CV/KV) includes (Fig. 1) a runway having the linear electric engine (LEE). The runway may be located on ground or over columns. The LEE can be located into the runway cover. In this case the runway may be used as a conventional aircraft take-off way (runway) or a car highway (quite straight) may double as launcher. In speed over 50 m/s (180 km/s) the catapult vehicle supported by its wings and do not have the friction with ground. As it shows the computation the length of runway is 1400 m for the subsonic vehicles having range 50-70 km; 4 - 67 km for the supersonic vehicle having range 200 – 1600 km; and 270 – 600 km for hypersonic vehicles having range up 10,000 km (and more) for acceptable (for conventional passengers) acceleration 3g. The trained cosmonauts can accept the "G" overload up to 9g and their start runway can be 400 km for final speed 8 km/s. For cargo space ships the runway will be significantly lower (because of higher G tolerance). The part of runway, where vehicle has supersonic or over Mach 1 speed may need reflectors, which will reflect the shock wave (sound boom). The system has a starting trolley where the catapulted vehicle is supported during launch. After release this trolley brakes at high acceleration and the additional braking distance is small. This part of spent energy is retuned back into the system.

This system is significantly cheaper than MagLev because one does not needed in the expensive magnetic suspension system. Rather than expensive liquid fuels, it uses the cheaper electric energy. The vehicles save greatly on expensive engines.

The system works in the following way. The catapult vehicle (aircraft without engines, wing container) locates on the start trolley, accelerates (overload n = 3g), separates from trolley, climbs to the need altitude (one may has the vertical overload n = 3g), flights (using its kinetic energy, gradually loses speed and increases its attack angle or/and wing area), glides and lands as a conventional aircraft.

The range strongly depend upon the ratio K = lift/drag. The subsonic civil aircraft has $K \approx 12 - 20$ (gliders have K up 70). For example, Boeing-747 has K = 17 [19]. The supersonic aircraft in the range Max number M = 1.5 - 4 has $K \approx 6 - 8$. For example, Concord has K = 7.14 [19]. The hypersonic aircraft has $K \approx 4 - 4.5$. Approximately $K = 4(1+3/M)$ for $M > 1.5$, where M is Mach number. The special catapult aircraft will has K in +(1 ÷ 3) more because one does not have the motor gondolas. The good trajectory is the trajectory when aircraft climbs the high altitude and glides. The hypersonic CV may reach rarely or out of atmosphere and significantly increase the range. It is very useful if the aircraft has the variable swept and wing area. Many current supersonic aircraft have these properties (B-1, Tu-160)[19].

The subsonic CV starts from a conventional aerodrome equipped by LEE, and is accelerated (with 3g) up to a speed of 270–300 m/s (Mach number 0.9) by the linear electric engine into the runway which is 1500–1800 m long (Fig. 1). The aircraft takes off, flies (50–70 km, Fig. 1a), gradually loses speed and increases its attack angle and extend the flaps. When the speed drops so it is close to landing speed, the aircraft extends the chasses and lands. At first the old aircraft (without engines and engine gondolas) can be used for the offered transport system.

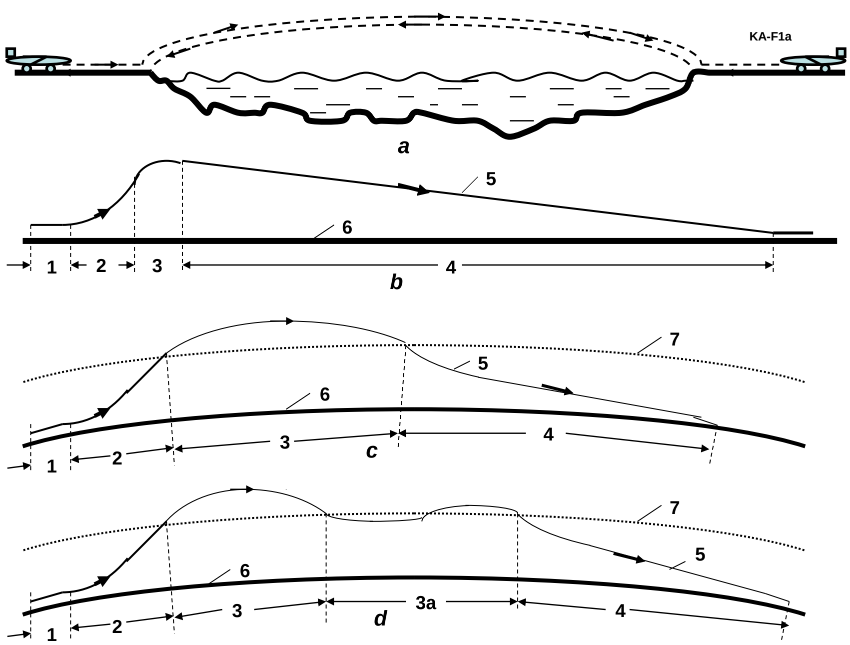

Fig. 1. Trajectories of the catapult vehicles (kinetic/ballistic vehicle, aircraft). (a) Short distance (up 70 km) subsonic vehicle (city – sub-city. Strait, mountain); (b) Middle distance (up 1500 km) supersonic vehicle (between cities); (c) Long distance (intercontinental, outer space) hypersonic vehicle, (space ship, satellites, probes). (d) Hypersonic vehicle with rebound from atmosphere. *Notations:* 1 – start, acceleration station; 2 – Climb to altitude; 3 – flight into atmosphere (subsonic and supersonic

vehicles), or outer space (hypersonic vehicle; 3a – flight with rebound from atmosphere; 4 – gliding in atmosphere; 5 – trajectory, 6 – surface, 7 – boundary of atmosphere (≈ 80 – 100 km).

The range of the high-speed aircraft may reach 200–10,000 km (or more)(see Fig. 3). The aircraft can make a full circle and return to its base. The flight data are drastically improved if the vehicle has variable wing area or variable swept wings [5]. Other similar ideas and useful points for kinetic aviation are presented in References [5 – 8]. The flight altitude does not its influence range because the energy spent in climbing will be returned in gliding.

This new type of transportation the author names as **Cattran** (Catapult transportation).

Theory of catapult transport (Cattran) and a general estimation of flight data

(In metric system)

1. The maximum range, R, of kinetic air vehicles is obtained from the kinetic energy of theoretical mechanics for K = const. It is equals

$$d\left(\frac{mV^2}{2}\right)=\frac{mg}{K}dR, \quad g=g_0-\frac{V^2}{R_0}, \quad R=-\frac{KR_0}{2g_0}\ln\frac{g_0-V_1^2/R_0}{g_0-V_0^2/R_0}, \quad R\approx\frac{K}{2g}\left(V_1^2-V_0^2\right) \qquad (1)$$

where R is range [m]; $R_0 = 6{,}378 \cdot 10^6$ is the Earth's radius [m]; K is the average aerodynamic efficiency (K = 10–22 for subsonic air vehicles and K = 5–8 for supersonic air vehicles. For example: the subsonic Boeing-747 has maximum K = 17; Tu-104 K=18; B-1, Tu-160 K > 19 (in subsonic regime); Boeing 47E K = 20; Boeing; Boeing B-52G K = 21.5; Rutan Voyager K = 27, Lockheed U-2 K = 28; M-17 (high altitude aircraft) K = 30; gliders have K = 40 - 70; the supersonic "Concorde" has maximum K = 75, supersonic aircraft XB-70 and YF-12 have K = 7, and Boeing 2707-300 has K = 7.8); g_o = 9.81 m/s^2 is gravity; V_1 is initial (after acceleration) speed [m/s]; V_0 is final (near landing) speed [m/s] (V_0 = 50–60 m/s); V is variable speed, $V_0 < V < V_1$ [m/s]. For estimation average $V = 0.5(V_1+V_0)$; $mg/K = D$ is air drag [N]; m is vehicle mass [kg]. For V < 2000 m/s, variable gravity $g \approx g_o$. Last equation in (1) is obtained from the first equation using integration.

The ratio K approximately equals:

$$\begin{aligned}&\text{For } M<0.9 \quad K\approx 0.5(\pi A/C_{d,0})^{0.5}, \quad \text{where} \quad A=L^2/S,\\ &\text{For } M>1{,}5 \quad K\approx 4(1+3/M), \quad \text{where} \quad M=V/a,\end{aligned} \qquad (2)$$

Here M is Mach number; L is wing span, [m]; S is wing area, [m^2]; a is sound speed, at H = 0, T = 0^{o}C a = 330 m/s; for T = 20^{o}C a = 342 m/s. For H > 11 km $a \approx$ 295 m/s; $C_{d,0} \approx$ 0.008 - 0.012 is the vehicle drag coefficient for attack angle = 0.

Results of computations for subsonic (V < 300 m/s, M < 0.9, M is Mach number) and supersonic vehicles are presented in Figs. 2 and 3. The range of a subsonic vehicle is 45–90 km for V_1 = 300 m/s (fig.2); the range of a supersonic vehicle can reach 4000–8200 km for V_1 = 4500 m/s (fig.3).

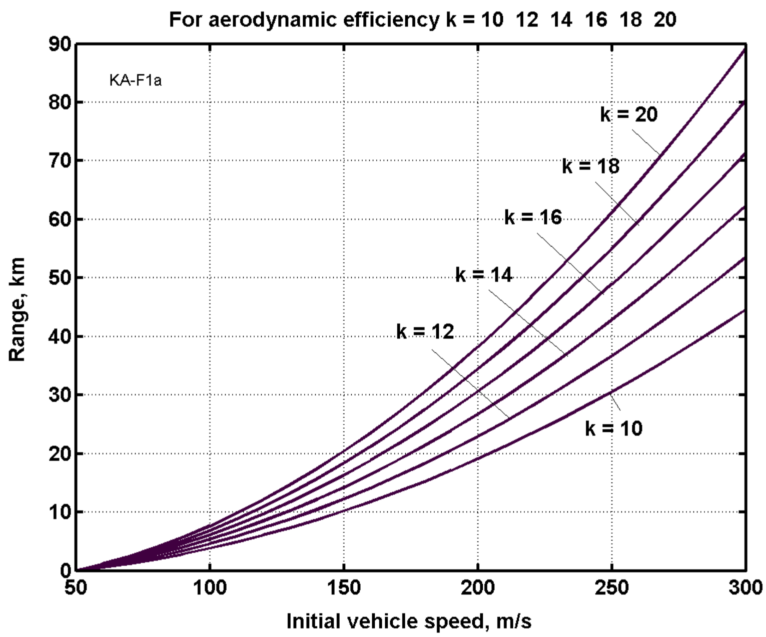

Fig. 2. Range of the subsonic catapult (kinetic) vehicle versus initial speed for different aerodynamic efficiency K = 10 12 14 16 18 20.

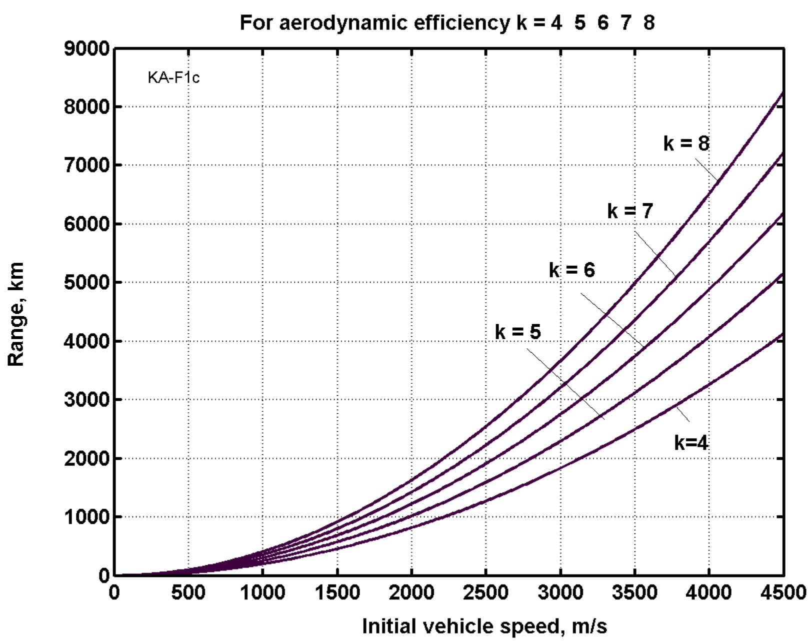

Fig. 3. Range of the supersonic catapult vehicle versus initial speed for different aerodynamic efficiency K = 4 5 6 7 8.

2. Maximum acceleration sub-distance 1 (S_1) (fig.1) and required energy (E) (only for acceleration – that is main part of common energy) can be calculated using the equation

$$S_1 = \frac{V_1^2}{2gn}, \quad E = \frac{mV_1^2}{2}, \tag{3}$$

where n is overload, [g]; m is vehicle mass, [kg].

Results of computations for subsonic and supersonic aircraft are presented in Figs. 4 and 5.

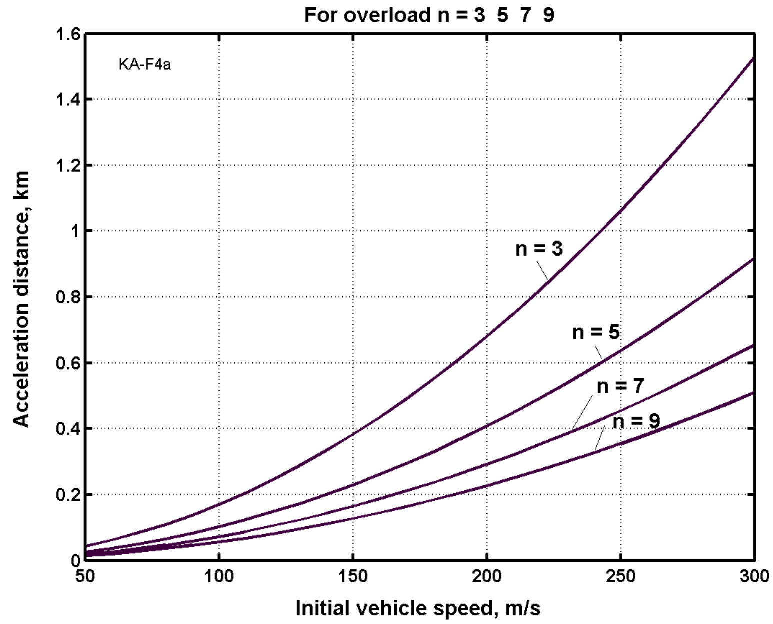

Fig. 4. Acceleration distance of subsonic catapult vehicle versus initial speed and different overloads.

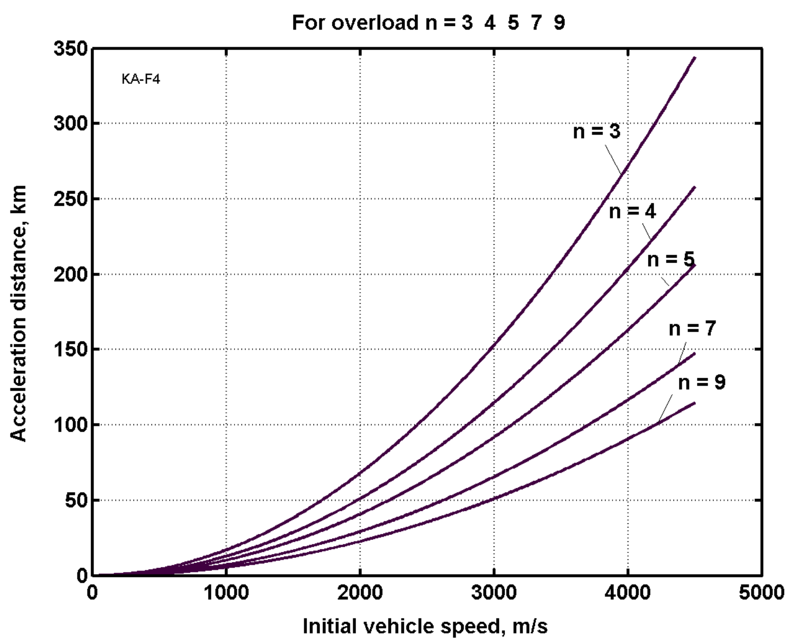

Fig. 5 . Acceleration distance of supersonic catapult aircraft versus initial speed and different overload.

Acceleration (3g) distance is 1500 m for a speed of 300 m/s for the subsonic vehicle and 340 km for a speed of 4.5 km/s for the supersonic vehicle.

3. Average speed and flight time are

$$V_a = \frac{V_1 + V_0}{2}, \quad T = \frac{R}{V_a}. \tag{4}$$

The results of computation of eq.(4) are presented in Figs. 6 and 7. The subsonic vehicle has an average speed 1.5 times greater than conventional aircraft (because the catapult vehicle has high subsonic speed of the beginning), and the average speed of the supersonic (hypersonic) vehicle is more than 6–9 times that of a conventional subsonic vehicle. The flight time is less for both cases.

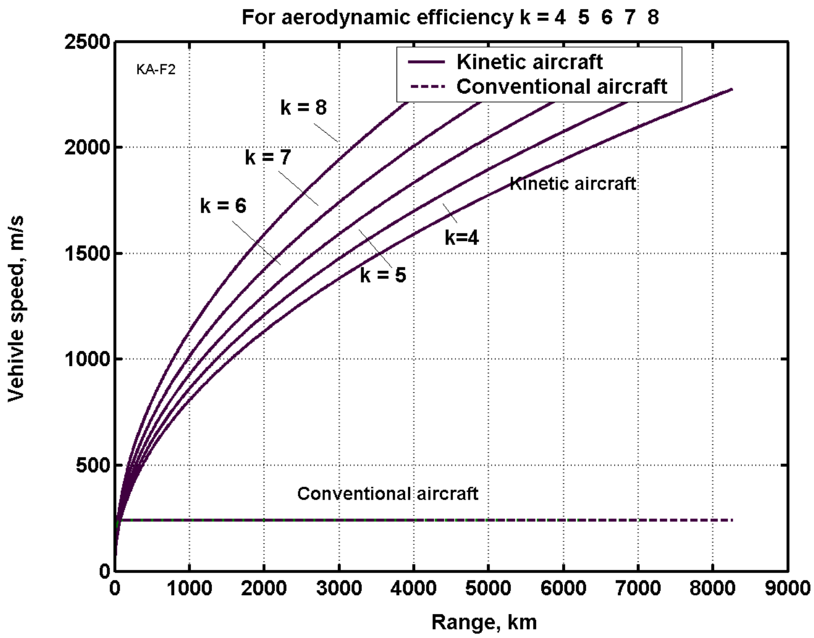

Fig. 6. Average speed of the kinetic/catapult and conventional vehicle versus range for different aerodynamic efficiency $K = 4\ 5\ 6\ 7\ 8$.

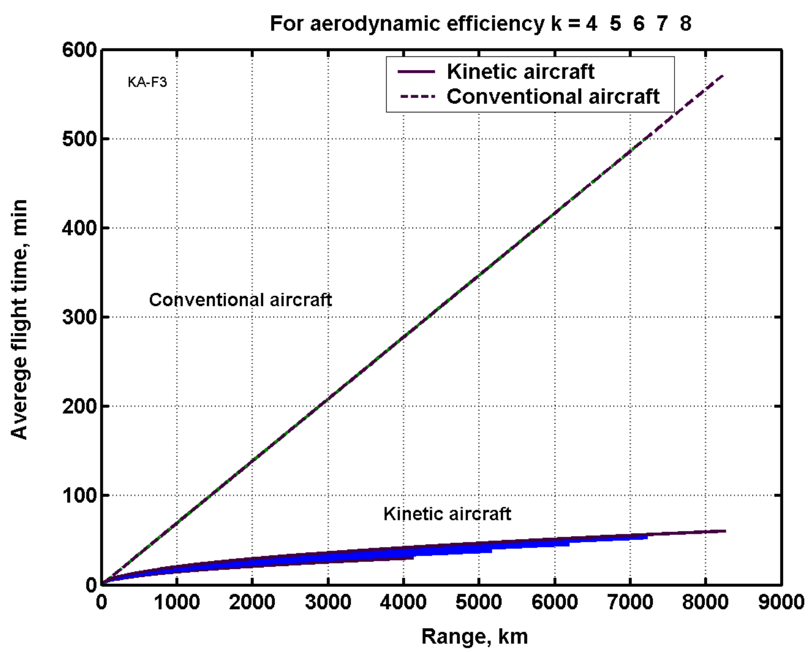

Fig. 7. Avarage flight time of the kinetic/catapult vehicle and conventional aircraft versus range.

4. The trajectory of horizontal turn can be found from the following differential equations

$$\dot{V} = -\frac{gn}{K}, \quad \dot{\varphi} = \frac{L_1}{mV} = \frac{g\sqrt{n^2-1}}{V}, \quad \dot{x} = V\cos\varphi, \quad \dot{y} = V\sin\varphi, \quad or$$
$$V = V_1 - \frac{gn}{K}t > V_0, \quad \varphi = -\frac{K\sqrt{n^2-1}}{n}\ln\left(1-\frac{gn}{K}t\right), \quad \dot{x} = V\cos\varphi, \quad \dot{y} = V\sin\varphi, \qquad (5)$$

where L_1 is the projection of the vehicle lift force to a horizontal plane (vertical overload is n = 3g); t is time [s; φ is turn angle [rad].

Results of computations for different overloads show that the vehicle can turn back and return to its original aerodrome (for example, the transport/passenger vehicle in emergency case or a bomber after a flight into enemy territory) (see [1], [8] p.366, figs. A.2.8-9).

5. Computation of the complex trajectory used the high altitude and outer space.
Accuracy equations of ballistic trajectory are:

$$\dot{r} = \frac{R_0}{R}V\cos\theta,$$
$$\dot{H} = V\sin\theta,$$
$$\dot{V} = -\frac{D}{m} - g\sin\theta, \qquad (6)$$
$$\dot{\theta} = \frac{L}{mV} - \frac{g}{V}\cos\theta + \frac{V\cos\theta}{R} + 2\omega_E\cos\varphi_E.$$

For subsonic speed (M < 0.9)

$$L = 0.5C_L\rho V^2S, \quad D = 0.5C_L\rho V^2S, \quad g = g_o,$$

For supersonic (M > 1.5) and hypersonic speed

$$L = 0.5C_L\rho aVS, \quad D = 0.5C_D\rho aVS, \quad g = g_o(R_o/R)^2,$$

where r is range of ship flight, [m]; R_0 = 6,378,000 is radius of Earth, [m]; R is radius of ship flight from Earth's center, [m]. $R = R_o+H$; V is ship speed, [m/s]; H is ship altitude, m; θ is trajectory angle, radians; D is ship drag, [N]; m is ship mass, [kg]; g is gravity at altitude H, [m/s^2]; L is ship lift force, [N]; $\omega_E = 7.27\cdot10^{-5}$ is angle Earth speed, rad/sec; $\varphi_E = 0$ is lesser angle between perpendicular to flight plate and Earth polar axis; t is flight time, [s].; C_L is lift force coefficient, for subsonic speed C_L = 0 - 3.5 , for supersonic speed $C_L \approx 4\alpha$, where α is the wing attack angle, [rad]; C_D is air drag coefficient. For supersonic wing $C_D \approx \alpha^2$; $a \approx 295$ m/s for H > 11 km is sonic speed in atmosphere; S is wing area, [m^2]; ρ is the air density, for H = 0 ρ_o = 1.225 kg/m^3. For H = 0 - 100 km $\rho \approx \rho_o \exp(-1.4\cdot10^{-4})$.

6. Estimation of range.

The computation of equation (5) requests the complex numerical integration.
For estimation of climb range (sub-distance 2 in fig.1) can be used more simple equation

$$\begin{aligned}
&\dot{r} = V\cos\theta, \\
&\dot{H} = V\sin\theta, \\
&\dot{V} = -\frac{gn}{K} - g\sin\theta, \\
&\dot{\theta} = \frac{gn}{V} - \frac{g}{V}\cos\theta + \frac{V\cos\theta}{R}.
\end{aligned} \tag{7}$$

where $g \approx 10$ m/s^2 is Earth gravitation; $n = 3 \div 9$ is vehicle overload; $K = L/D$ is the ratio lift/drag. For subsonic speed ($M < 0.9$) $K \approx 17$ - 22, for supersonic speed ($M > 1.5$) $K \approx 4(1+3/M)$, where $M = V/a$ is Mach number. The ratio K for subsonic aircraft is significantly more than K for supersonic aircraft. The way for large range at the start is to get a high altitude and glide from it (fig.1b). For the same reason after entering to atmosphere from vacuum it may be useful to reflect from atmosphere and return to vacuum (fig.1d). It is also useful for cooling of vehicle.

Sub-distance 3 (flight out Earth atmosphere, H >≈ 80 -100 km) can be computed by equations:

$$L_3 = 2R_0\beta, \quad \nu = \left(\frac{V_a}{V_0}\right)^2, \quad \tan\beta = \frac{\nu\tan\theta_a}{1-\nu+\tan^2\theta_a}, \quad \tan\theta_{a,opt} = (1-\nu)^{0.5}, \tag{8}$$

where L_3 is sub-distance 3 (fig.1) (flight out Earth atmosphere, H >≈ 80 -100 km), [m]; β is Earth angle, rad; V_a is vehicle speed at the exit from atmosphere, [m/s]; θ_a is trajectory angle at the exit from atmosphere; $\theta_{a,opt}$ is optimal trajectory angle (maximal range of sub-distance 3) at the exit from atmosphere.

7. Estimation of heating.

The magnitudes in equations (5)-(6) for hypersonic speed compute as:

$$\begin{aligned}
&g = g_0\left(\frac{R_0}{R_0+H}\right)^2, \quad \rho = a_1 e^{(H-10000)/b}, \quad a_1 = 0.414, \quad b = 6719, \\
&Q = \frac{0.5\cdot 11040\cdot 10^4}{R_n^{0.5}}\left(\frac{\rho}{\rho_{SL}}\right)^{0.5}\left(\frac{V}{V_{CO}}\right)^{3.15}, \quad R_n = \sqrt{\frac{S_P}{\pi}}, \\
&T_1 = 100\left(\frac{Q}{\varepsilon C_S} + \left(\frac{T_2}{100}\right)^4\right)^{1/4}, \quad T = T_1 - 273, \\
&D = 0.5C_D\rho aVS, \quad L = 2\alpha\rho aVS, \quad D = L/K,
\end{aligned} \tag{9}$$

where $g_0 = 9.81$ m/s^2 is gravity at Earth surface; ρ is air density, [kg/m^3]; Q is heat flow in 1 m^2/s of leading sharp, [J/s·m^2]; S is wing area, m^2; ρ_{SL}= 1.225 kg/m^3 is air density at sea level; V_{CO} = 7950 m/s is circle orbit speed; T_1 is temperature of leading edge (tip) in stagnation point in Kelvin, ^{o}K; T is temperature of leading edge in stagnation point in centigrade, ^{o}C; T_2 is temperature of the standard atmosphere at given altitude, [K]; D is vehicle drag, [N]; L is vehicle lift force, [N]; C_D is drag coefficient; a = 295 m/s is sound speed; C_S = 5.67 W/(m^2·K^4) is coefficient radiation of black body; ε is coefficient of a black ($\varepsilon \approx 0.03$ - 0.99*)*.

For speed less $M = 3$ ($V < 900$ m/s) the heating of the leading edge from a shock wave is small. For example, for Concord and Ty-144 it is about 127^{o}C. The aluminum alloys can resist 175^{o}C. But for hypersonic vehicle that heat may reach 1500^{o}C. But for the offered vehicle that is not a problem. The current material can keep up to 2500^{o}C, the leading edge is under this temperature a shot time (about only 40 seconds), that can require only a small cooling. The problem of heating for re-entry apparatus such as Shuttle and Apollo and the catapult vehicle is opposite. The re-entry apparatus must SPEND its gigantic kinetic energy as soon as possible (to brake). That way Shuttle has a BLUNT (obtuse) fuselage and wing edge, which give a high air drag. That gives a very high heat flow. Our vehicle must SAVE the kinetic energy. One has a sharp fuselage and wing edge, which has a small air drag and small heat flow.

The Shuttle must decrease speed from 8000 m/s to zero (Apollo must lose 11 km/s). Our vehicle loses only 500 -1000 m/s at a lifting (climbing) in atmosphere. That means one get the specific heat (in $1m^2$) of 500 - 4000 times less than Shuttle. The flight time of Shuttle in dense atmosphere is tens of minutes, our vehicle - only 40 [s].

8. Linear electric engine.

There is a lot of linear electric (magnetic) engine (LEE). They widely use for subsonic Maglev [8]. The record speed of MagLev is 581 km/h (2011), the railroad is 575 km/h. Some hypersonic LEE offered and researched by author in [14]-[16].

The new linear electrostatic engine was offered by author in [17].

9. Levitation of vehicle. The current railroad wheels cannot support high speed vehicles because the centrifugal force of wheels is very large. For supporting vehicle was suggested magnetic force (as Maglev) or an air cushion (as hovercraft). Author offers the new method of the ground vehicle levitation by lift from wings. That is very simple. The ratio $K = L/D$ can be up 100 and more. The specific feature of offered apparatus from flarecraft**,** sea skimmer**,** ekranoplan**,** is next: ekranoplan and others has engine located in apparatus and they can fly anywhere. The offered apparatus has engine located **at ground** and moves only over a special track. One has the ability to run only on special flat, smooth way (as Maglev) with *very high K*. Therefore I name them the **Skimplane [8]**.

Advantages

The offered method has the following advantages:

The load capability of catapult vehicle increases as a factor of two in comparison with conventional aircraft (no fuel or engine in the catapult vehicle. Fuel mass reaches 30 – 40%, engine mass is about 10% of total aircraft mass).

The catapult vehicle (cattran) is significantly cheaper than conventional aircraft (no aviation engines, which are very expensive and have limited engine life: 2000-9000 hours. The aircraft body has a lifetime of 20-30 years). In comparison of ground transport, we don’t need in expensive bridges, tunnels, roads.

The linear electric engine located on the ground can work on cheaper electric energy.

The average speed for long-distance travel is increased by 6–9 times (see Fig. 6).

The maximum flight time is about 34 min for a distance at 10,000 km (see Table 3 and Fig. 7).

The flight article production cost is dramatically reduced.

One installation can have a very large capability and can serve many airlines, for example, most airlines from the USA to Europe (New York to London, Paris, Berlin, Madrid, Brussels, Fan Francisco – Tokyo, Shanghais, etc). The load capability is also increased greatly.

The installation can be used to launch outer space passenger and cargo ships, satellites and probes (some accelerator projects currently offered use conventional airplanes as a Stage 0 booster but they have a maximum speed of only 270 m/s).

The installation can be used for space tourism and flights along high altitude ballistic trajectories.
The installation can be used as the conventional very high-speed ground transport between big cities (skimplane).
The installation can be used for mass launch of military projectiles in wartime.

Projects (Cattran, Skimplane)

The offered project contains only the well-known technologies. The risk is small. The full project contains the 4 subprojects. The realization of this project is best to start from the cheapest subproject 1, which allows getting the experience for more complex subprojects.

Subproject 1. Subsonic speed sort distance (50 -70 km) catapult passenger vehicle (for city and sub city, straits, mountains, and etc.).
There are a lot of islands in the world, located close to one another or located close to a continent, which have large transportation flows. For example:
1. Straits of Gibraltar (16 km); connects Europe with Africa.
2. English Channel (40 km); connects England with Europe.
3. Sicily and Italy (5 km).
4. The Dardanelles (from 2 to 5 km).
5. Various Japanese Islands.
6. Taiwan with mainland China (25 km).
7. Bering Straits (100 km) (Russia and America).
8. Sakhalin-Asia (20 km) (Russia).

Assume the mass of the passenger vehicle is m = 15 tons (100 passengers and 4 members of crew); the start acceleration is $a = 3g \approx 60$ m/s^2 (this acceleration is acceptable for conventional people [8]). The range is approximately 67 km (see Fig. 2) or calculate using $R \approx KV^2/2g$ = 67.3 km for a final acceleration speed of 290 m/s and K = 16, g = 9.81 m/s^2.
The required acceleration distance is about $S_1 = V^2/2a$ =1400 m. The time of horizontal acceleration is $t = V/a$ = 9.7 [s] The energy required for acceleration of the aircraft is $E = mV^2/2$. This is about E=0.63·10^9 Giga joules (1 Giga joules = 10^9 J) if V = 290 m/s. A power is about $P = E/t$ = 0.63·10^9/ 9.7≈ 65,000 kW. If the engine efficiency is η = 0.95 [8], the energy consumption will be $F = E/\eta$ = 0.63·10^9/0.95 = 0.66 GJ per flight or 6.6 MJ per one passenger. As it is shown below the 1 MJ of electric energy cost US$ 0.00877. Therefore the energy spent by 1 passenger will be cost 6.6·0.00877 = 0.0578$ or about 6 cents.
Flight time is about 394 [s] or 6.57 minutes. In present time the car or train requires at distance 67 km about 1 hour and in traffic period it is requires a significantly more time.
Summary of the main results:
For the start speed – 300 m/s, landing speed – 50 m/s, maximal range 70 km, average speed 175 m/s = 630 km/h, flight time – 400 [s] = 6.7 min, acceleration distance for overload 3g is 1500 m, acceleration time is 10 [s].

Subproject 2. Supersonic speed catapult passenger vehicle for distance 200 – 1500 km.
Distance between main cities are: New York – Washington 329 km, London-Paris 344 km, Berlin-Warsaw 517 km, Moscow-St.-Petersburg 653 km, Moscow-Kiev 756 km, Berlin-Paris 878 km, Paris-Madrid 1054 km, Tokyo-Vladivostok 1157 km, Tokyo-Seoul 1157 km, Rome-Berlin 1185 km, Rome-Madrid 1365 km.

Assume the mass of the passenger vehicle is m = 15 tons (100 passengers and 4 members of crew); the start acceleration is $a = 3g$. The result of computations in the trajectory #2 (climbing of altitude up speed 270 m/s and gliding with ratio lift/drag K = 20) are presented in Table 1. Used equations are (7).

Table 1. Computations supersonic catapult passenger vehicle for range 200 – 1500 km. Overload is n = 3g.

Initial speed V, m/s	500	600	700	800	900	2000
Range L, km	193	269	360	458	571	1550
Altitude H_{max}, km	5	8,5	12.7	17.3	22.5	30
Flight time T, min	11	15	20	26	32	40
Acceleration Distance S_1, km	4.167	6.009	8.167	10.67	13.5	66.7
Acceleration time T_a, sec. n=3g	16.7	20	23.3	26.7	30	66.7

Subproject 3. Catapult hypersonic speed passenger vehicle for distance 4000 – 10000 km.

The distance between main cities are (aircraft line is not strait line): New York-Paris 5838 km, Washington-London 7373 km, San-Francisco – Tokyo 8277 km, San-Francisco – Vladivostok (Russia) 8377 km, New York – Moscow 7519 km, Moscow – Beijing 5800 km, Moscow – Tokyo 7487 km, New York – Berlin 6392 km.

Assume the mass of the space vehicle is m = 15 tons (100 passengers and 4 members of crew); the acceleration is $a = 3g$ (this acceleration is acceptable for conventional people). Results of computation in Trajectory 3 (climbing of altitude 100 km, ballistic flight in space and gliding with ratio lift/drag K_1 = 4.5 up V = 290 m/s and K = 20 for V < 290 m/s) are presented in Table 2. Equations are (6) - (7).

Table 2. Computations the hypersonic catapult passenger vehicle for range 4000 – 10,000 km. Overload n = 3g.

Initial speed V, m/s	4000	5000	6000
Speed at altitude 100 km, m/s	3076	4148	5215
Range L, km	3909	7035	10700
Flight time T, min	21	28	34
Acceleration Distance S, km. n=3g	267	416	600
Acceleration time T_a, min. n=3g	2.2	2.8	3.3

Flight time (NY – Paris, range 5838 km) is about 25 minutes. In present time the trip NY – Paris takes about 7 hours. The required acceleration distance is S_1 = 340 km. The time of horizontal acceleration is $t = V/a = V/3g$ = 150 seconds = 2.5 minutes (see also Reference [7]).

As you see for acceleration up to hypersonic speed requires a special launch track having a linear electric engine and the special trolley (cart) where the catapult vehicle is located. A small additional way is required for braking this cart at high G. This launch track may be used:

1) For very high speed transportation between cities.
2) As cheap space launcher.

Subproject 4. A high speed (up 1000 km/h) ground transport system between cities (skimplane).

There are a lot of conventional projects for high speed transportation between cities [9]. For our case are suitable city pairs: New York – Washington 329 km, Berlin-Warsaw 517 km, Moscow-St.-Petersburg 653 km, etc.

Economical efficiency

The conventional railroad costs about 0.8 - 1.3 M$/km (in permafrost (Siberia) - 11M$/km), highway system (8 lanes) 30 M$/km (USA), sea bridge 50- 80 M$/km, underground tunnel about 200 M$/km (English-France $12B, 50 km, 240 M$/km), Maglev about 25 M$/km.

Our system does not have a magnetic suspending system and one will be cheaper than Maglev . In present time the significant part of the passenger ticket cost is the cost of fuel. In aviation, car and bus this fuel percentage of cost reaches up 50%. For comparison of different transport systems we compute the cost of energy receiving from dissimilar types of fuel and the cost of delivery of one passenger to one kilometer by different types of transportation.

In Table 3 the reader will find the approximate costs of the different form of energy converted to mechanical energy.

Table 3. Average cost of mechanical energy for different fuels.

No	Fuel	Price, $/kg	Energy, J/kg	Price of $/10^6 J	Conv. coeff.	Cost of mech. energy, $/10^6 J
1	Oil, $100/barrel (159 liter)	0.44	$35\cdot10^6$	0.0126	0.3	0.042
2	Liquid[1] (avia, bus)(USA)	1	$43\cdot10^6$	0.0233	0.3	0.0775
3	Electricity[2] (wholesale)	0.03$/kWh	-	0.00833	0.95	0.00877
4	Natural gas[3], $0.4/m^3(Rus)	0.55	$45\cdot10^6$	0.0122	0.3	0.041
5	Coal	0.04	$22\cdot10^6$	0.0018	0.3	0.006

Issue: Internet, Cost of fuel, December 2011.

Notes: 1. Price of the wholesale aviation (turbojet) fuel and an average retail price of gas/diesel fuel for car/bus in the USA.
2. Average wholesale price in the USA. Retail price is $0.065/kWh.
3. Russia sells natural gas to Europe $400/1000 m^3 (2011).

As you see the cost of a unit of the electric energy in 9 times is less than aviation liquid fuel. The aviation, cars, buses, most military vehicles can work only by liquid fuel, but the electric power plant can be hydro, wind, nuclear power installations. This is an advantage for countries wishing to cut oil imports.

Method estimation of the cost of fuel for moving one passenger (100 kg) per the distance 1 km by the conventional transport (aviation, bus, railroad, sea ship) and cattran, skimplane.

1. Energy required for moving one passenger (100kg) per the distance 1 km by *conventional* transport and skimplane

$$E_v = \frac{mg}{K} D, \quad E_p = \frac{E_v}{b}, \quad C = cE_p \, , \qquad (10)$$

where E_v is energy requested for moving 100 kg of the loaded vehicle per 1 km = 1000 m [J/km]; m is mass of vehicle, 100 kg; g = 9.81m/s^2; D = 1 km = 1000 m is distance; $K = L/D_r$ is ratio of lift force to drag of the vehicle; E_p is energy required for moving one passenger per 1 km, J/man·km; b =

m_p/m is ratio of total mass passengers to total mass of vehicle (load coefficient); C is cost of fuel for moving one passenger to distance 1 km; c is cost of energy.

2. Energy required for moving one passenger (100kg) per the distance 1 km by *catapult* transport (cattran)

$$E_v = \frac{mV_m^2}{2D_f}, \quad E_p = \frac{E_v}{b}, \quad C = cE_p \ , \qquad (11)$$

where V_m is the maximal speed of catapulting, m/s; D_f is distance of full flight, km.

For the sea ship the equations in (10) are

$$E_v = \frac{mN}{WV}D, \quad E_p = \frac{E_v}{d}, \quad C = cE_p \ . \qquad (12)$$

Here N is power of engine, W; V is ship speed, m/s; W is displacement of the sea ship, kg. The results of computation are presented in Table 4.

Table 4. Average cost of fuel for moving one passenger (100 kg) per distance 1 km by conventional, *catapult* transport (cuttran) and skimplane

#	Type of transport	Speed, m/s or km/h	Rang, km	Ratio, $K=L/D$	b,Load coeff.	E_v, J/kg·km	E_p, J/man·km	c, \$/10^6J	C, \$/man·km
1	Aviation	270/972	7000	15	0.3	$6.7 \cdot 10^4$	$2.22 \cdot 10^5$	0.0775	0.0172
2	Cattran, subsonic	170/612	60	15	0.5	$6.1 \cdot 10^4$	$1.22 \cdot 10^5$	0.00877	0.00123
3	Cattran, supersonic	1500/5400	1500	7	0.5	$7.5 \cdot 10^4$	$1.5 \cdot 10^5$	0.00877	0.00132
4	Cattran, hypersonic	5000/18000	7000	5	0.5	$1.78 \cdot 10^5$	$3.56 \cdot 10^5$	0.00877	0.00312
5	Skimplane	270/972	-	20	0.5	$5 \cdot 10^4$	$1 \cdot 10^5$	0.00877	0.000877
6	Bus[1]	28/100	-	15	0.176	$6.7 \cdot 10^4$	$3.81 \cdot 10^5$	0.0775	0.0295
7	Railroad[2](electr)	28/100	-	20	0.19	$5 \cdot 10^4$	$2.63 \cdot 10^5$	0.00877	0.00264
8	Sea ship[3] (diesel)	8.57/31	-	201	0.0074	$0.5 \cdot 10^4$	$6.8 \cdot 10^5$	0.042	0.0292

Notes: 1. Bus has 60 passengers; total mass of bus is 28 tons.
2. Wagon has 54 sleeping places; total mass of the empty wagon is 23 tons.
3. Sea ship has displacement 14660 tons, engine 6252 kW, passengers 1078.

As you see the fuel cost of delivery of one passenger to one kilometer by cattran is 5.5 times less than long distance aviation and in 14 times less than by middle range aviation. The fuel cost of the delivery passengers from a sub-city to city by the subsonic cattran is 24 times less than a bus.

At present time the fuel cost is 20 – 50% of a ticket cost in aviation, bus and ship. The real consumption of fuel for Boeing-747 (M = 0.9) is 0.031 liter/passenger.km, for supersonic (M = 2) Concord the fuel consumption is 0.166 liter/passenger.km [19]. That way the Concord is not profitable.

Fuel prices change with time, but in any case the cost of delivery will be some times less than delivery by conventional aircraft. Critics must remember that main content of this article is not economic estimations, but the new idea for transportation, aviation and space launch.

Discussion of Problems

1. **Vehicle heating**. The proposed hypersonic vehicle will experience heating from compressed air. The space ship Space Shuttle and warheads of ballistic rockets have the same problem and

in more difficult form because they have greater maximum speed (about 8-11 km/s). The heat flow increases by more than a third power of speed as $V^{3.15}$. This problem is successfully solved by a demountable terminal cover on Space Shuttle and on warheads. The same solution may apply in the proposed catapult vehicle (CV). The other solution is cooling, but that needs additional research. The nose and the leading edges of the wing of Mach 2 aircraft have temperature 127°C and do not need cooling because the current aluminum alloys keep the temperature up 175°C. If speed is 3, the leading edges of aircraft flying a long time has been used stainless steel (XB-70 Valkyne) or titanium (SR-71) [19]. The cattran flights are for a short time in atmosphere with a high speed. Middle range cattran decreases speed to subsonic at high altitude. The long range hypersonic cattran quickly reaches outer space.

If speed is less the 5-7 Mach, the catapult vehicles (the leading edges) can be made from heat-resistant material. If the speed is more than Mach 7, the hypersonic CV may need to have a cooling system. However, this problem is not as difficult for catapult vehicles as it is for the Space Shuttle. The problems of the Space Shuttle and the CV are different. The Space Shuttle has much greater speed (about 8000 m/s) and kinetic energy, and needs to reduce this speed and energy by air drag. For this the Space Shuttle has an obtuse (blunt) nose and leading edges of the wings. The CV must conserve its speed and energy for the long flight. The CV has a sharp nose and leading edges of the wings. The Shuttle must lose 8 km/s of speed, the CV loses in atmosphere only about 1 km/s. That means CV gets heated about (8^3) 300-500 times less than the Space Shuttle. This problem can be solved by a light knockout ceramic cover (as on the Space Shuttle) or a cooling system. If it uses water for cooling, the vapor can be used for additional thrust. Lithium as a cooler has 5 times the capability of water, 0.9 kg of lithium is enough to cooling a 5-ton projectile launched from the ground at a speed of 8 km/s. However, this method needs more research and computation.

2. **High aerodynamic efficiency**. The CV can be more efficient than a conventional hypersonic aircraft with an engine because it does not have the air intake needed for air breathing engines. The permanent high aerodynamic efficiency can be preserved by having variable wing area and variable swept wing (swing wing). The effective trajectory is as follows: after acceleration the hypersonic vehicle has a high vertical acceleration (3g), reaches its optimal (high) altitude (or outer space), and flies along the optimal trajectory [8]. After this the CV glides to the air port. On arrival the CV brakes and lands.
3. **Maneuverability in a landing**. This problem can be solved by conventional methods – air brakes and a small engine.
4. **High speed catapult system may be used for launch of rockets and satellites.**
5. **Skimplane** system is cheaper than MagLev because one does not need in an expensive magnetic suspending system (one supports by wings) and has a higher speed. Skimplane system may be used as the cattran and space launcher.
6. **Disadvantages**. The cattran has two possible disadvantages: the passenger has for a short time G overload (3g, 4 – 45 seconds) and some minutes of weightlessness (zero gravity)(for long distance hypersonic, intercontinental flights). But the same effects are encountered during amusement rides. The ill and very old passengers cannot use the cattran. The big airport can have a simple centrifugal test installation, which allows testing the ill and very old people before flight.

   The second possible problem is shock wave (sonic boom) from supersonic vehicle at acceleration time. Reflecting walls (tube is better) must protect the part of acceleration track if there are close inhabited localities.

7. **Advantages**. 1) The big advantages of offered method are very high speed. You can live in one continent (country) and work at another continent (country). Any trip will continue less than one hour – the average current time of journey to work.
   2) One installation can be used as high speed ground transport, catapult aviation, space launcher and the launcher of mass military projectiles in war time.

Some other ideas of the author the reader find in the References [5–17]. Cost of projects may be calculated using [18]. The closed works to this topic are [19 -29].

Conclusion

Author offers and researches the new transportation which increases speed in 2 - 9 times, decreases the fuel consumption in some time (decreases trip cost) and allows the cheap launch to outer space.

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