Ultimate City Vehicle UCV

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Abstract
The limits imposed by oil reserves, global warming, road space and air pollution are a great challenge for mass transportation in densely populated cities. A compact two seat electric vehicle, only 1.7 m long and 1.2 m wide, with an empty weight of only 45 kg without batteries is possible through a revolutionary structure. The innovation consists of a light but strong sandwich plate with a foam core, to which the 4 wheels and two seats are attached. The cabin has the function and shape of a large safety helmet and is made of EPP foam with exterior reinforcing. Instead of doors the entire cabin is lifted up from the platform and swings back. The brushless DC motor with permanent magnets has a mechanical power of 1250 W. On a flat road only 360 W electrical are needed at a top speed of 24 km/h. Steering is with a mechanical "joystick", equipped with a lever for braking and a sliding sleeve for power control. Safety, also for pedestrians and cyclists, is assured by the foam cabin and fast braking with the hand.

Keywords
sandwich platform, helmet cabin, joystick steering

1. INTRODUCTION
The automobile concept introduced by Henry Ford hundred years ago was ideal for American suburbs, together with a supply of cheap oil, which was the case until domestic oil production in the United States attained its peak around 1970. Today the rapid increase of oil price is a sign that the "global peak of oil" is imminent. At the same time global warming requires that the use of fossil energy be substancially reduced.

In densily populated cities the limitation of road and parking space makes it impossible to use automobiles efficiently for individual mass transportation. The resulting slow stop-and-go traffic causes an enormous waste of energy and air pollution. Here automobiles are more a problem than a solution. For longer distances public transport by an underground rail system is most efficient, followed by buses and taxis. For individual transport from point to point over shorter distances the bicycle is the best solution, also with assistance by an electric motor. Cyclists however would prefer to be inside a closed cabin.

Here a revolutionary vehicle concept is presented, constructed with lightweight methods as used for airplanes, but at low cost, with a performance similar to electric bicycles [Janach, 2006, 2008]. It has 4 wheels and a closed cabin with two seats (Figure 1 and Figure 2). Because batteries are expensive and heavy, electric vehicles must be as light as possible. Typically the cost of the battery is much higher than the cost of all the elec-

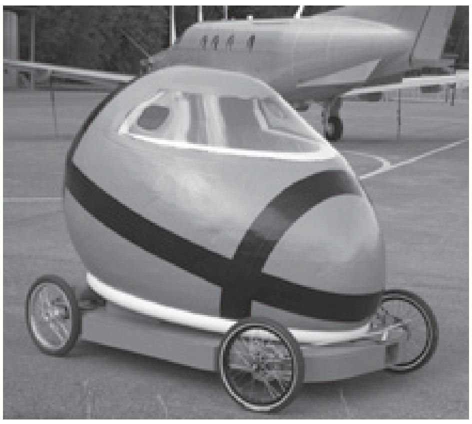

Fig. 1 UCV prototype with sandwich platform and helmet cabin

Fig. 2 Rolling platform with two seats under the open cabin

tricity it will store during its whole life. Therefore the higher cost of a lightweight structure can be compensated by the lower cost of the smaller battery. The size of the battery increases with the vehicle speed and the distance between recharging. Because a slower vehicle will be used over shorter distances, its battery can be much smaller than for a faster vehicle that covers a larger distance in the same time.

2. CHARACTERISTICS OF ULTIMATE CITY VEHICLE (UCV)

Because the energy needed per kilometer depends on the weight and the speed of the vehicle, while the total energy of the battery depends also on the maximum driving distance, it is important that the vehicle performance is carefully adjusted to the transportation requirements in cities. This means that unnecessary reserves of speed and driving distance must be avoided in order to limit the weight and cost of the battery. At the same time the vehicle must be as light as possible, which is obtained by small size and lightweight construction.

A maximum speed of 30 km/h is more than sufficient because the UCV must be compatible with electric bicycles. At an average speed of about 20 km/h, which is realistic under such conditions, a maximum distance of 40 km before rechargin (2 hours driving time) is more than sufficient. For comparison, with a maximum speed of 60 km/h the energy consumption per kilometer is about a factor of 2.5 higher (air resistance increases with the square of speed) and about 80 km of driving range are needed. This requires a battery which is 5 times larger, heavier and more expensive.

The vehicle must also be as short and narrow as possible because of the limited road and parking space in cities. A design with 4 wheels in the corners needs less road space than with 3 wheels because it is narrower and shorter. Two seats are sufficient for a city vehicle used mainly for daily commuting. Side by side seating with the passenger about 0.25 m further back than the driver allows more elbow space and results in minimum width times length (ground surface area). The prototype shown in Figure 1 and Figure 2 is 1.7 m long and 1.2 m wide, which is no more space than needed by two bicycles rolling side by side. Because of the small vehicle length the seats must be higher than in an automobile so that the legs are not stretched forward; and a higher seating position offers a better view. The small size is also important to reduce the weight and cost of the vehicle.

3. SANDWICH PLATFORM AND HELMET CABIN

The main innovation of the UCV is to divide its structure into a stable rolling platform and a lightweight foam cabin above it, which is lifted up for access and has no doors (Figure 2 and Figure 3). This cabin with the function of a large safety helmet is strong but not rigid and is locked to the platform when closed, so that in a crash it can deform without separating from the platform. In a collision with a similar vehicle or with a pedestrian there is no risk of injury from heavy structural parts above the platform.

Fig. 3 Sandwich platform with EPS foam core and foam cabin

The rolling platform consists of a lightweight sandwich plate, to which the wheels, the electric drive, the steering mechanism and the seats are attached (Figure 2, Figure 3, Figure 4, and Figure 5). The sandwich plate of the prototype is made of a 100 mm thick core of expanded polystyrene foam (EPS) with a 0.5 mm aluminium sheet adhesively bonded to its bottom and a 4 mm plywood sheet bonded to its top. The EPS core is sufficiently strong because the bending loads on the sandwich plate are carried by the facing sheets on the top and the bottom. In the future these will be of fiber reinforced plastic. The thick platform has a large cavity for the feet with a thin bottom plate (Figure 3) and weighs 8.5 kg without attached parts.

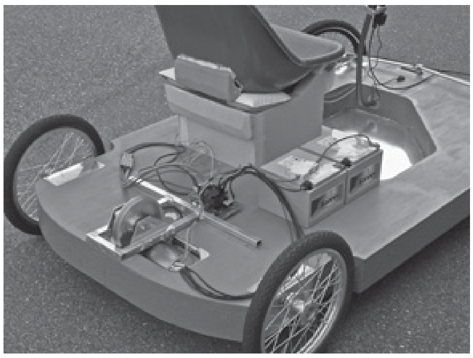

Fig. 4 Electric power train and batteries

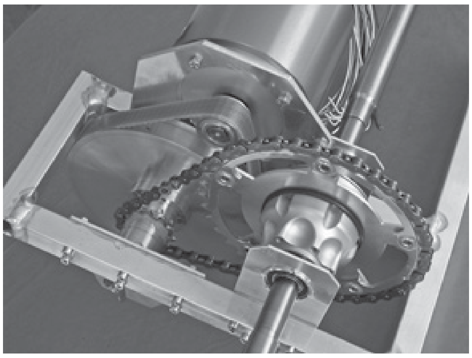

Fig. 5 Electric motor, reduction gear and differential

The wheel attachments are designed such that the concentrated point loads are distributed over a large surface of the sandwich plate with similar design methods as used for attaching the undercarriage of an airplane to the wing. Figure 6 shows the front wheel assembly with the welded aluminium support for the steering element which holds the axle. The support is screwed to a reinforcement consisting of a 0.5 mm U-shaped aluminium sheet, glued to the sandwich plate, with thicker profiles inside for the screws. The attachments for the two half-axles of the rear wheels are similar, whereby the 4 ball bearings are held in rings, which are fixed in 2 mm plates, both of aluminium. The plates with the two exterior bearings are glued directly to the sandwich core, with 0.5 mm reinforcings around the edges of the platform (Figure 4). The two plates with the interior bearings are attached to the aluminium frame carrying the electric drive (Figure 5). The two half-axles are coupled to a compact differential gear, normally used for human powered vehicles (Figure 5).

The wheels are not provided with a suspension using

Fig. 6 Front wheel with disc brake and steering mechanics

springs and dampers because of the following reasons: (1) the dynamic loads on the platform are small because the sandwich plate is very light; (2) the light vehicle would lean to one side with only one person on board; (3) similar to bicycles, it is logical and simpler to provide the spring function directly under each seat, here in form of air cushions (Figure 4), which can also be used to change the seat level. By replacing the EPS foam core with expanded polypropylene (EPP) in the future, its elasticity can be used to make the entire platform elastic and provide it with an integrated wheel suspension.

The cabin of the prototype (Figure 3) has a 60 to 70 mm thick wall of EPS foam, in the future also of EPP, which is more elastic and a better energy absorber. On the exterior it is coated with strong adhesive tape so that in a collision the wall can deform but will not break open. In the future this flexible exterior layer with strong tensile strength will be integrated in the fabrication of the EPP shell. The windshield of 0.8 mm PET is adhesively bonded to the cabin wall. The prototype cabin has a total weight of also 8.5 kg.

For opening, the cabin has a rolling hinge made of two PET bottles with 1 bar air overpressure inside. Figure 2 and Figure 3 show a rim around the opening at the bottom of the cabin, which is made of soft foam and serves as a seal between the cabin and the platform. In the future this seal will be in form of a thin-walled hose, inflated with air as for airplane doors. The rolling hinge for opening the cabin will be integrated into this pneumatic rim.

In addition to the 17 kg for the platform and cabin, the wheels with attachments and axles weigh 9 kg, the two seats 4 kg, and the electric motor with reduction gear 6 kg, resulting in a total weight of 36 kg. With 18 kg of batteries the prototype weighs 54 kg.

The future version for the road will need lights, mudguards for the wheels and other items, so that its weight is estimated to increase to 45 kg with an additional 15 to 25 kg for the batteries. This will bring the total vehicle weight to between 60 and 70 kg, depending on the type of battery, its capacity and its cost. This empty weight is not higher than for two electric bicycles and is much lower than the 150 kg of the two persons the vehicle can transport.

4. ELECTRIC DRIVE SYSTEM

Battery powered electric drives for lightweight vehicles have reached a high level of maturity and state of the art components are available on the market. In China 17 million electric bicycles and scooters were produced in 2007. The prototype UCV uses a Swiss made brushless DC motor with permanent magnets. It runs on 24 V and has electronic commutation with hall sensors. At 4000 rpm it attains a torque of 3.0 Nm, resulting in a mechanical power of 1250 W and an electrical power 1500 W (efficiency of 83%). The speed is first reduced by a factor of 4.38 with a tooth belt and then with a bicycle chain by a factor of 3.45 (Figure 5). With the 16 inch wheels (400 mm diameter) this results in a speed of 20 km/h and a maximum traction force of about 220 N (neglecting the mechanical losses between the motor and the wheels). At 5000 rpm, the torque drops to 0.5 Nm and the motor has almost reached its idling speed of 5100 rpm. The electricity is provided by two 12 V sealed lead acid batteries (Figure 4) with a nominal capacity of 26 Ah and a total weight of 18 kg.

The electronic control unit serves to reduce the battery voltage by chopping the DC current from the battery and smoothing it again at lower voltage. The result is a reduction of the current and of the torque as requested by the driver. At lower speeds than 4000 rpm, the electric motor could provide a higher torque when the full voltage of 24 V is applied. However the maximum current to the motor is limited by the control unit to about 70 A, which limits the maximum torque to 3.2 Nm. This is sufficient because the current needed for constant speed is not higher than 10 to 15 A, which allows sufficient extra torque for acceleration and climbing.

The electronic control unit does not provide recuperative braking, except when rolling downhill with over 25.5 km/h, so that the motor attains a higher rpm than its idling speed.

5. TEST RESULTS

With only one person (70 kg) in the prototype vehicle (54 kg) the electric current was measured between the battery and the electronic control unit when driving on a flat road. The speed is measured with an electromagnetic sensor as used for bicycles with a display at the top of the brake lever (Figure 7). At constant speeds of 15 km/h and 20 km/h currents of 6 A and 9 A were measured, corresponding to 145 W and 215 W of electric power at 24 V. Maximum speed was 24 km/h with 15 A and 360 W electrical and 300 W mechanical power, corresponding to a traction force of 45 N. This allows to estimate how much of the power is used for rolling drag and for aerodynamic drag. For the wheel rolling friction a coefficient of 1.5% was obtained from a low speed test on a sloping road. This results in a friction drag force of 18,2 N (total weight 124 kg) and an aerodynamic drag force of 26.8 N. With two persons on board (total weight of about 200 kg) the friction drag increases to 29.5 N. Experience with similar vehicles confirms that the two kinds of drag become equal at a speed of around 25 km/h. This means that for higher speeds it is

Fig. 7 Mechanical "joystick" with brake lever carrying display and sleeve for power control

necessary to improve the aerodynamic design in order to reduce the energy consumption, especially for very light vehicles with low rolling resistance.

A test was also made on a steep road with a constant slope of 10%, again with only one person (124 kg total). At full voltage to the motor (24 V) the speed was 20 km/h with a current of 48 A, resulting in 1150 W electrical and 950 W mechanical power, of which about 700 W were needed to push the weight upslope against gravity. With two persons on board (200 kg total) the current would rise to over 60 A, at the limit of the electronic control unit. A reduction gear with two different ratios would solve this problem.

The maximum driving distance with a single battery charge was tested with only one person on board at a speed of between 20 and 24 km/h on a closed course, so that braking before slower turns could be avoided. After 30 km the motor power began to decrease and the battery was unloaded after 32 km. The battery has a nominal capacity of 26 Ah, corresponding to 620 Wh at 24 V. During the charging of the battery after the test, the current was integrated over time, resulting in a total energy input of exactly 500 Wh (at 24 V). Assuming that the battery has 80% efficiency between loading and unloading, the electric motor had used 400 Wh for the distance of 32 km. Alternatively one can assume that the vehicle would cover the 32 km with a constant speed of 22 km/h and 270 W electric power, which results in 390 Wh of total energy consumed.

The electric energy of 500 Wh used for the 32 km, corresponding to 1.56 kWh per 100km, can be compared to the fossil energy used by automobiles. Gasoline has about 32 MJ or 8.8 kWh of calorific value per liter. Assuming that the electricity is generated in a modern

gas fired power plant, the efficiency from fossil to electrical energy, including losses in the grid, is about 50 %. The electric energy consumption of 1.56 kWh per 100 km is therefore equivalent to a consumption of 0.35 liters of gasoline per 100 km, which is much lower than the 5 to 7 liters per 100 km of automobiles.
Here however it must be considered that the fabrication of batteries needs a lot of energy. For lead acid batteries this “grey” energy is about the same as the total electric energy stored in the battery during its entire life. When this is taken into account, the above value increases to 0.7 liters per 100 km. This again explains why it is important that battery electric vehicles are lightweight and not overpowered.

6. SUMMARY AND CONCLUSIONS

A revolutionary structure makes it possible to design a compact and light electric vehicle consisting of a sandwich platform with 4 wheels and two seats. The cabin made of foam has the function of a large safety helmet. It has no doors and is lifted up for access to the seats. The vehicle is 1.7 m long and 1.2 m wide, which is no more road space than two bicycles rolling side by side. The two seats are positioned side by side, with the passenger 0.25 m further back to give more elbow space. Steering is with a mechanical “joystick” equipped with a lever for braking and a sliding sleeve for power control. In the future the joystick will be positioned in the centre of the vehicle so that a driver with long legs can sit on the right seat and steer with his left hand as the captain in modern airliners (joystick on the left wall). Another advantage of a central joystick is that in a crash it is positioned between the two seats and not in front of one of them.
The weight of 54 kg for the prototype including batteries and 65 kg for the future road version is not higher than the weight of two electric bicycles. And the soft foam cabin offers better safety than a bicycle, also for pedestrians. The minimum weight is important for reducing the energy consumption, the manufacturing cost and the size of the expensive battery. In densely populated Asian cities the small size will help to reduce traffic jams. Because in mass production the manufacturing cost depends mainly on the amount of materials used, it is estimated that a vehicle with a total weight of only 1/20 of an automobile will cost about 500 dollars.
The prototype has a maximum speed of 24 km/h so that the vehicle remains compatible with bicycles and is no risk for pedestrians. This is sufficient for city traffic and helps to make the dense traffic smoother and safer. It also allows to use a smaller and less expensive battery because 40 km of driving distance before recharging is sufficient at this speed. The maximum speed could be increased to 30 km/h with a smaller ratio of the reduction gear, which would reduce the motor rpm and increase its torque accordingly. Because this reduces the maximum traction force, it is necessary to provide two gears with different ratios, the first for accelerating or climbing and the second for faster driving on flat roads.
The very low energy consumption of 1.56 kWh/100km results from minimum weight and limited maximum speed. When the convertion efficiency from fossil to electric energy in a modern power plant and the large manufacturing energy for the battery are included, this is equivalent to 0.7 liters of gasoline per 100 km.

References

Janach, W., and X. J. Tan, Ultra-Light Vehicle Concept, *Proceedings Electric Vehicle Symposium EVS-22*, 510-518, 2006.
Janach, W., Ultralight Electric Vehicle for Urban Mass Transportation, submitted to VPPC 2008, *IEEE Vehicle Power and Propulsion Conference*, 2008.

(Received March 3, 2008; accepted May 6, 2008)