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SUPERCAR DESIGN CONSTRUCTION

Professor A Frank
University of California at Davis
USA

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Abstract

A "Super Car" is an automobile which has performance equal to or better than conventional cars, and has fuel efficiency three times better at 2.3 to 2.9 $\ell/_{100km}$ (80-100 mpg) for a mid size vehicle and 1.6 to 2.0 $\ell/_{100km}$ (120 - 150 MPG) for a compact vehicl at 100 km/hr. on gasoline. In addition, it should have ZEV capability in the city as well as be able to meet or exceed all safety requirements. Design concepts which can achieve these goals are presented and discussed. An example vehicle with measured performance figures are presented.

Introduction and Motivation

The objective of the super car concept is to demonstrate that a vehicle with high performance, super fuel efficiency and cost competitive can be constructed. In addition, it should have ZEV (zero emission vehicle) capability or at least ULEV (ultra low emissions) capability. To accomplish these objectives some fundamental concepts need to be explored to find constraint boundaries which cannot be violated. One of the boundaries is engine efficiency. It is possible for an engine to operate over a narrow torque-speed range around 1/2 peak power at 274 gms/kwhr of gasoline (0.45 lb/hp-hr). If an engine is tuned to operate at this point at highway cruise (100-110 km/hr), then super fuel efficiency can be achieved if attention is also paid to reducing friction drag and driveline efficiency. To keep driveline efficiency up, a manual transmission or a no torque converter automatic transmission with an electric servo hydraulic system could be 90% efficient at 100 km/hr. This should be easy to accomplish with a manual transmission, but a little more difficult with an automatic. The fuel efficiency at the tires at this engine operation then becomes 304 $^{gm}/_{kwhr}$ at 100 km/hr (62 MPH) (0.5 #/hp hr).

To achieve 2.3 $\ell/_{100km}$ (100 miles/gallon) the power to drive the car cannot exceed 5.5 kw (7.44 HP) which means the drag force must be less than 207 N (46.5 lb) at 100 km/hr (60 mph). If the requirement is reduced to 4.6 $\ell/_{100km}$, then the drag can be 414 N (93 lb).

To compare the requirements between aerodrag, vehicle tire drag and fuel economy for a vehicle mass of 1130 kg and 1.6 M^2 frontal area, Figure 1 can be used. From the figure, it can be seen that to achieve the fuel consumption figure above at cruise speed, the aerodrag and the tire drag are about 1/2 of today's conventional cars. The weight is also about 200 to 300 kg less than most midsize luxury cars of today. The rest of the paper will describe such an automobile.

Fuel economy is dictated by speed because aerodynamic power increases as the cube of speed and rolling power increases proportional to speed. At 100 km/hr the aerodrag on the super car is about 2/3 of the total drag. At 200 km/hr the aerodrag becomes completely dominant. Where the fuel consumption climbs drastically even if the engine could be kept operating at this peak efficiency to over 9.2 l/100km (25 mpg). Thus to design a super car achieving 2.3 l/100km the speed must be specified. The speed of 100 to 110 km/hr (60-65 mph) is a reasonable design speed. The trade off between tire and aerodrag and fuel economy is shown in Figure 1 for a 1130 kg (2500 lb), 1.6 m^2 streamline automobile..

Reasonable gradeability should also be specified. Most highway systems throughout the world are limited to approx. 6% grade. Thus a vehicle with the capability of sustaining this speed at this grade is also necessary. A driving cycle for hybrid electric vehicles is being evolved in the vehicle design community. This cycle may represent driving from San Francisco to Los Angeles on Interstate Highway 5 in the USA, a distance of 400 miles (660 km) at the speed limit of 65 MPH (105 km/hr). This drive leaves San Francisco at sea level, goes to about 500 meters in about 100 km, then drops to sea level for 400 km and climbs to 1200 meters in 50 km then back to sea level in the last 150 km. Climbing power is of course proportional to weight and at 6% grade with 0.2 c_d and 0.006 c_r the power increase from 7.4 hp to over 25 hp. Thus, either the engine power must be increased, or power must be supplemented from some auxiliary source. One of the most important features of the Super Car is to design the system so that fuel efficiency doesn't suffer when climbing grades. This can only be done by having some auxiliary energy storage system.

We have now described the general characteristics of a supercar except for performance. Performance should be about 0 to 100 km/hr in less than 10 seconds. To accomplish this requires about 75 kw (100 hp) at the wheels of the car. Conventional cars create this acceleration by having an engine with this capability. But at an output of 5.5 kw (7.44 hp), its efficiency is very poor, consuming twice as much fuel per kilowatt -hour of energy produced. Thus the Super Car must also over come this fact of conventional cars.

Next the supercar is to have zero or no emissions when driving in town. To satisfy this requirement , the term "Town" must be defined. European towns are relatively small in some areas and large in most areas. In the US, the problems are in California where Los Angeles County is about 160km (100 miles) across. Thus, the California supercar should have a ZEV range of about 160 km. In particularly, it should be able to provide 5.5 kw for 1.6 hrs to maintain 100 km/hr. This is a minimum of 8 kw hrs.

Finally, the supercar must have all the amenities of a conventional car, i.e. heating ventilating and air conditioning system (HVAC) as well as other amenities such as power steering, brakes (ABS) etc. To satisfy all these features which are now powered by a large engine, new concepts of auxiliary power need to be explored. Prototypes of these system exist which consume less than 10% of the energy of conventional systems.

Table I
<u>Super Car Specifications</u>

Weight 1130 kg (2,500 lb)	- ZEV range / 160 km @ 100 km/hr.
Frontal area 1.6 m^2 (18 ft)	- all amenities such asHVAC
4 passenger	- power steering brakes etc.
Performance 0-100 km/hr (under 10 sec)	
Gradeability at 6% - 100 km/hr	
Fuel consumption 2.3 l/100km or 100 mpg at 100 km/hr	

<u>The Super Car Components</u>

The first thing is to explore ways of storing 8+ kwhrs of useful energy. If batteries are used this means about 10 kwhrs of battery energy accounting for electrical and mechanical losses. Adding auxiliary power increases this to about 12 kwhrs. A 15 kilowatt hour battery pack may be appropriate. With current battery technology nickle cadmium of nickle metal hydride batteries with 2000 deep discharge cycles is necessary. This translates to 320,000 km or 200,000 miles life for the batteries. In addition, these batteries can be deep discharged with no harm. Thus, these batteries are clearly the choice. Their energy density however is a problem. Current technology can provide about 40 to 50 watt hrs/ kg. This means about a 400 kg battery pack. Since the whole car is to weigh 1130 kg (2500 lb) with one passenger, then the rest of the car can only be 730 kg. This includes the power train with 65 - 75 kw - (80 - 100 Hp) capability.

Next the chassis and body must be much lighter than current steel bodies. The work of Audi and the aluminum companies show that body weight can be reduced by 50% by use of aluminum. Plastic composite structures have only been used in limited production vehicles but have demonstrated that light weight can be achieved. More research is required but such bodies can be designed for manufacturability reparability and durability. Figure 2 shows a "body in white" by Audi and the super car frame for comparison. The chassis of the super car is to provide safety and handling equivalent to or better than a conventional car. This can be done by distributing the mass and tuning the suspension as shown in Figure 3. By making the batteries and power train components act as protective elements, the ride and handling can also be improved because of the larger moment of inertia. For a luxury car, a larger moment of inertia can provide a smoother ride.

Finally, power production and transmission concepts need to be explored. The objective is to design and construct a power train which utilizes as much of the current technology as possible. But keeping in mind the requirements of cruise BSFC of 304 gms/kwhr (0.5#/hp hr) at the wheels means that peak efficiency must occur around cruise speed (2500 rpm at the engine) and 5.5 kw (7.4 hp) at the wheels. This means that the engine peak power will be around 12-15 kw (16-20 hp). This cannot satisfy the gradeability requirements, and certainly not the performance requirements.

Before the complete power train is discussed, let us discuss the ZEV power train and the philosophy of control. To follow work of others (GM impact, BMW, etc.) a 75 kw (100 hp), electric motor and controller is now quite available. If such a motor is used, then ZEV performance can be 0-100 km/hr in less than 10 seconds, since the vehicle weighs less than 1130 kg (2500 lbs). In order to achieve this kind of power, however, the power capability of the energy storage system is important. There are only a few energy storage systems which have the 75 to 100 kw capability. These are: 1) flywheel energy storage, 2) hydraulic energy storage, and 3) battery energy storage.

From the requirements for ZEV range discussed above, it is clear that state of the art flywheels and hydraulic (compressed air) energy storage are not developed highly enough to be able to store the kind of energy required. Thus in the short term (the next 10-15 years), only battery energy storage appears practical. The author has constructed two flywheel energy storage vehicles and know that projected energy densities are difficult to realize when compared with electrochemical electric motor systems which now exist (ref. 2, 3). Thus the only reasonable near term energy storage system is an electrochemical battery. The main questions are now cost, durability, and reliability. For a cost effective system, a demonstrated life of 160,000 to 320,000 km (100,000 to 200,000 miles) is necessary. The battery system with this capability now is only the nickle cadmium (nicd) type. Saft is a major manufacturer of these batteries. Nickle metal hydrides may have similar characteristics but they are still at a developmental stage while nicds are a proven technology. The key to practicality is cost. If a nicd battery pack costs $20,000 and lasts 320,000 km (200,000 mi), the cost is 7¢/km or 10¢/mi. It is almost certain the production cost of nicds will be about $10,000 or less for a 15 kwhr pack. It is difficult for other technologies to match this cost of 3 ½¢/km or 5¢/mi. In addition, these Nids or Nimhd are recyclable.

Now let us discuss the internal combustion (I/C) engine. The engine needs to produce power at 270 gm/kwhr (0.45 hw/hp-hr). To do this, the engine needs to run at wide open throttle and at a point of maximum volumetric efficiency. This usually occurs at about 1/3 to 1/2 power at 1/3 to 1/2 maximum speed. Thus, 11-18 kw (15 to 25 hp is all that can be produced)by the engine at full speed. Thus, it is not possible with conventional piston engine technology to provide enough power to meet the performance requirements when maintaining this BSFC without fuel enhancers etc.

The electric motor is the next component to be discussed. High power density electric motors are now available from a number of companies either as a permanent magnet brushless dc or as a high speed ac motor. The choice of either motor style is not too important except for weight and speed. The highest possible power density including the controller today is about 2 kw/kg [1]. There are a number of companies which have produced motors of this power density. The next variable is motor speed. It is desirable for this application to have a motor with a speed approximately compatible with an I/C engine to make all components compatible with existing transmissions and I/C engines without additional gear reductions. The choice of motors for this vehicle has been a permanent magnet brushless dc. Other choices of course can be made but it is only à matter of availability and costs. Torque characteristics are limited by the electric current availability of the controller, motor, battery combination.

Now all components for a super car have been discussed. Next will be to discuss how a system can be put together and what is required to control the various component.

The component arrangement which make sense is to have both the I/C engine and E/M on the same shaft eliminating the need for a starter motor or alternator (see Figure 4). If this is done, then an extremely simple control scheme can be derived. The electric motor needs to be current or torque controlled by an accelerator pedal. If the I/C motor throttle is also on the same accelerator pedal, then the mechanism of control is to have the accelerator pedal control first the engine throttle providing engine torque as in a conventional car and then when the pedal is deflected beyond wide open throttle, the electric motor torque is gradually added. The effect of the E/M then is like that of a super charger for the I/C engine, where torque to the transmission is automatically increased to the desired level by the driver. The I/C engine may be clutched on or off, dependent on a variety of policies. For example, in no case will the I/C engine be allowed to idle. An electric clutch on the I/C engine will allow it to be coupled or de-coupled to the electric motor. Simultaneous to clutch operation will be fuel injection operation. Fuel shut off will be used on deceleration and de-coupling. The I/C engine coupling can be done with different control choices. The simplest will be to use a vehicle speed signal. For example, the I/C could be de-coupled at about 15 kw/hr (10 mph) and set to couple at 20 km/hr (14 mph). This means that vehicle launch is always by the E/M. In the hybrid mode then, the I/C engine is loaded very heavily (wide open throttle WOT) most of the time since it is such a small engine. If the speed is not allowed to be greater than 3600 RPM then minimum BSFC is obtained most of the time. Acceleration is then equivalent or better than an equal power (75 kw) I/C only vehicle because of the E/M torque. For the E/M to achieve the power of 60 kw, 300 to 400 kg (600 - 800 lb) of batteries are required today. If better batteries become available, then the system becomes more attractive with even better performance.

ZEV operation is of course the same as a high performance EV with regeneration by control of the transmission and brake pedal. One view of the HEV system is that this is simply an EV with two I/C cylinders on the E/M shaft that can be coupled on/off. This power train can be coupled to a conventional transmission either a 5 speed manual or an automatic without a torque converter. A transmission is necessary for best performance. This concept however can be implemented without a transmission saving some weight and providing a little less performance.

The system is designed to discourage use of gasoline except for cruise. If the HEV mode is used in the city, it uses about 1.15 $\ell/_{100km}$ (200 mpg) and uses about 60 watt hrs/mi of electrical energy, which results in very low emissions and super fuel efficiency. Of course, electrical energy is being used, but its range is now about 350 km (250 miles). See Figure 5. Of course, ZEV capability is always available by simply disconnecting the IC engine by a switch. Pure IC engine operation can only be done by tricking the system and not meeting the driving cycle acceleration requirements.

Additional incentive is provided to operate ZEV with wall plug charge because the cost is less than 1/2 the cost of using gasoline. Emergency charge is simply done by using the regenerative brake control if the batteries are drained by mistake. Cost/mi rises drastically when this is done.

The top speed of the vehicle is over 160 km/hr. The car can cruise at 100 km/hr indenfinately but once the vehicle cruise speed is increased over 100 km/hr, electrical energy is used decreasing the range and time of operation. For example, 130 km/hr cruise can be maintained for only about one hour (see Figure 5).

Conclusions.

It is shown in this paper theoretically that a super car is possible. A vehicle has been constructed which demonstrates that the Super Car can be built with ZEV capabilities and super fuel efficiency while maintaining excellent performance. [4] The vehicle shown in Figure 6 was constructed for the hybrid vehicle contest in the USA [5] and has the following performance figures:

Accel	(0 - 100 km/hr) 13 sec ZEV 12 sec HEV
Fuel Econ	(100 km/hr) 2.3 l/100 km (100 mpg) (EPA city) 200 mpg + (0.06 kw/mi)
Emission	HEV (ULEV) or less
ZEV Range	160 km (100 mi) @ 100 km/hr (62 mph); 200 km (120 mi) city cycle.
HEV Range	1000 km (620 mi) @ 100 km/hr (62 mph); and 350 km (250 mi) city to zero battery state. With recharge city range can be greater but is discouraged.
Vehicle weight	1100 kg, 2 passengers.

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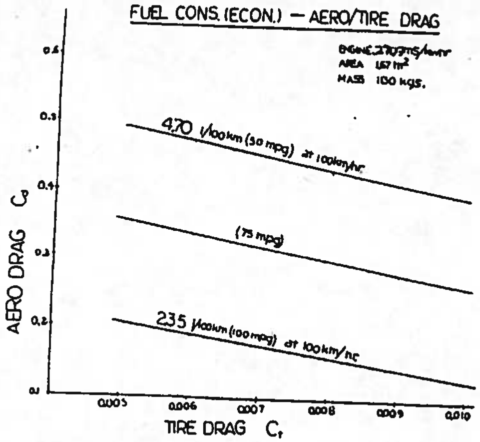
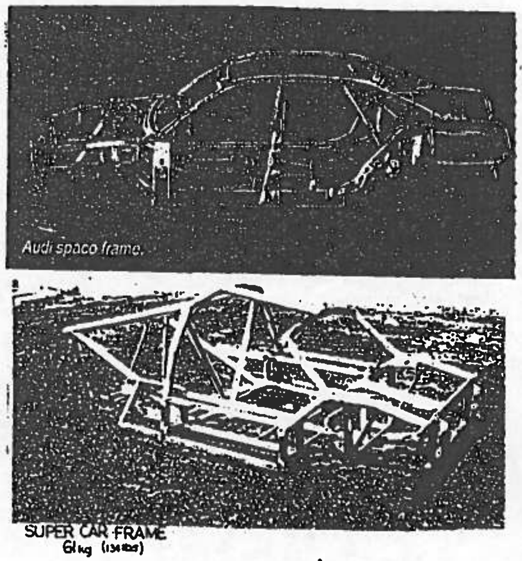
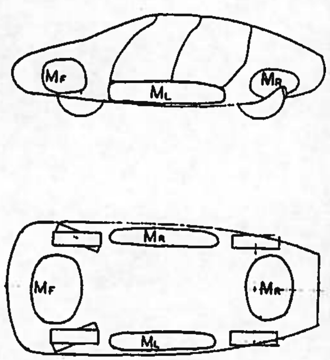


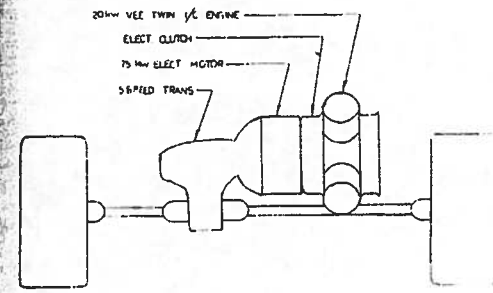
FIGURE 1.



SUPER CAR ALUMINUM FRAMES
FIGURE 2



SUPER CAR MASS DISTRIBUTION
FIGURE 3



A SUPER CAR POWERTRAIN
FIGURE 4.

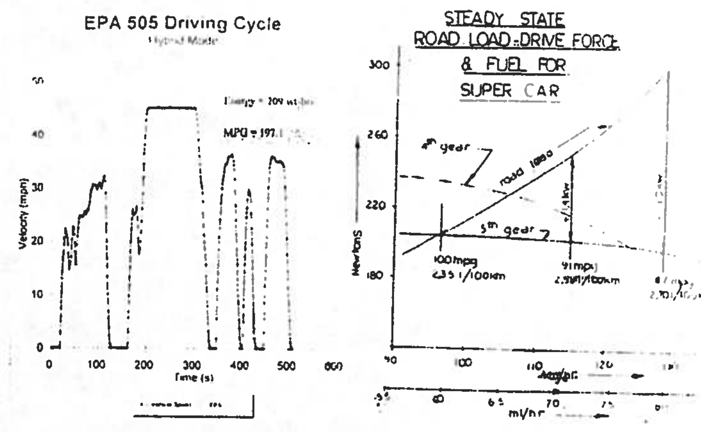
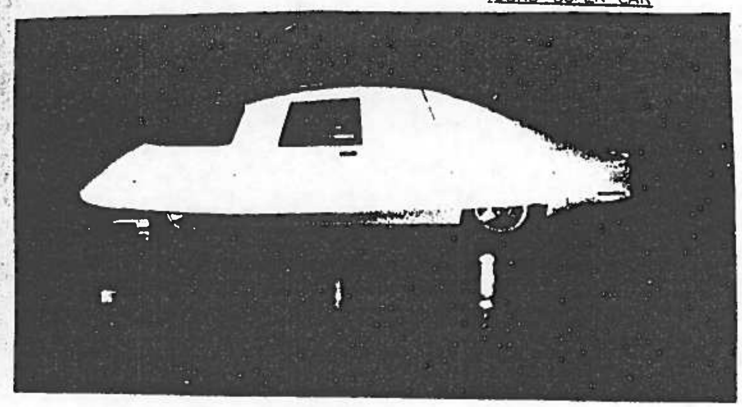


FIGURE 5 GASOLINE-ENERGY CONSUMPTION
180KG SUPER CAR



The 1994 UNIV OF CA DAVIS
SUPER CAR
FIGURE 6