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# THE POTENTIAL FOR FUEL SAVING IN ROAD VEHICLES

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## 1. Introduction

The question marks facing the designer as he takes up the energy challenge are :

- What limits can be attained in terms of car fuel consumption with current technolcgies ?
- What new technologies, now on the horizon, have a potential for fuel consumption reduction and at what level ?
- Within the potential actions above what would be the threshold of acceptability imposed by other conditions such as cost, safety, etc. ?

Let us examine the distribution of the energy required for vehicle propulsion referred to the Federal Standards for a small-to medium-sized European car (2000-2250 lb); the case in point is particularly relevant to the Italian, or European situation. The propulsion energy requirement distribution is indicated in Fig.1.

Individual parameters, namely aerodynamics, weight, rolling resistance, etc. are dealt with separately below.

## 2. Aerodynamics

Right back from the thirties much work has been done in the field of car aerodynamics, but it is easy to foresee further progress in this field for the near future.
Car drag coefficients Cx has evolved with time as shown in Fig.2.
The drag coefficient in current motor cars have stabilized in the range between 0.5 and 0.4.
For the car taken as reference, the drag coefficient is 0.45.

To overcome drag the car in question must dissipate :
- 16 % of global energy, according to federal driving cycle (FDC)
- 51 %, according to highway driving cycle (HDC)
- 32 %, according to the combined cycle (55% FDC + 45% HDC).

A number of manufacturers are systematically studying vehicle areodynamics.

For instanèe, in Italy, the National Research Countil (C.N.R.) has sponsored and directed a research programme for the purpose of identifying the limit of Cx for a vehicle in the presence of ground effect, the results of which indicate that it is possible to reach value of Cx = 0.05, typical of the isolated spindle-like body. Applying the criteria indicated by this analysis to a car of to-day,maintaining layout and internal space it is possible to arrive at value approximately of Cx = 0.15.
However this would necessitate body shapes which are hardly applicable to the everyday car. The interesting conclusion emanating from these results is that in the very near future it will be possible to endow all our cars with a drag coefficient which has now only been attained very sporadically.

This means that it is fairly realistic to think that in the coming years all cars will shift from the current Cx = 0.4-0.5 to a level of 0.3-0.4. Farther away in time it is sound to think to be possible to reach value of 0.25.

Simply by altering drag coefficient Cx on our reference vehicle, without changing any other conditions such as weight, performance, frontal area, etc., road consumption referred to Federal Standards (H.D.C) would vary as indicated in the diagram of Fig.3 which also shows the limit case for Cx = 0.15.

It is unthinkable that even in the more distant future the 0.25 limit will be exceeded because of cost, functionality, bulk and safety reasons.

In the case of trucks, the effect is more tangible. Simple measures involving only the cab, virtually halve Cx coefficient. This is due to the fact that up to now trucks, which in many countries have been the object of severe limitations on speed, were never considered from the viewpoint of aerodynamics. Nowadays, when this type of vehicle is operated at the same speed as motor cars, this attitude is no longer acceptable (see Fig.4).

## 3. Weight reduction

Weight is one of the parameters affecting rolling and bracking losses.
Current technology remaining unchanged, car weight and dimensions are strictly correlated parameters.
The use of high strength steels may lead to a weight reduction; however the reduction, percentage-wise, is quite modest, with consequent small reductions in fuel consumption.
Ferrous materials can be replaced with aluminium alloys.
Again speaking in terms of our small car, let us consider the highly unlikely possibility of replacing ferrous materials with aluminium.
In our typical car, 56% of the weight is that of ferrous materiais. If these were to be replaced by aluminium alloys, vehicle weight would be reduced by approximately 30%. Vehicle fuel consumption on the road would therefore diminish by 16%.
Kowever, aluminium should be used sparingly owing to its current cost in tenns of energy. Indeed, such a considerable weight reduction, and the related savings in fuel consumption could be offset by a sharp increase in consumption required for vehicle manufacturing.
If a country such as Italy *were* to start manufacturing all aluminium alloy cars at a particular time, the transport energy consumption of that country would be according to the curve plotted in Fig.5.
Only after a number of years, say ten to fifteen, when the majority of the car park had been converted to aluminium, would the weight reduction advantage begin to show. In the first years of introduction of the new generation of cars, the greater consumption required by aluminium production would make itself heavily felt.
The level of reduction in global consumption at full capacity will depend on the level of aluminium recycling obtainable.
Conversely, a technology already established in the space industry, though not yet popular in the automotive field, but likely to bring about major changes in automobile construction because of its potential for overall weight reduction is that of high performance composites.
The introduction of these materials in the automobile field have to overcome the problems of cost and technology for large series production.

To give an idea of the importance of the weight factor let us see what happens to our reference car when only the weight is changed, leaving all other parameters, such as dimensions, performance, aerodynamic drag, etc., unaltered.
The consequent variation in consumption follows the trend indicated in Fig.6.

## 4. Rolling resistance, car dimensions and performances

Following the widespread adoption of radial ply tyres there does not seem to be any measure which could in the future bring considerable reductions in rolling resistance.
The foregoing considerations are limited to vehicle dimensions and performance. It is clear that consumption can be reduced by restricting dimensions and performance (see Fig.7).
However, these two parameters are more market dependent than in the hands of the designer.

## 5. Power plant and transmission

The characteristics examined above are all concerned with how the vehicle dissipates the energy needed for propulsion.
Let us get inside the vehicle and examine whether it is thinkable to improve overall efficiency of conversion of the fuel energy content in term of mechanical energy useful for propulsion.

### a) The power plant

The reciprocating engine, both in the spark ignition and diesel configurations, is now generally accepted to bevery near the limit of its efficiency.
Current developments by the various manufacturers, about to be introduced in production in the very near future, show the reciprocating engine to be virtually at the limit of its possibilities and no major breakthrough seems currently possible (see Fig.8).
The levels of efficiency attainable obviously depend on the emission levels to be met.
What the reciprocating engine can do is to obviate the need for strict fuel characteristics.

In other words, some quarters are investigating the possibility of designing a reciprocating engine similar to the one we have today but which, though at least maintaining the levels of energy conversion efficiency of current engines, is capable of running on wide-cut distillation products.

Thismeans fuels of high or low volatility, high or low octane number (98 or 60 ON), high or low cetane number.

Such a family of engines would have a tremendqus potential impact on the petroleum system management of any country and, therefore, on the possibility of reducing crude requirements.

Another type of change that today engines will undergo, is that conceming the capability of burning fuels not derived from petroleum. However, in this field the conventional engine has two strong potential competitors, namely the turbine engine and the electrical propulsion engine.

To be really competitive, the turbine engine must have available low cost materials permitting operation at higher temperatures than those allowed by current super alloys. Much work is now in progress towards this objective, investigating ceramics technology.

Clectric motor propulsion is extremely interesting for the great degree of freedon it allows in the selection of primary energy source.

For this type of propulsion to be competitive and not languish in a marginal role, a solution must be found to the problems connected with on-board electric energy storage with acceptable limits of weight, size, cost and serviceability.

## b) The power transmission

This is a sector where there is still room for manoeuvre. Let us examine the reasons why. The spark ignition engine maximum efficiency is today of 0.33-0.34, close to the ideal cycle efficiency, when mechanical losses are included.

On the other hand, the ratio of the work needed to overcome-the exsternal resistance for the vehicle movement to the energy burned by the engine is in urban driving on the average of 0.12, i.d. the actual total efficiency is from 1/3 to 1/2 less then the optimal engine efficiency (see Fig.9).

This is due in small part to mechanical transmission losses and in greater part to the fact that the engine works in conditions which are very far from those of maximum efficiency

The consequences of the energy crisis for manufacturers were :

- a tendency to adopt longer transmission ratios with a consequent decrease in the level of vehicle performance
- a trend towards increasing the number of transmission shifts (from 3 to 4 and from 4 to 5).

The latter measure is taken to afford the driver greater freed of choice in terms of engine speed and, therefore, greater possibility for operating in high-efficiency conditions.

Available technology, however, enables us to produce automated engine-transmission management systems with a view to minimizi consumption.

That is, transmission and engine management hitherto under dir control of the driver is taken over by logics which optimise instant-by-instant the engine-transmission coupling in relatio to driver's demand, thereby minimizing the negative effect of transients.

The obstacle to the widespread adoption of these systems is co which, however, should decrease considerably in the near futur

Its is not over-optimistic to assert that with these centraliz management systems our reference car can attain fuel saving of the order of 20-25% (see Fig.10).

Looking further into the future, the electric transmission cou to the heat engine (i.e. the type of solution currently known hybrid power plant) is very appealing.

However, the hybrid power plant can compete with current and n future solutions only if it will be possible to increase the e ficiency of conversion from thermal energy to electrical and mechanical energy, and if ways will be found to reduce cost anc size of electrical machines.

## Traffic control

Optimization of the engine and power transmission system is technically a difficult task because of the large variety of vehicle operating conditions.

One can foresee that this task will be somewhat easier if efficient traffic control is developed, especially in urban areas.

It is too early to report any quantitative estimates on the practical effects in terms of fuel consumption savings.

FIG. 1 THE RESPONSABILITY FOR FUEL CONSUMPTION OF THE VARIOUS CAR SUBSYSTEMS

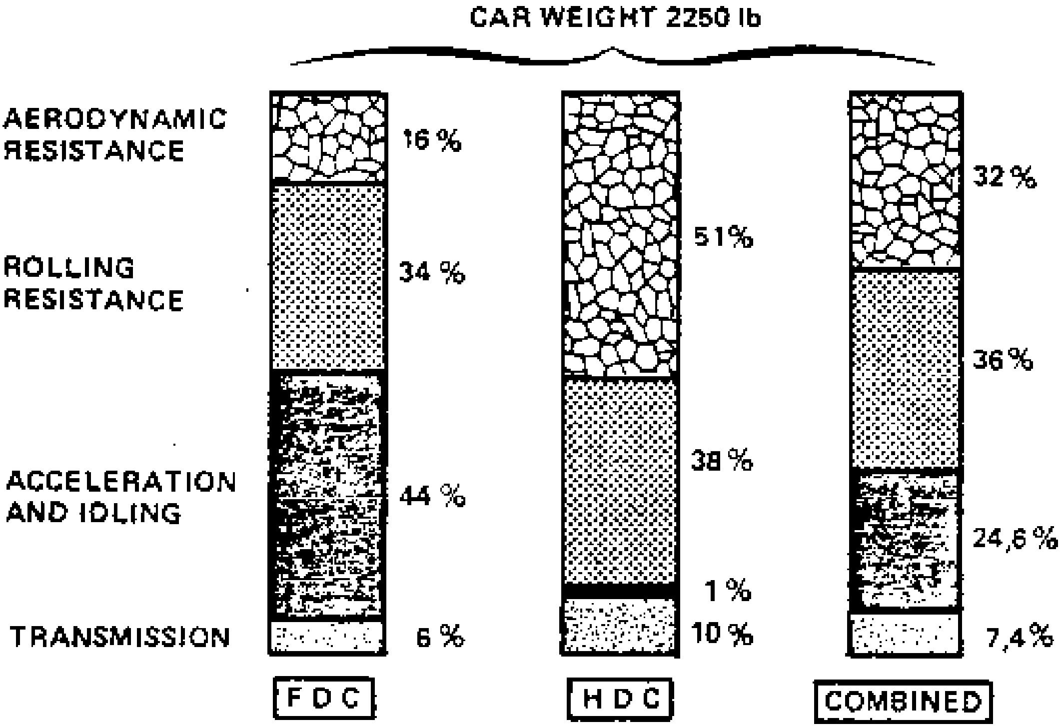
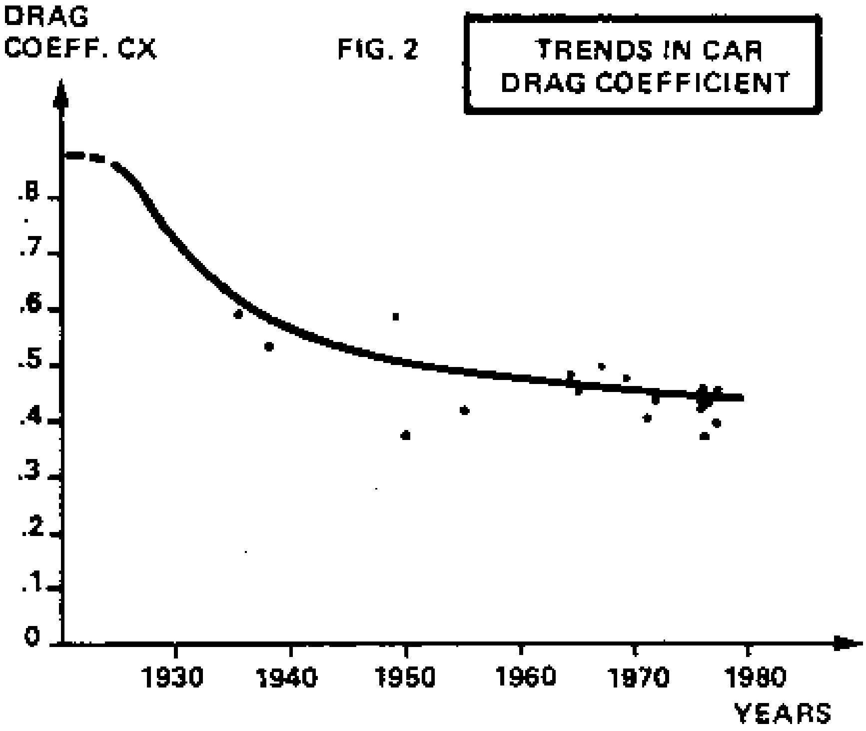


FIG. 2



TRENDS IN CAR DRAG COEFFICIENT

FIG. 3

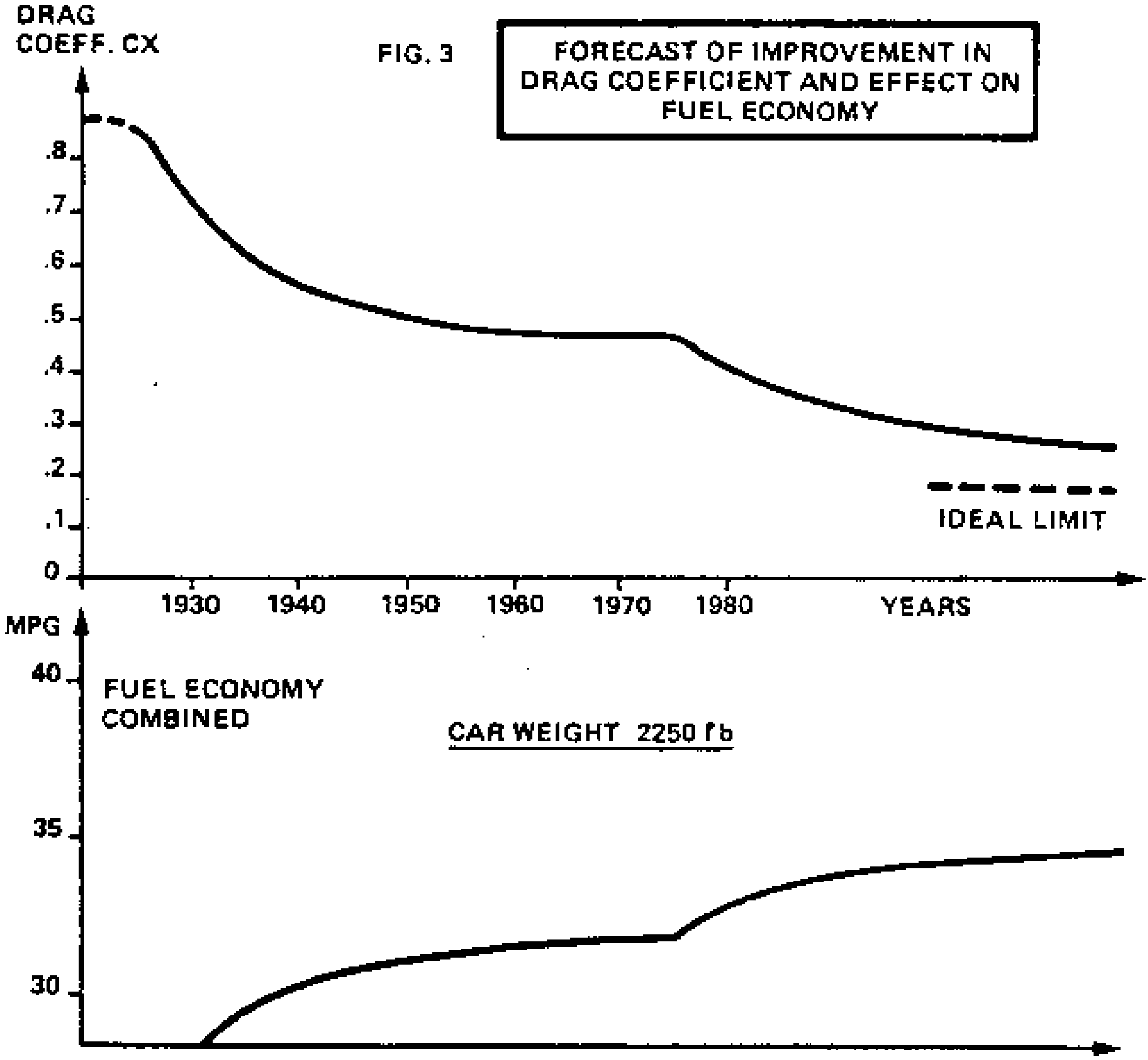

FORECAST OF IMPROVEMENT IN DRAG COEFFICIENT AND EFFECT ON FUEL ECONOMY
DRAG COEFF. CX
.8
.7
.6
.5
.4
.3
.2
.1
0
IDEAL LIMIT
1930
1940
1950
1960
1970
1980
YEARS
MPG
40
35
30
FUEL ECONOMY COMBINED
CAR WEIGHT 2250 ℓb

FIG. 4

DRAG COEFFICIENT REDUCTION IN TRUCK AND EFFECT ON FUEL ECONOMY

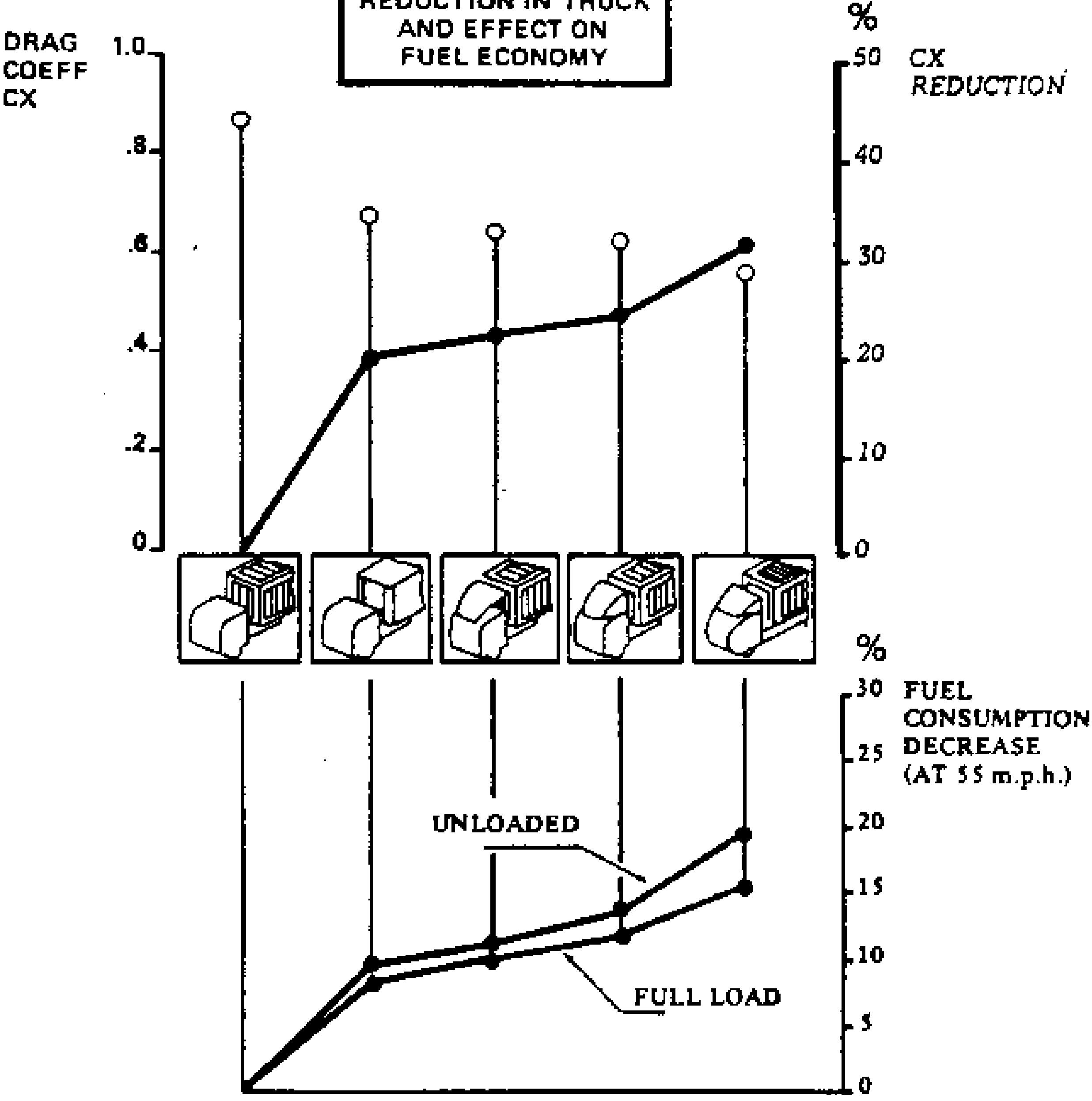


FIG. 5

THE "ALL ALLUMINIUM" CAR MARKET
TOTAL (CAR PRODUCTION PLUS FUEL ECONOMY)
ENERGY SAVINGS

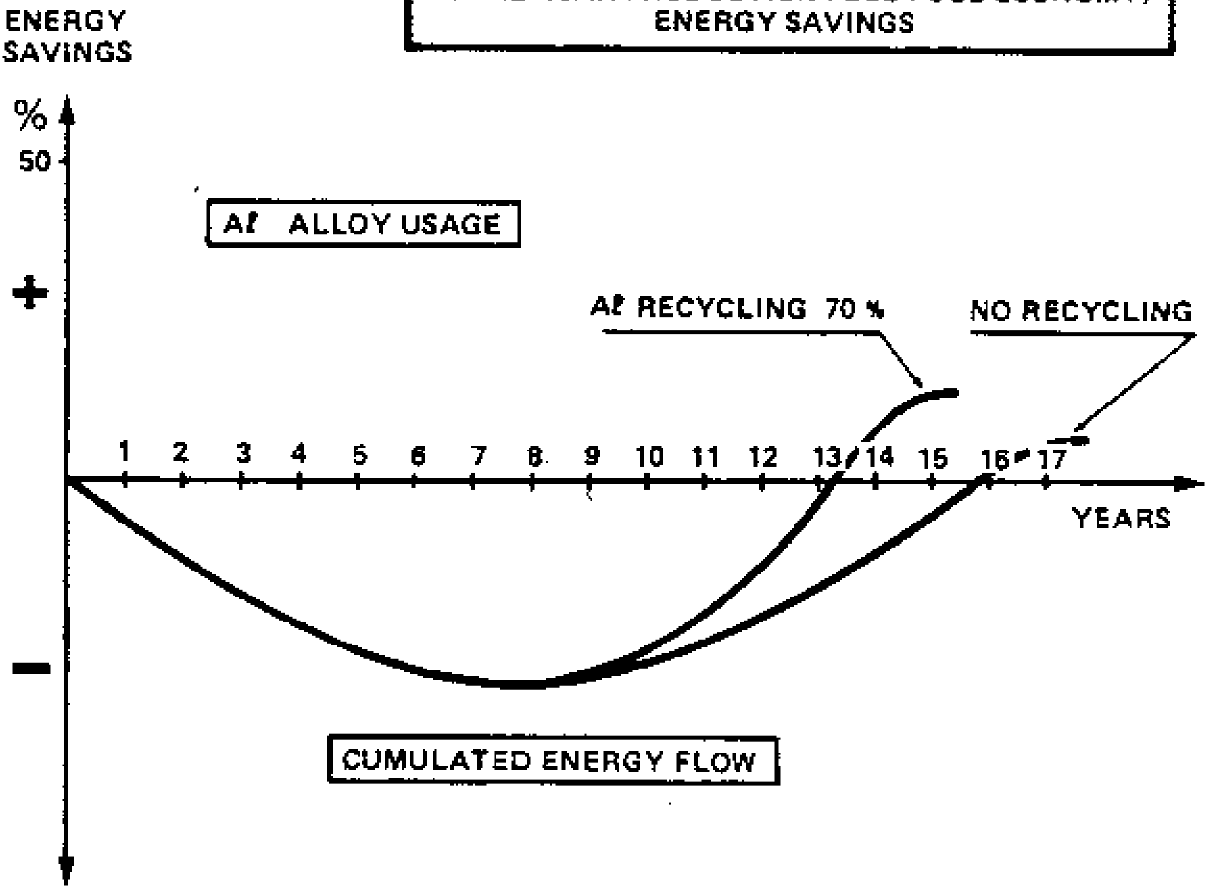


FIG. 6 INFLUENCE OF CAR WEIGHT REDUCTION ON FUEL ECONOMY

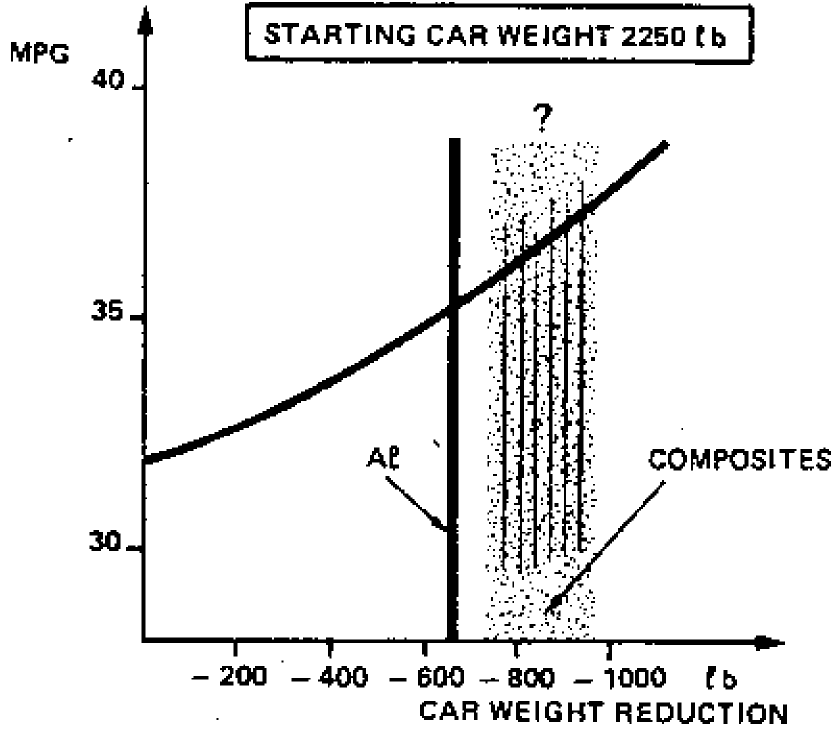
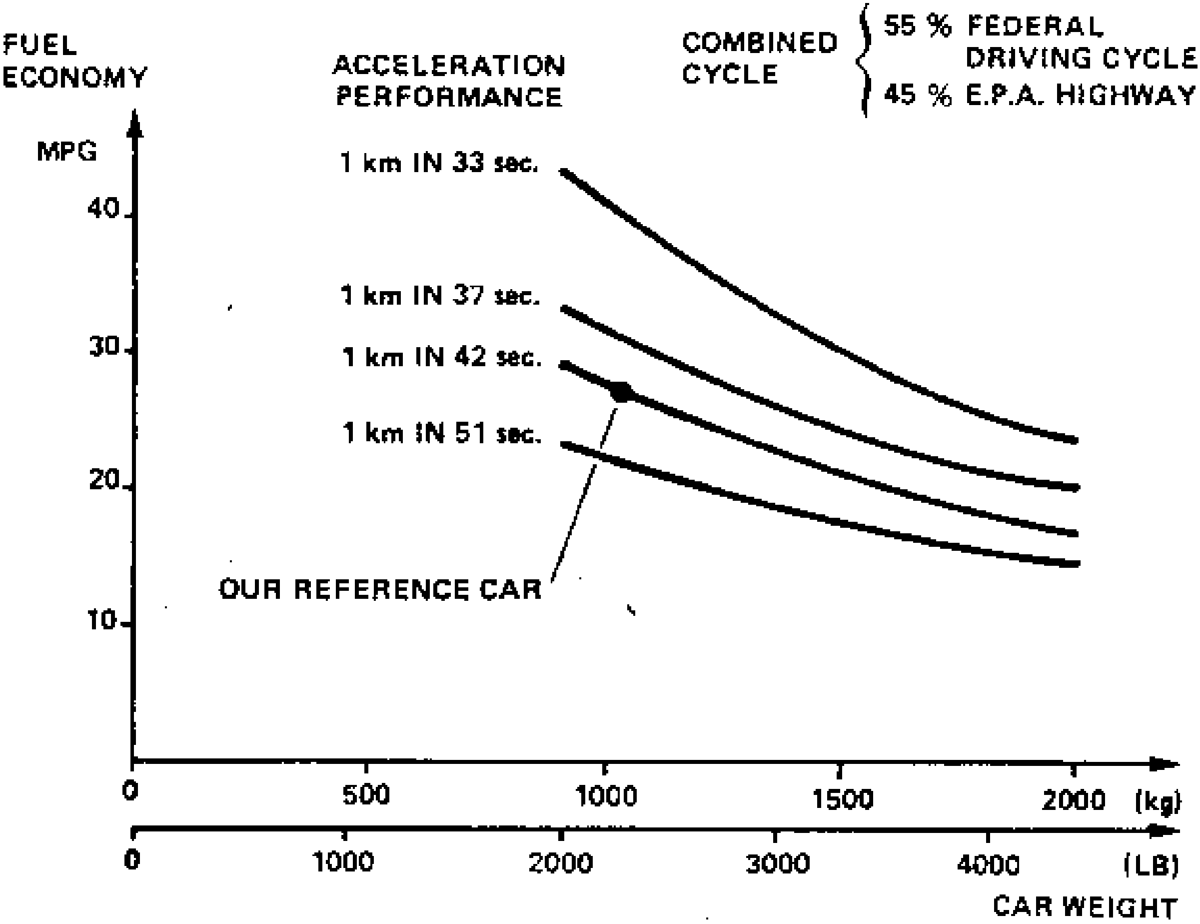


FIG. 7

# INFLUENCE OF PERFORMANCE AND WEIGHT ON CAR FUEL ECONOMY



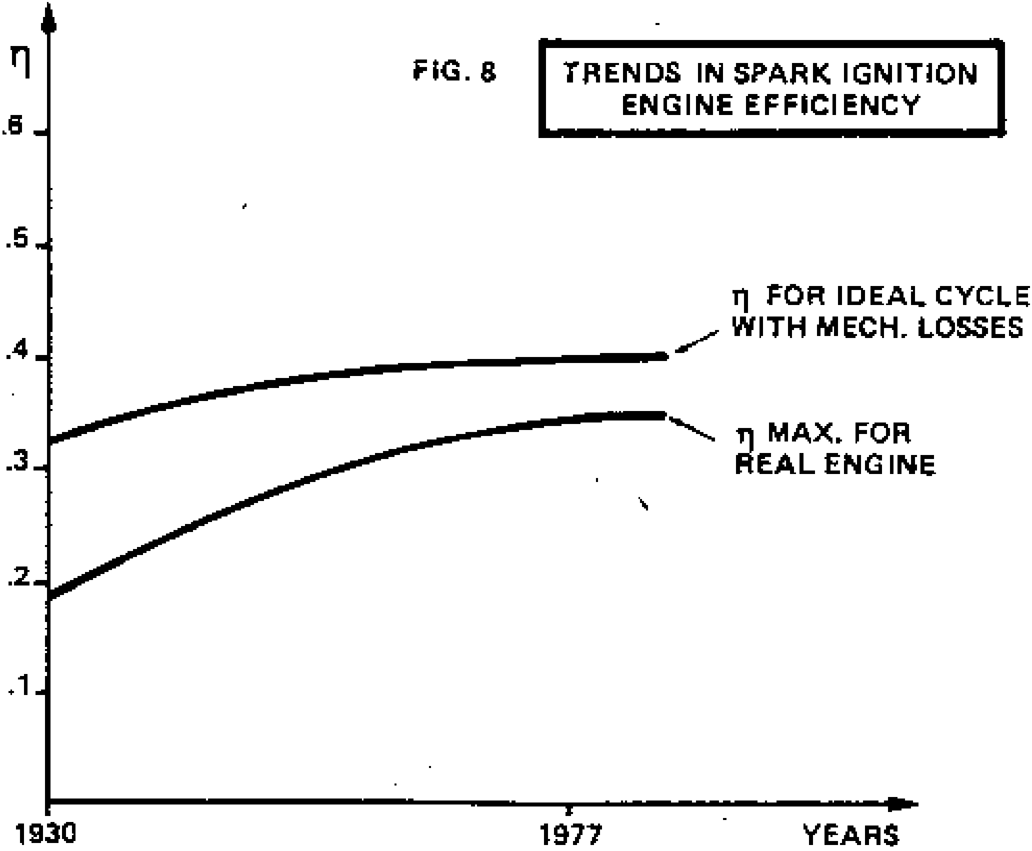
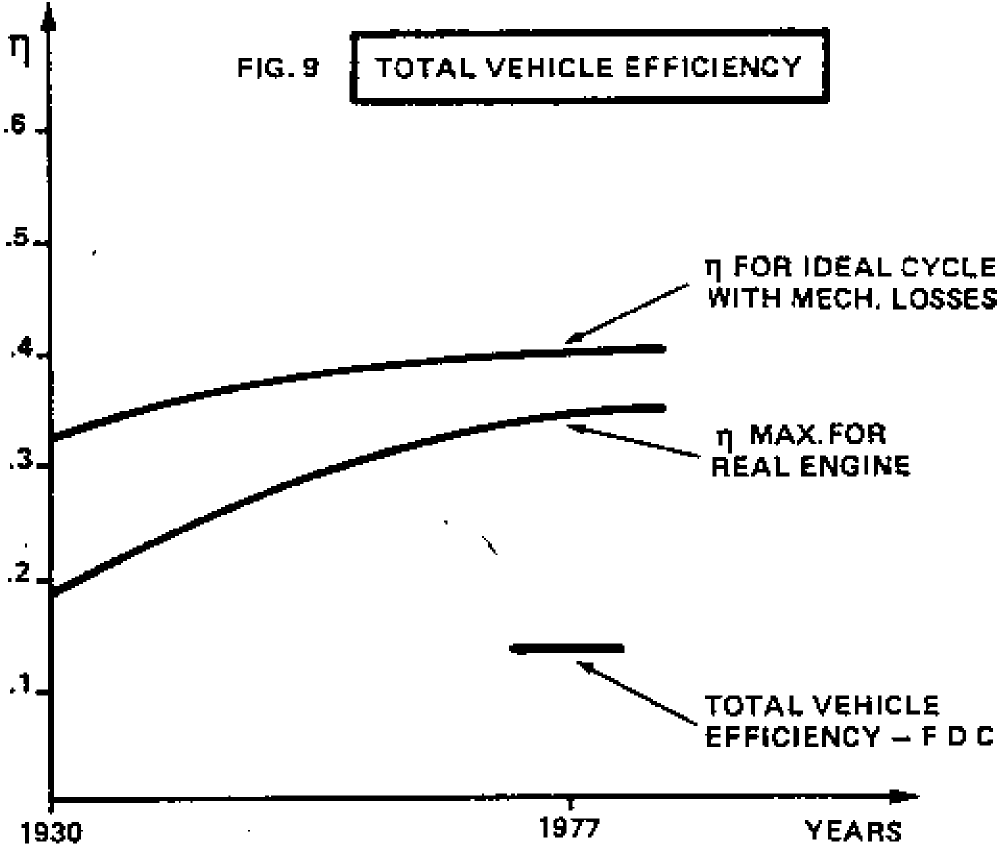


FIG. 8

TRENDS IN SPARK IGNITION ENGINE EFFICIENCY

FIG. 9 TOTAL VEHICLE EFFICIENCY



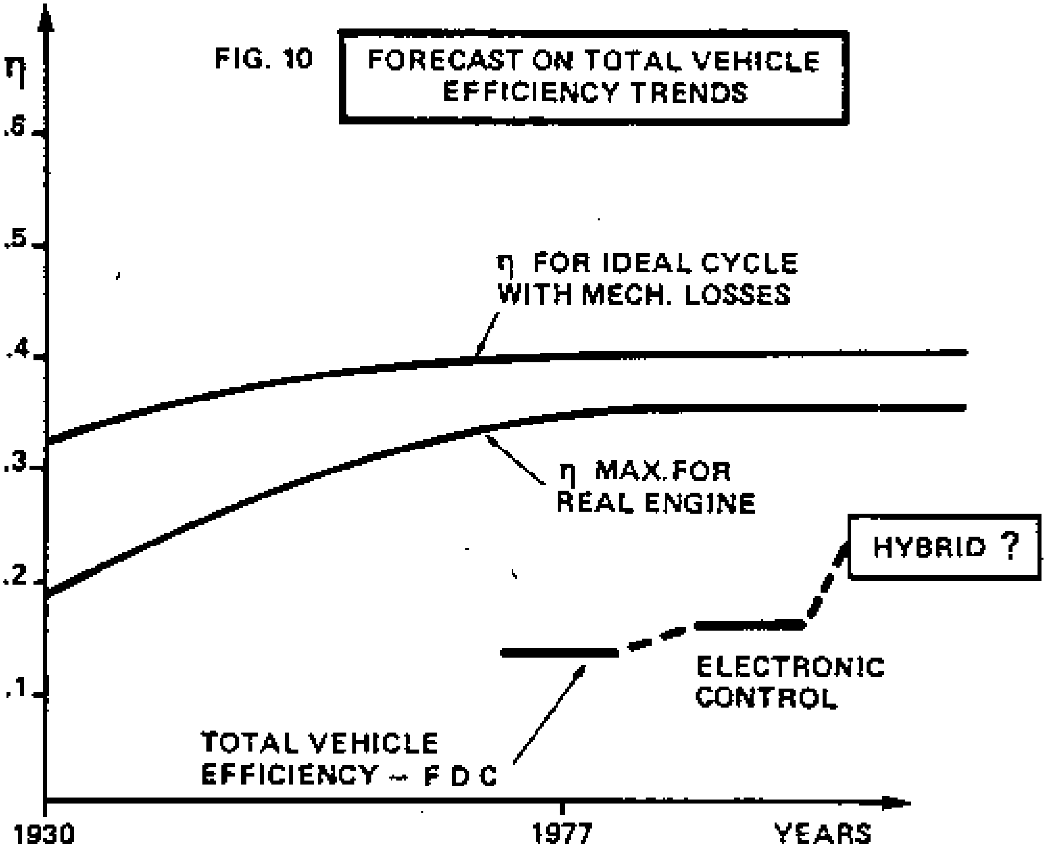


FIG. 10

FORECAST ON TOTAL VEHICLE EFFICIENCY TRENDS