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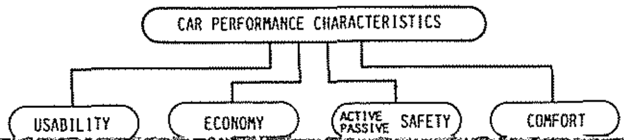
ABSTRACT

The purpose of this article is to describe the work conduced in aerodynamic field throughout the 4-year development and



that envelops the occupant (Fig. 2) with the greatest height in passenger compartment dimensions.

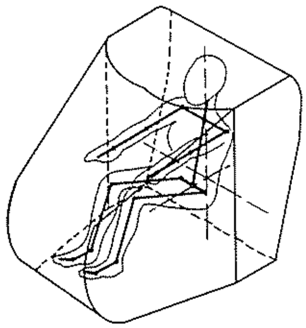


Fig. 2 - Isometric view of optimum pas-

The emphasis with which each phase is actually considered, developed or located in time with respect to the others varies from case to case. In the specific case of the UNO, the phase with small scale models was deliberately constrained whereas phases 2 and 3 were developed extensively and phase 4 partially. By working with full-scale models it was thus possible to obtain the best trade-off between weight, roominess and aerodynamic requirements. This strategy required a great deal of resources since it was applied to several different shape proposals and associated test results. However the full-scale models were useful for styling evaluations.

From the strictly aerodynamic point of view, shape was developed along three main

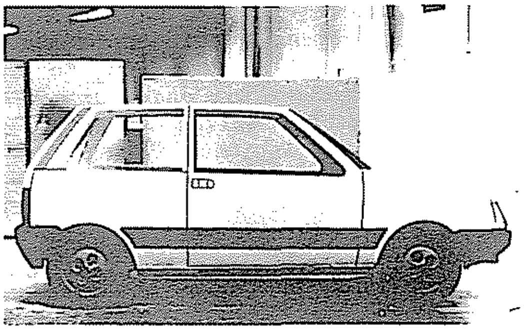


Fig. 4 - Final styling proposal (model for wind-tunnel test)

divided front from rear to change the wheelbase by introducing inserts, and was provided with a removable rear section to accomodate blocks of different angles and with a roof whose height could be varied by the addition of suitable layers.

Fig. 5 shows the positive effect - not fully exploited by the final value selected - on drag coefficient due to the longer car wheelbase.

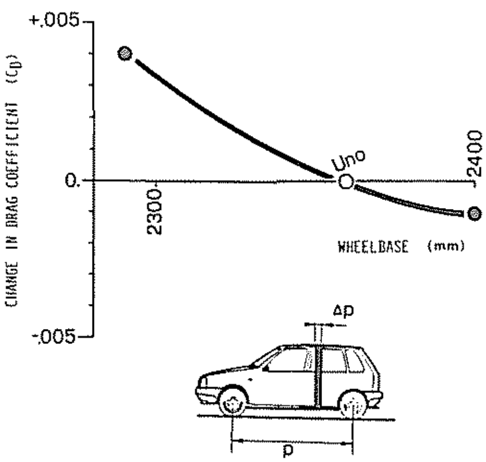


Fig. 5 - Influence of wheel base change

Fig. 6 illustrates the influence of the extremely critical parameter of back-window slant angle. The styling of the UNO gives an aerodynamic rating close to the minimum that was observed.

For the future sports version the adoption of an add-on device will reduce the drag coefficient to a value corresponding to the smaller slant angle at the minimum in Fig. 6 (See later page 8).

Fig. 7 illustrates the effect of an increase in roof height. This produces both an increase in the frontal area and a deterioration of the drag coefficient. The line $C_D \cdot S$ = const. allow us to give an idea of the amount of drag coefficient (arrows segment) that has been necessary to recover in order to maintain the same drag of the original height (h = 0). In these tests the angle Ø has been kept constant.

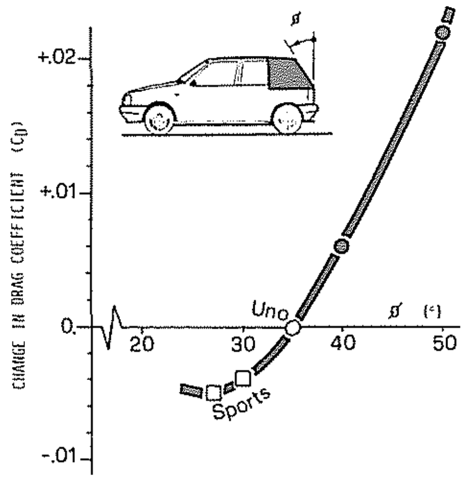


Fig. 6 - Influence of back-window slant angle change

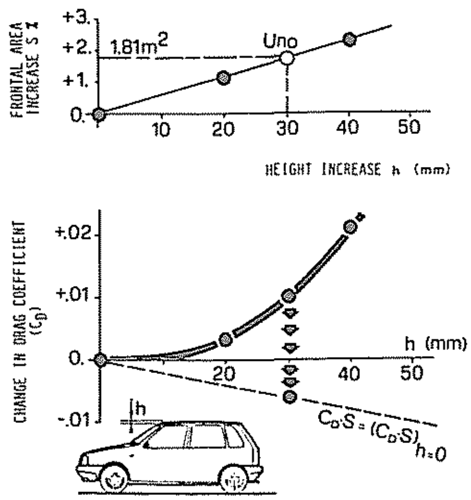


Fig. 7 - Influence of shape height increase

DETAILS : PARAMETRIC STUDIES - As shown in Fig. 8 the increase in roof height has permitted the exploitation of roof slant at the rear end.

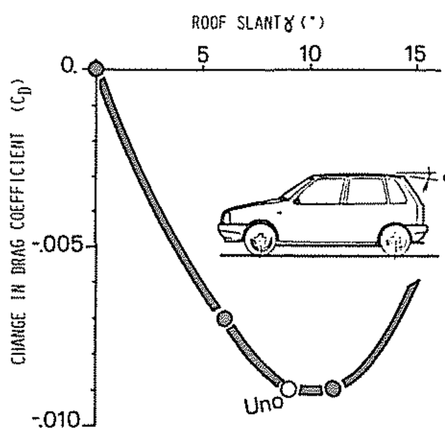


Fig. 8 - Influence of rear roof slant

The lower part of the front end is also a very significant area as far as the aerodynamic characteristics of a car are concerned; moreover, it also contributes significantly to styling differentiation. In this connection, Fig. 9 shows the effect of the main dimensions involved. The final UNO

air flow is necessary to meet engine cooling and other requirements, but represents a penality for external aerodynamics. Correct control of the optimum air quantity can be achieved by suitable sealing and ducting, but with consequent increase in production cost. Fig. 11 shows how the basic car is a

In the adopted configurations the drag penalty was constrained to a small value even though air passages were maintained.

The rocker panel area contributes significantly to the general equilibrium of air flow between the side and the underbody of a car, and consequently to the drag coefficient. Different configurations were, therefore, analyzed in this area, as illustrated in Fig. 13. The basic UNO car is also in this case a compromise among all those tested. The ES version with the adoption of the air deflectors on the rear wheels (shown in the figure) and the future sports version, with different costs and styling, will benefit from further advantages.

The parametric analysis also required the optimization of the exterior rearview mirror by reducing the corresponding drag penalty to a very low value (ΔC_D = + 0,005).

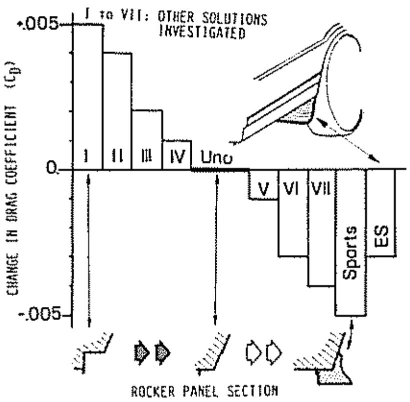


Fig. 13 - Influence of rocker panel configuration

AERODYNAMIC CHARACTERISTICS OF FINAL VERSIONS

The extensive experimental program carried out in the wind tunnel made available a wide range of possible design configurations for each of the shape areas analyzed.

By making evaluations in terms of production cost and styling, three possible configurations emerged: the UNO car, with different engines and versions; the UNO ES; and the future sports versions. With a reference frontal area of 1.81 m^2, measured with standard method [7], the corresponding aerodynamic characteristics for yaw angle β = 0 are shown in Table II.

The above values are the average obtained from a statistical check made on mass production cars (max deviation for C_D coefficient : ± 1,3%).

Versions checked were : 45 S (three doors, 45 HP engine), 55 S (three doors, 55 HP engine), 55 S (five doors) and 45 ES (three doors).

Table II - Synthesis of the UNO car aerodynamic characteristics

CAR TYPE	C_D	$C_D \cdot S$ (m^2)	ΔC_D	C_{L-F}	C_{L-R}	S (m^2)
UNO CAR	0.34	0.62		0.08	0.05	1.81
UNO ES CAR	0.33	0.60		0.06	0.04	1.81
FEATURING:						
• HOOD SEALING			-0.003			
• FLUSH TIRE RIMS			-0.004			
• REAR WHEELS AIR DEFLECTORS			-0.003			
FUTURE SPORTS VERSION	0.30	0.54				
FEATURING:						
• MOLDING APPLIED TO TAIL GATE			-0.005			
• MODIFIED FRONT BUMPER			-0.006			
• FLUSH GLASS ON FONT DOORS			-0.004			
• IMPROVED UNDER HOOD AIR FLOW			-0.011			
• MODIFIED ROCKER PANELS			-0.004			

Five units were checked for each version.

The values in Table II refer to car standard attitude with two persons, 20 kg of luggage and filled fluid tanks and reservoirs.

The behaviour of one of the UNO cars checked with varying ground clearence (but constant trim angle) is shown in Fig. 14.

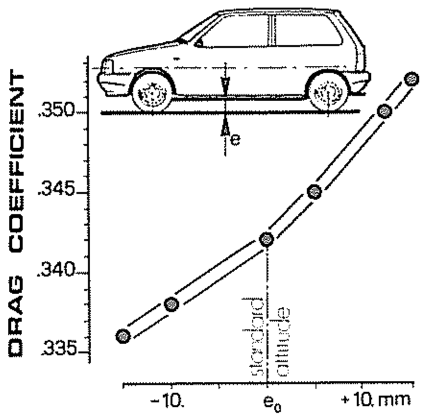


Fig. 14 - Influence of vehicle clearence

The behaviour of the same car with varying trim angle (but constant clearence) is shown in Fig. 15.

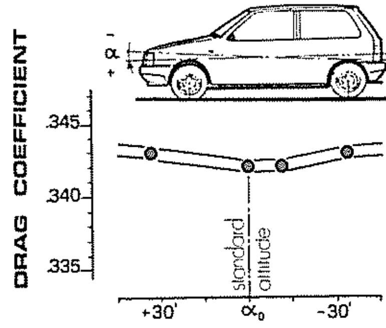


Fig. 15 - Influence of vehicle trim attitude

It can be noticed that the C_D value is not affected by such variation.

The behaviour of the car with yaw angles is shown in Fig. 16 where coefficients C_D, C_{L-F} and C_{L-R} are provided.

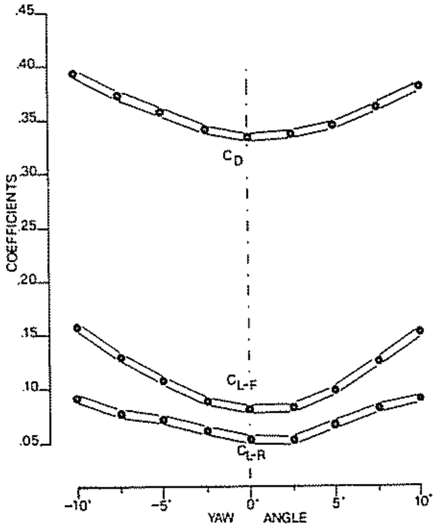


Fig. 16 - Influence of yaw angle

The variation of drag even beyond the yaw angle range included in the evaluation of the wind-averaged drag coefficient is very small.

The corresponding axle lift variation is minimum and therefore does not affect car handling. The absolute lift value is not significant for car handling with varying speed.

All the above coefficients were determined in our wind tunnel whose major specifications are as follows:

- Test chamber : semi open type (fixed ground)
- Nozzle : 30 m^2
- Max air velocity : 200 km/h (empty test section).

For more details see Ref. [8]. As to the correlation with other European wind tunnels see Ref. [9].

It is now possible to evaluate the aerodynamic "quality" of the vehicle, taking into account the car over all dimensions. Fig. 17 obtained from the literature [10] shows the effect on C_D of the reduction in length, with and without taper, for two wing profiles, in the presence or absence of ground. Fig. 18, also from the literature [11], illustrates the same effect on a simplified car model when the fineness ratio changes. Both these figures indicate that a body - when its length/height ratio is modified - generates other bodies and a corresponding specific curve, identifying a "family" whose C_D is affected by such parameter. The aerodynamic quality of the family is given by its position with respect to the Cartesian coordinates: the nearer the curve to the origin, the better the aerodynamics. Each car presently on the market can be identified by the an L/H ratio as a shape index, even though only approximately because it does not take into account the third dimension. It is therefore possible to consider each car in Fig. 19 as belonging to a family whose curve passes through the point that identifies the family itself.

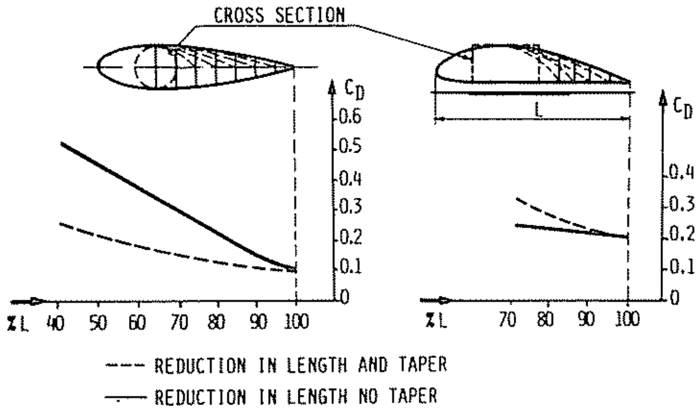


Fig. 17 - Influence of wing profile lenght variation

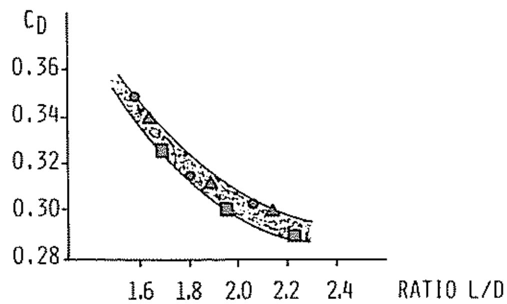


Fig. 18 - Influence of car fineness-ratio

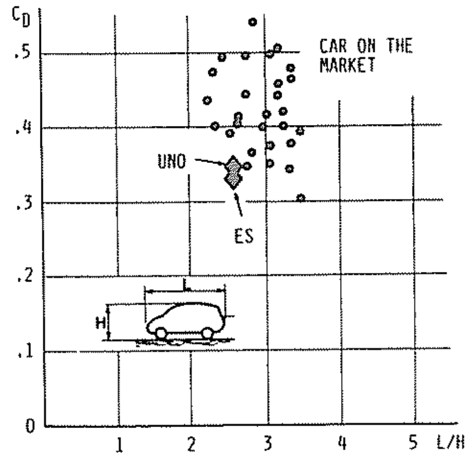


Fig. 19 - Comparison between cars on the market

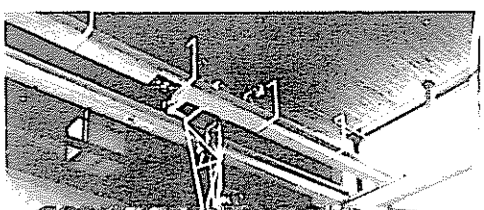
GENERAL FLOW FIELD

Based on the foregoing it is clear that the fundamental criterion followed to define the aerodynamic shape of the UNO car was that of parameterizing the geometry of critical areas. This was achieved by correlating the dimensional variations with those of total drag for all the styling proposals investigated.

Even though yielding satisfactory results, this empirical method is extremely expensive because it requires many hours of work in the wind tunnel. Also, it does not permit rationalizing the knowledge achieved because of the interference phenomenon that exist [12]. The above method is therefore a "blind alley".

In order to find a less empirical method, FIAT started, some time ago, a cooperative program with the Politecnico of Turin to pursue a different approach that adds quantitative analysis of the wake to what has been done so far [13, 14]. This approach, based on tests run in the Politecnico's wind tunnel on small scale models, serves to determine, among other parameters, the loss of total pressure in a cross section of the wake. Although this work is still in the development phase, from the beginning it has provided interesting information.

For this reason, it was decided to start a parallel activity in the Fiat full-scale wind tunnel. A very simple device (Fig. 20) was set up to permit a Pitot tube to be moved horizontally throughout the area covered by the wake down-stream of the test car at selected distance.



This device was put into service subsequent to the basic choices of the UNO car shape. Processing of the signal from the Pitot tube is possible through the wind tunnel computer that also controls the mechanical movement of the probe. Plots in real time are made of the pattern of the lines of total-pressure loss. Fig. 21 shows these patterns for both the standard UNO car version (C_D= 0.34) and the possible sports versions (C_D = 0.30).

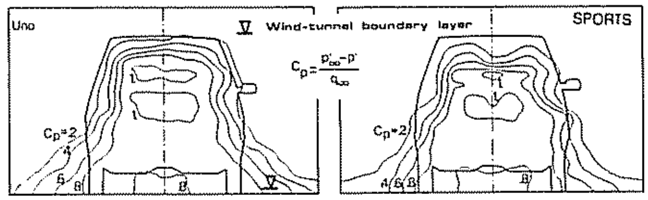
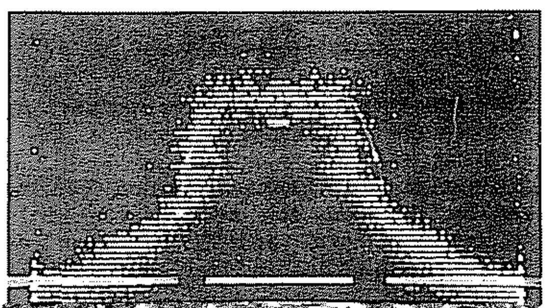


Fig. 21 - Pattern of total-pressure loss in the wake (looking down-stream)

The distance from the rear bumper is 1,2 m for both cases. In the figure is also indicated the boundary layer thickness of the empty rest section of the wind tunnel at that position [8].

Another approach is to send the signal to a small LED matrix placed behind the Pitot tube - according to the procedure set up by J.W. Crowder [15] - and to obtain a picture in various colors of the total-pressure distribution, as shown in Fig. 22. We prefer the first system in that it provides more complete information.



This variation tends to sucks back the fine sprays of water spattered by the wheels and to deposit them on the rear of the vehicle. Fig. 23 shows the static pressures in the longitudinal vertical plane behind the car, measured by the device of Fig. 20. Also shown are the local base pressures in the same plane, measured by static pressures taps on the back of the car. Over imposed is the pattern of water sprays (heavy-faced lines). This pattern is perpendicular to the constant pressures lines with directions from higher pressure to lower pressure region and has been confirmed by smoke visualisations.

It can be observed how base pressure is very close to nil.

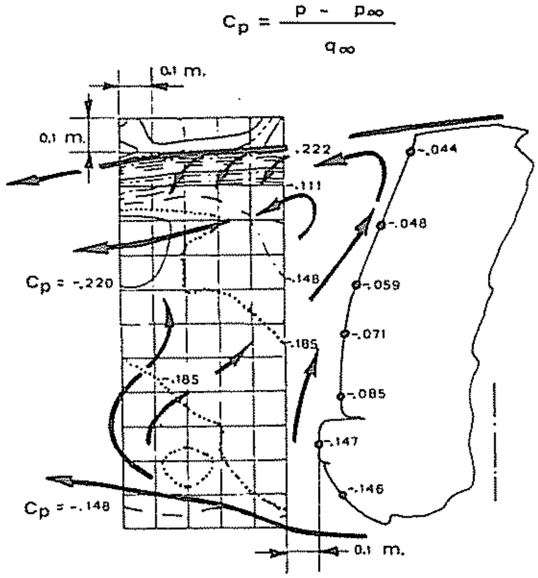


Fig. 23 - Pressures distribution and soiling on the back of the car

Elimination of this phenomenon can be

ement in C_D when "closed" in agreement with Fig. 6.

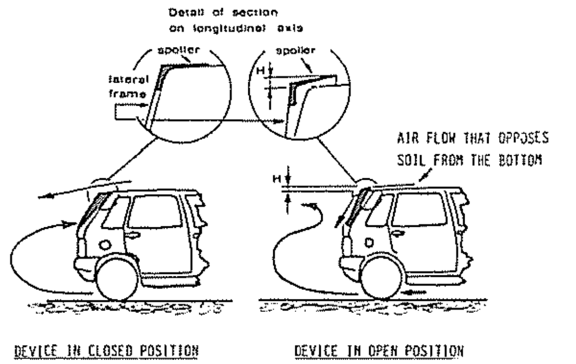


Fig. 24 - Diagram of back-window anti-soiling device

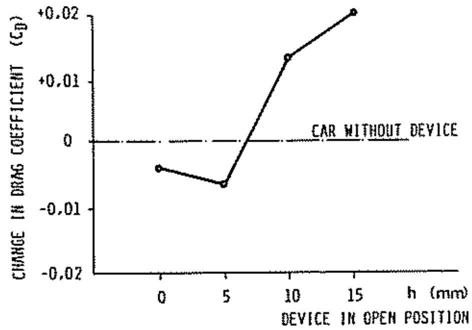
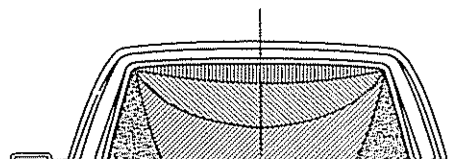


Fig. 25 - Influence of anti-soiling device on car drag

Its effectiveness in terms of "swept" area is shown in Fig. 26.



As said earlier, Fig. 21 shows the narrower wake of the sports version. In addition it also shows, for both cases, a wake with very wide contour at the bottom. The thickness of the tunnel boundary layer is also given in the figure. It will be interesting to assess to what extent it will contribute to determining the contour found. It is also evident, however, that the thickness of the boundary layer is very small. Another feasible assumption therefore is that what has been indicated in Fig. 21 is a disturbance generated already at car front end. In this case any further improvements of the flow field could still be obtained through modifications of the car front end. On the other hand the bottom of the sports car wake is already smaller, the bumper of this version being different from that of the basic UNO (Fig. 9 and Table II).

Another comment concerns the total pressure loss contour. It is evident that the general scatter of this loss is very unbalanced; loss at the car underbody is, infact, higher. It is likely that influence on C_D of the variation of car clearence (Fig. 14) should be related to this unbalance in the general contour of the wake.

The contour (see Fig. 21) corresponding to $C_p = 1$ indicates that the measurement was made next to the end of the near-wake. For the sports version this contour delimits a smaller area, which indicates that the near-wake for this version is shorter. This shows the high sensitivity of this method of analysis.

CONCLUSION

The aerodynamic study carried out during the design phase of the UNO car has made it possible to :

- Define a basic version with different engines and 3 or 5-door body.
- Define an Energy Saving version derived from the basic version with additional components that make it different not only as regards the C_D but also styling.
- Acquire some elements for a possible future sports version characterized by further styling details and by an even lower C_D than the above.
- Define and patent an additional anti-soiling device.

As to the drag coefficient obtained it is possible to conclude that :

- the C_D deviation between production cars is not significant.
- The C_D of the current production UNO car (in its standard and ES versions) in one of the lowest in terms of absolute value (Fig. 19).
  The aerodynamic quality of the corresponding family is certainly at the limit of the area identified by cars presently on the market.
- Car lack of sensitivity to trim attitude angle is another confirmation of good shape.

Finally, as far as the determinations made in the flow field are concerned, it is possible to conclude that this method of analysis is full of promise.

The described aerodynamic performance was obtained through a comprehensive wind tunnel test program of more than 600 hours of testing. The UNO shows that it is also possible to obtain excellent aerodynamic qualities for mass produced subcompact cars, without any adverse effects in other areas of vehicle design. Above all, it also shows that the necessary trade-off leave ample freedom to styling.

NOMENCLATURE

C_D	-	Coefficient of drag
$C_D \cdot S$	(m^2)	Drag area
C_{L-F}	-	Coefficient of lift (front axle)
C_{L-R}	-	Coefficient of lift (rear axle)
c_p	-	Coefficient of pressure
ΔC_D	-	Change in coefficient C_D
D	(mm)	Diameter of circle having area S (Fig. 18)
e	(mm)	Ground clearence
H	(mm)	Car height
h	(mm)	Vertical variation of a dimensions relating to a particular area of the shape (always shown in figure)
L	(mm)	Car overall length
P'_∞	(N/m^2)	Total pressure of the undisturbed flow upstream of car
P'	(N/m^2)	Local total pressure
P_∞	(N/m^2)	Static pressure of the undisturbed flow upstream of car
P	(N/m^2)	Local static pressure
p	(mm)	Car wheelbase
Δp	(mm)	Wheelbase change
q_∞	(N/m^2)	Dynamic pressure of the undisturbed flow upstream of car

S	(m^2)	Car frontal area (shape projection on a plane perpendicular to the longitudinal axis)
s	(mm)	Longitudinal variation of a dimension relating to a particular area of the shape (always shown in figure)
t	(mm)	Window inset
α	(°)	Angle of attitude
β	(°)	Angle of yaw
γ	(°)	Roof upper slant angle with respect to a horizontal line
$\emptyset$	(°)	Rear shape angle with respect to a vertical line.

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