

Az áramlástan tervezés célja:

- a teljesítmény és
- üzemeltetési jellemzők valamint
- a közlekedésbiztonság és
- komfort javítása.

Üzemanyagfogyasztás, oldalszélérzékenység, menetstabilitás, szélzaj, karosszéria szennyeződés, a motor és a fékek hűtése, utastér fűtés és szellőzés az áramlási viszonyok függvénye:

- karosszéria körüláramlása,
- átáramlás a karosszérián,
- áramlás részegységekben és azok körül.

Áramlástan jelentősége

közúti járműveknél

repülőgépeknél

Közös:

törekvés kis áramlási ellenállásra és a haladási irányra merőleges síkba eső erők és nyomatékok összehangolása

Különbségek:

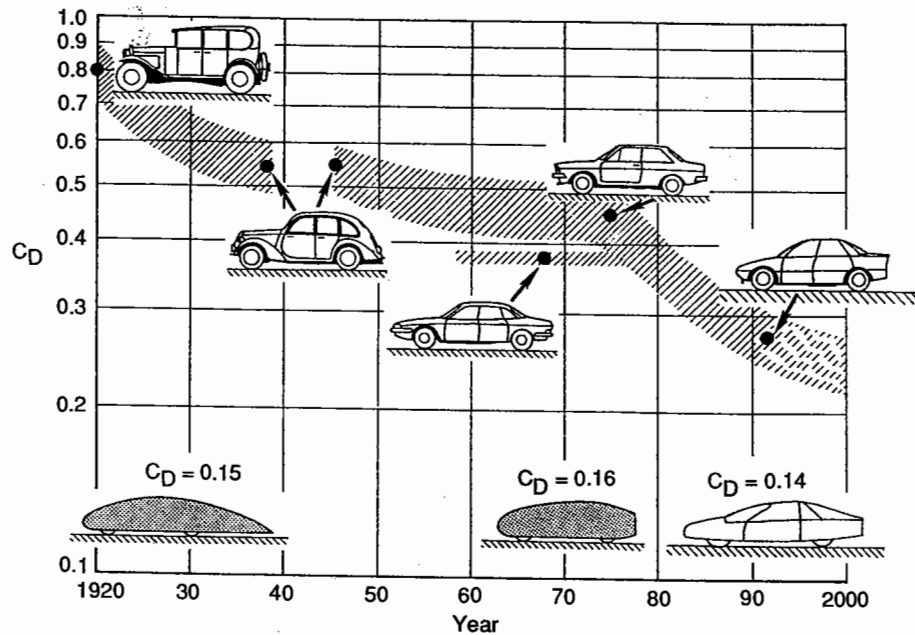
- | | |
|--|--|
| - funkcionális, technológiai, stilisztikai, közlekedésbiztonsági szempontok dominálnak | - az áramlástan szerepe alapvető |
| - jelentős részben levált áramlás | - nem levált áramlás |
| - talaj hatás | - nincs talaj hatás |
| - 3D áramlás | - jeletős részben 2D áramlás |
| - a számítási módszerek használhatósága korlátozott | - a számítási módszerek jól használhatók |

(2)

1.6

1.3/1

A fejlődés legjobban az ellenállástényező változásával jellemezhető:



Áramlástanai fejlesztési koncepciók (történelmi áttekintés):

I. 1900-1920 más területek formáinak átvétele

- 1/ 1899 Jenatzy villanyautó 106km/ó, torpedó alak,
- 2/ 1913 Alfa Romeo, léghajó alak
- 3/ 1913 Audi Alpensiegler, csónak alak

II. 1920-1970 "áramvonalazás", repülés módszereinek átvétele

Járműáramlástanai fejlesztések az I Világháború után Németországban:

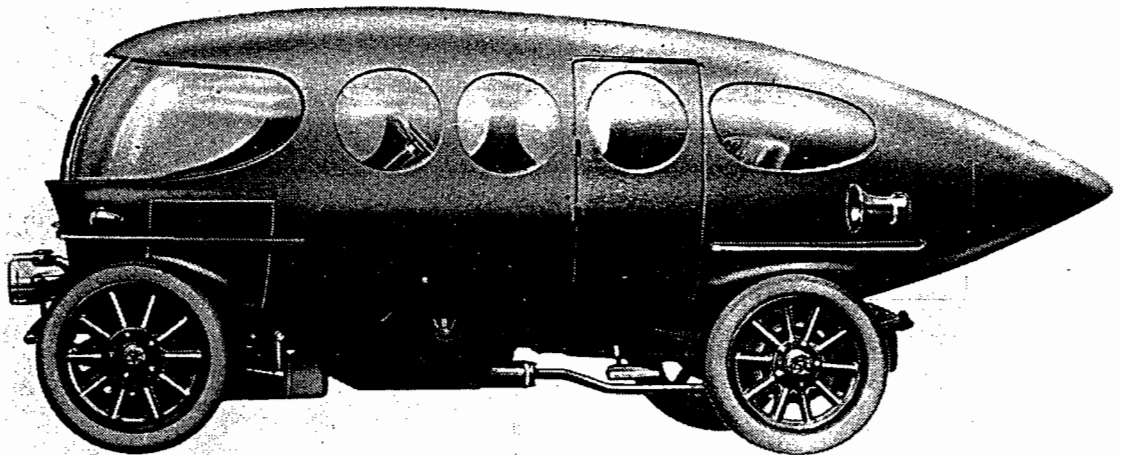
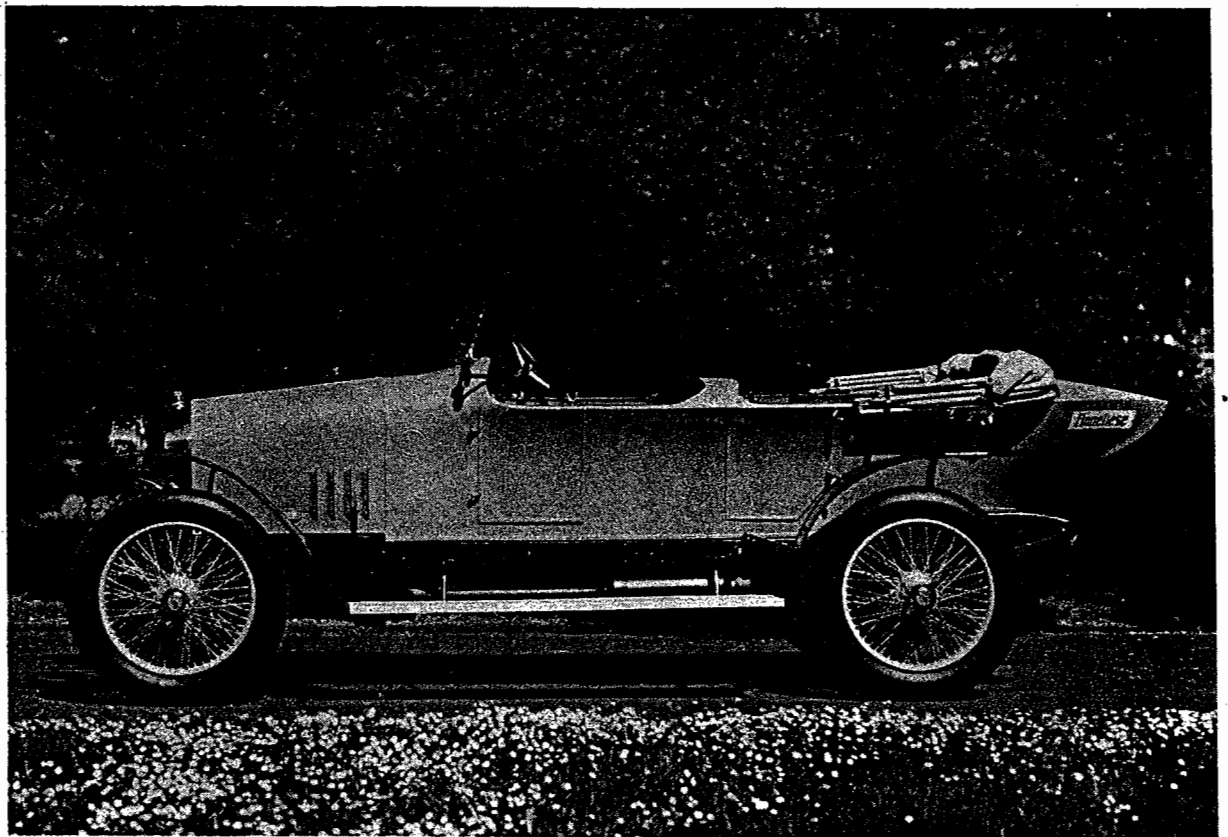
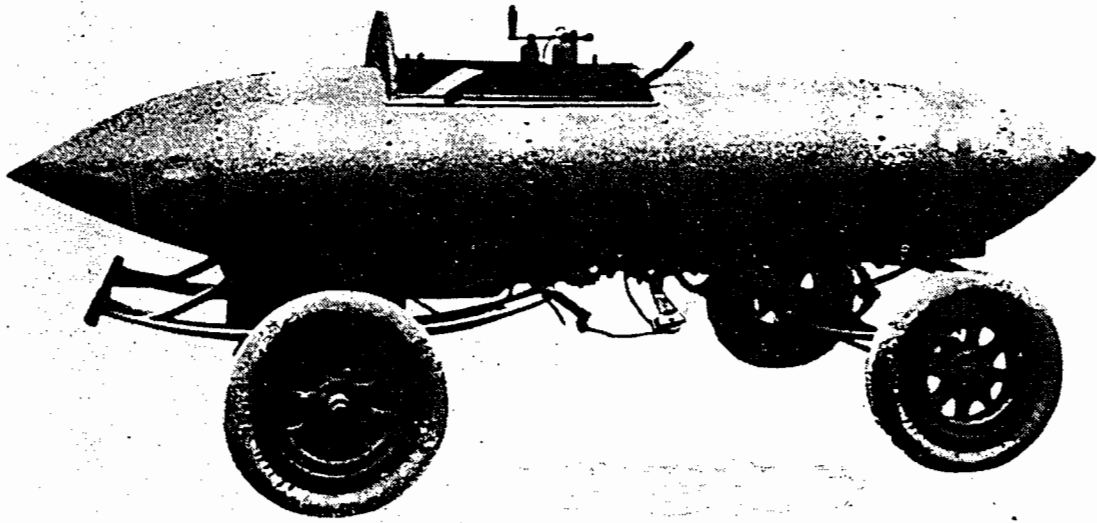
- 4/ 1923 Rumpler Taube $c_e = 0.28$
 - 5/ Járay Pál (Zeppelin léghajónál szerzett tapasztalatok), Klemperer 1922-től talaj hatás vizsgálata
 - 9/ Járay autók szárnyprofil, léghajó alakból összeállítva
 - 6/ Ellenállástényező adatok
 - 8/ 1940 Ledvinka Tatra
 - 7/ 1935-40 Járay gondolata alaján készült autók
- Később Citroen, Porsche
- Túl hosszú karosszériák, 1932-33 Lay USA,
- 10/ 1934 Kamm K-Heck $c_e = 0.37$
 - 1934 Reid USA ideális autó alak $c_e = 0.15$
 - 1930-tól Andreau Peugeot c_e 1938 Thunderbolt 665 km/h
 - 1932 Chrysler Airflow $c_e = 0.51 \Rightarrow 0.244$

3

1.8.

I/3

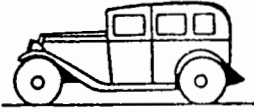
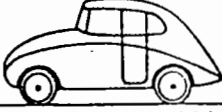

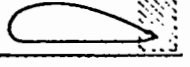
1.3/2



4

13/3

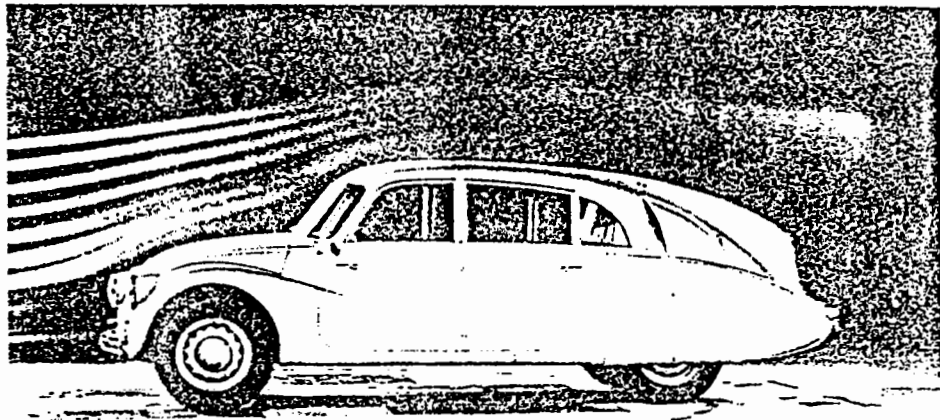
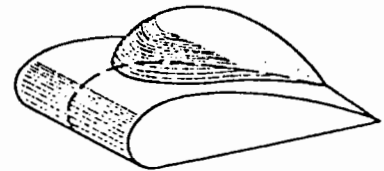
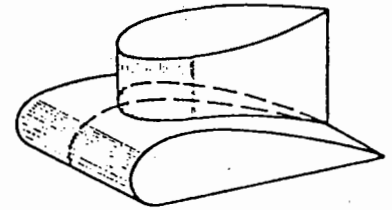
1.9.1.

| | $A_{1:1} [m^2]$ | c_w |
|---|----------------------|-------|
|  | 2,99 | 0,64 |
|  großer Jaray - Wagen | 2,86 | 0,30 |
|  kleiner Jaray - Wagen | 1,87 | 0,29 |
|  Halbkörper ohne Räder | 2,99 | |
| | vorn scharfkantig | 0,13 |
| | vorn gerundet | 0,09 |
| Halbkörper mit Rädern | | 0,15 |

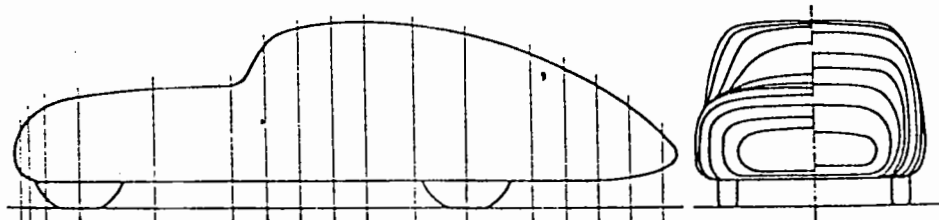
Widerstandsmessungen
von W. Klemperer, 1922, an Model-
len im Maßstab 1 : 10, Kühlluftfüh-
rung geschlossen

Kombinationsformen
nach P. Jaray. Oben eine aus zwei
Profilen zusammengesetzte Form;
untendie ein halber Rotationskör-
per als Aufbau

▽



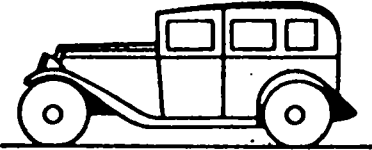
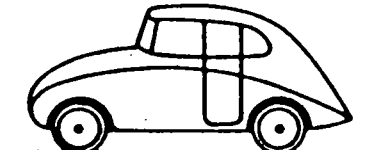


Tatra Typ 87, 1940, 3-Liter-8-Zylinder; gestaltet von H. Ledwinka, Aufnahme
R. Buchheim, Volkswagenwerk AG, 1979



Der Lange-Wagen; Länge l zu Höhe h , $l/h = 3,52$; $c_w = 0,14 \div 0,16$; völlig
glattes Modell

1.9.2

1.3/4

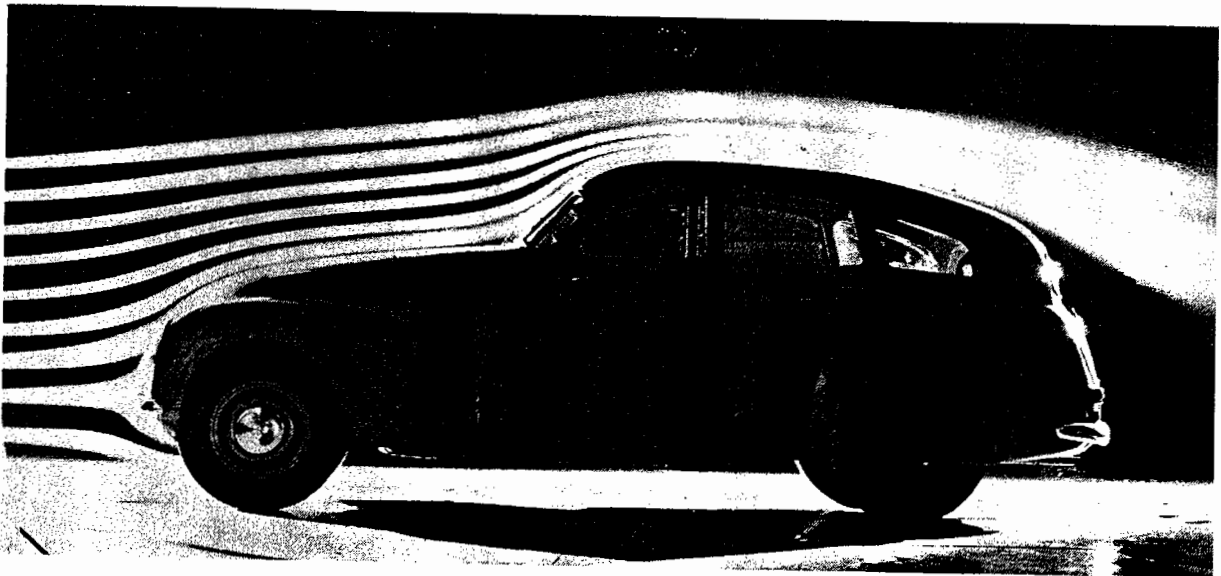
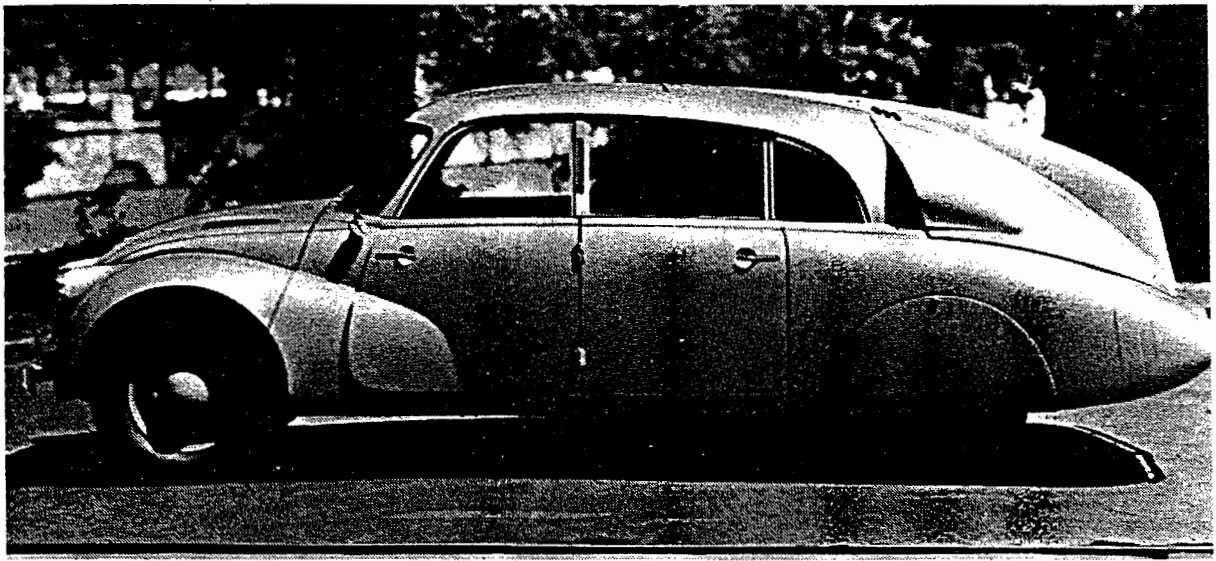
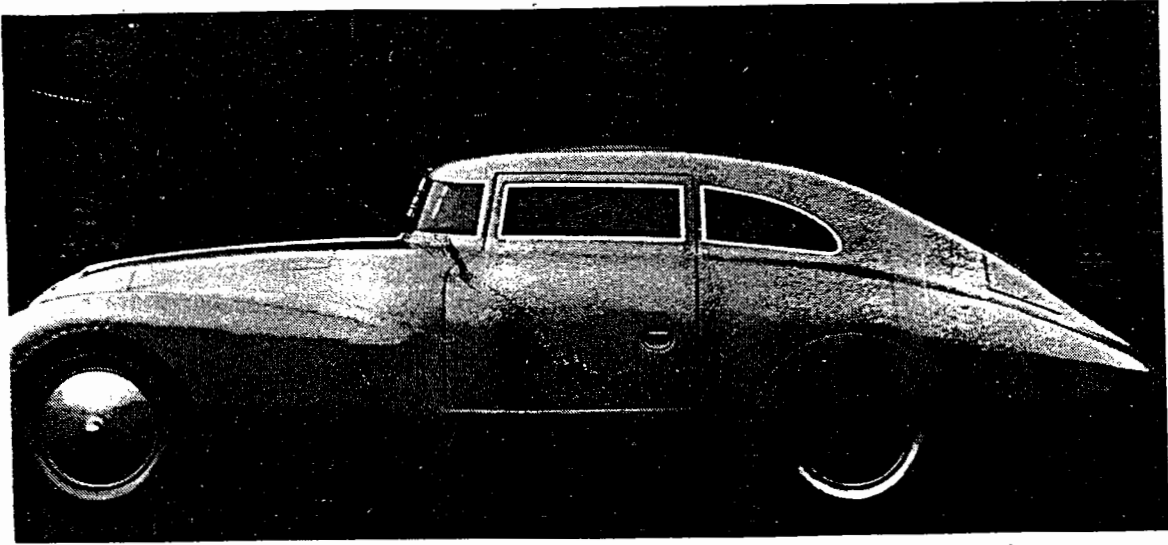
| | $A_{1:1}$ [m ²] | c_D |
|--|-----------------------------|-------|
|  | 2.99 | 0.64 |
|  Large Jaray cars | 2.86 | 0.30 |
|  Small Jaray car | 1.87 | 0.29 |
|  Half-body without wheels | 2.99 | |
| | | 0.15 |
| | front with sharp edges | 0.13 |
| Half-body with wheels | front edges rounded | 0.09 |

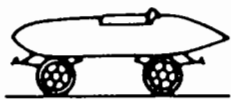
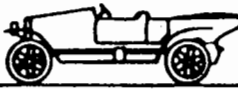
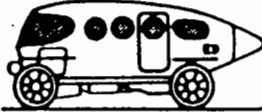




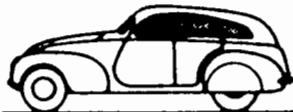







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1.10

I/5

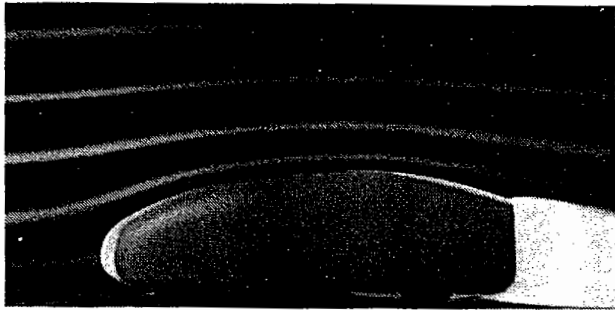
1.3/5



| | | | | |
|--------------------|---------------------|--|--|--|
| Basic shapes | 1900 to 1930 |  Torpedo |  Boat tail |  Air ship |
| Streamlined cars | 1921 to 1923 |  Rumpler | |  Bugatti |
| | 1922 to 1939 |   Jaray | | |
| | 1934 to 1939 |  Kamm |  Schlör | |
| | Since 1955 |  Citroen |  NSU-Ro 80 | |
| | Detail optimization | Since 1974 |  VW-Scirocco I |  VW-Golf I |
| Shape optimization | Since 1983 |  Audi 100 III |  Ford Sierra | |

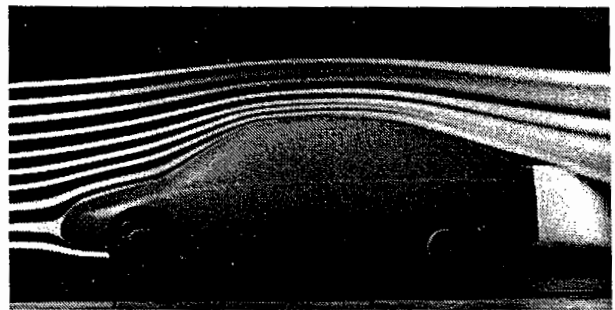
7

1.57
I/6
1.3/6



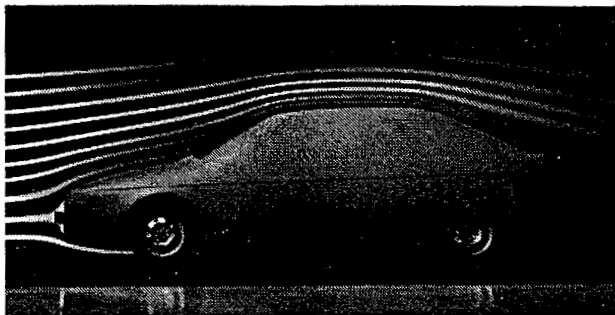
basic body

$c_D = 0.16$



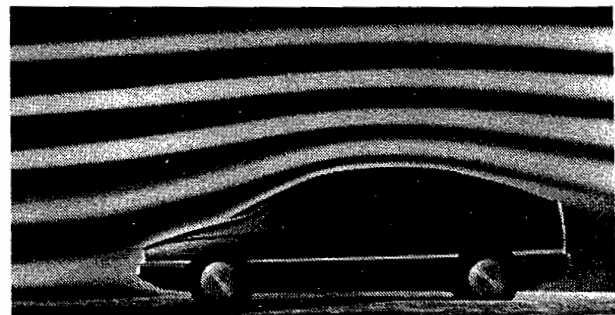
basic shape

$c_D = 0.18$



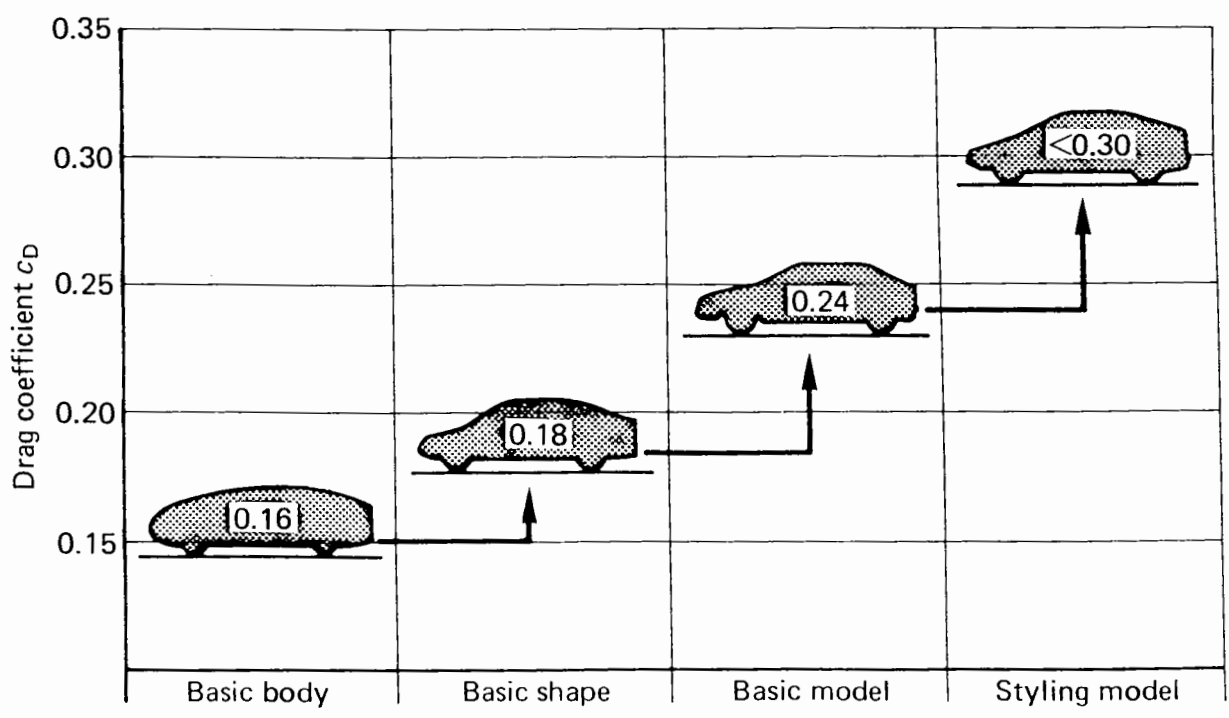
basic model

$c_D = 0.24$



styling model

$c_D < 0.30$



$$F_e = \rho/2 v^2 A c_e$$

$$F_g = m g f_R(v)$$

$$P = (F_e + F_g) v$$

Legyen $\rho = 1.2 \text{ kg/m}^3$, $A = 1.7 \text{ m}^2$,
 $m = 1000 \text{ kg}$, $f_R = 0.015 \Rightarrow 0.03$

$$c_e = 0.5 \text{ és } 0.3$$

| v (m/s) | c_e | $F_e v$ (kW) | $F_g v$ (kW) | P (kW) | $\Delta P/P$ |
|--------------|-------|-----------------|-----------------|----------|--------------|
| 20 | 0.5 | 4 (57%) | 3 | 7 | |
| | 0.3 | 2.4 (44%) | 3 | 5.4 | -23% |
| 40 | 0.5 | 32 (82%) | 7.2 | 39.2 | |
| | 0.3 | 19.2 (73) | 7.2 | 26.4 | -33% |
| 60 | 0.5 | 108 (86%) | 18 | 126 | |
| | 0.3 | 64.8 (78%) | 18 | 82.8 | -34% |

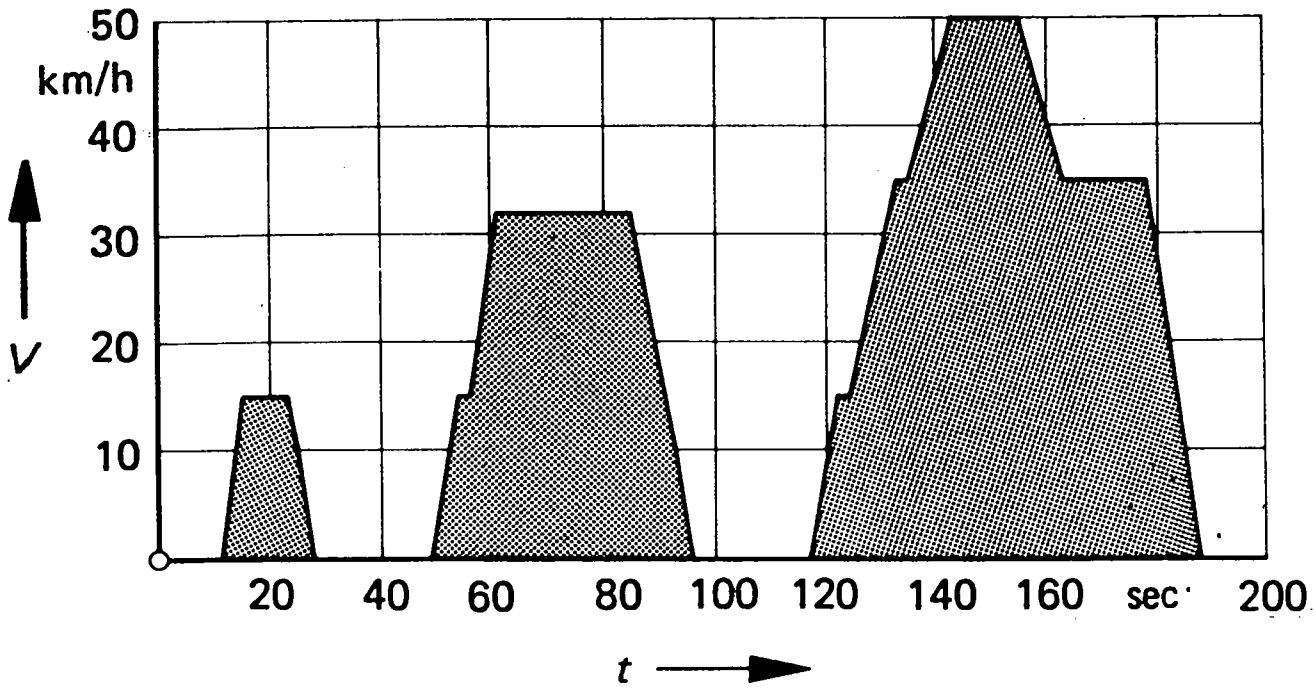
$$126 \text{ kW } c_e = 0.5 \Rightarrow 0.3 \quad v = 60 \text{ m/s} \Rightarrow 70 \text{ m/s}$$

European Urban Cycle (ECE)

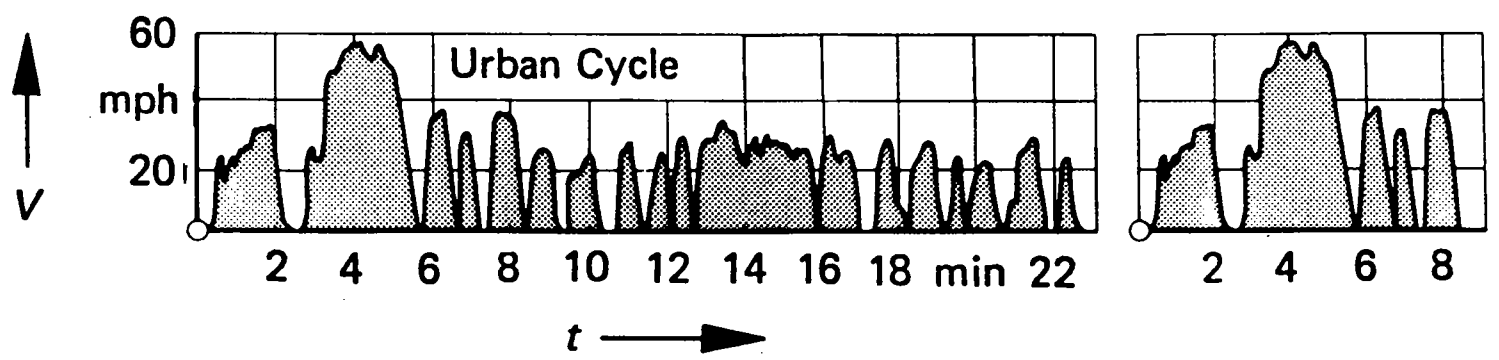
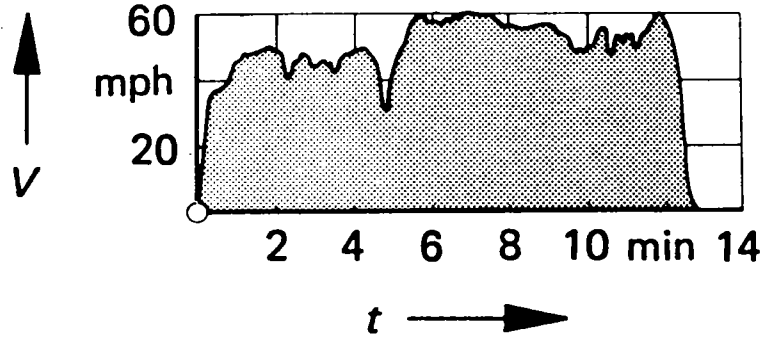
9

1.4.1

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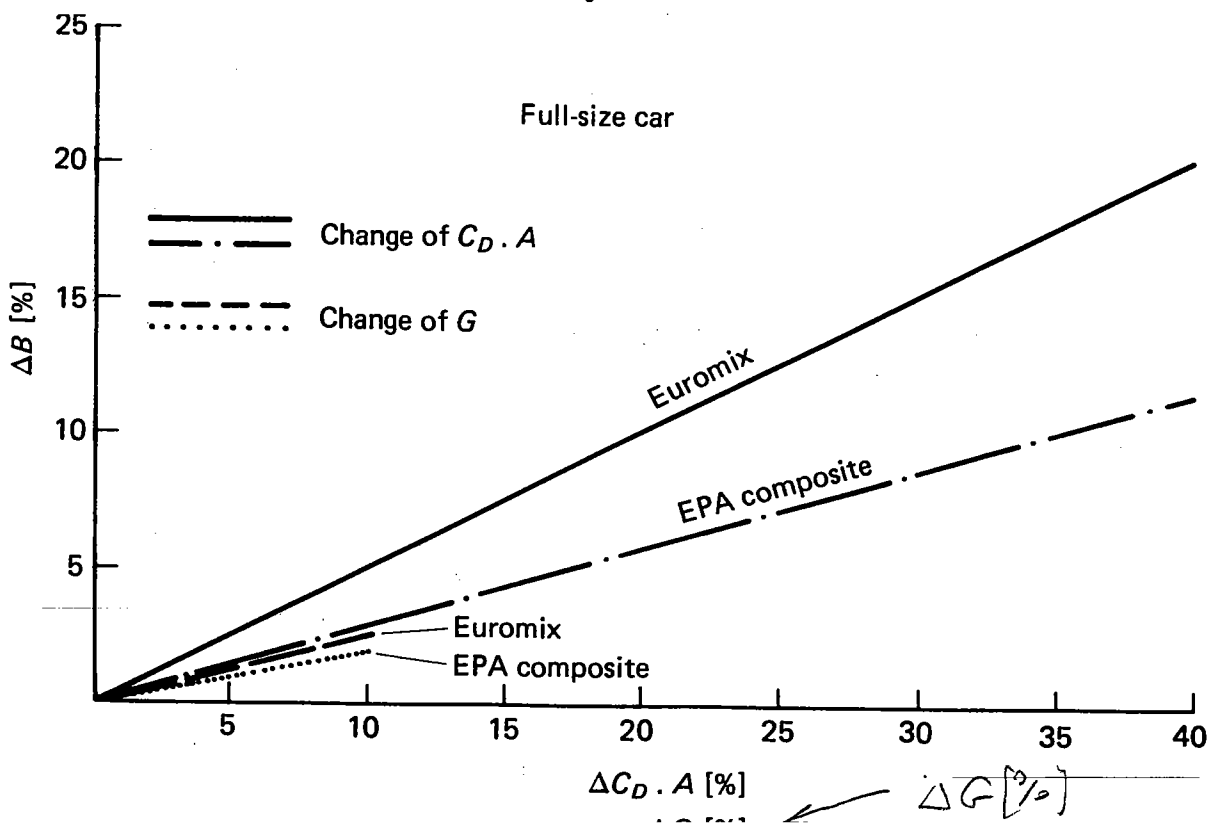
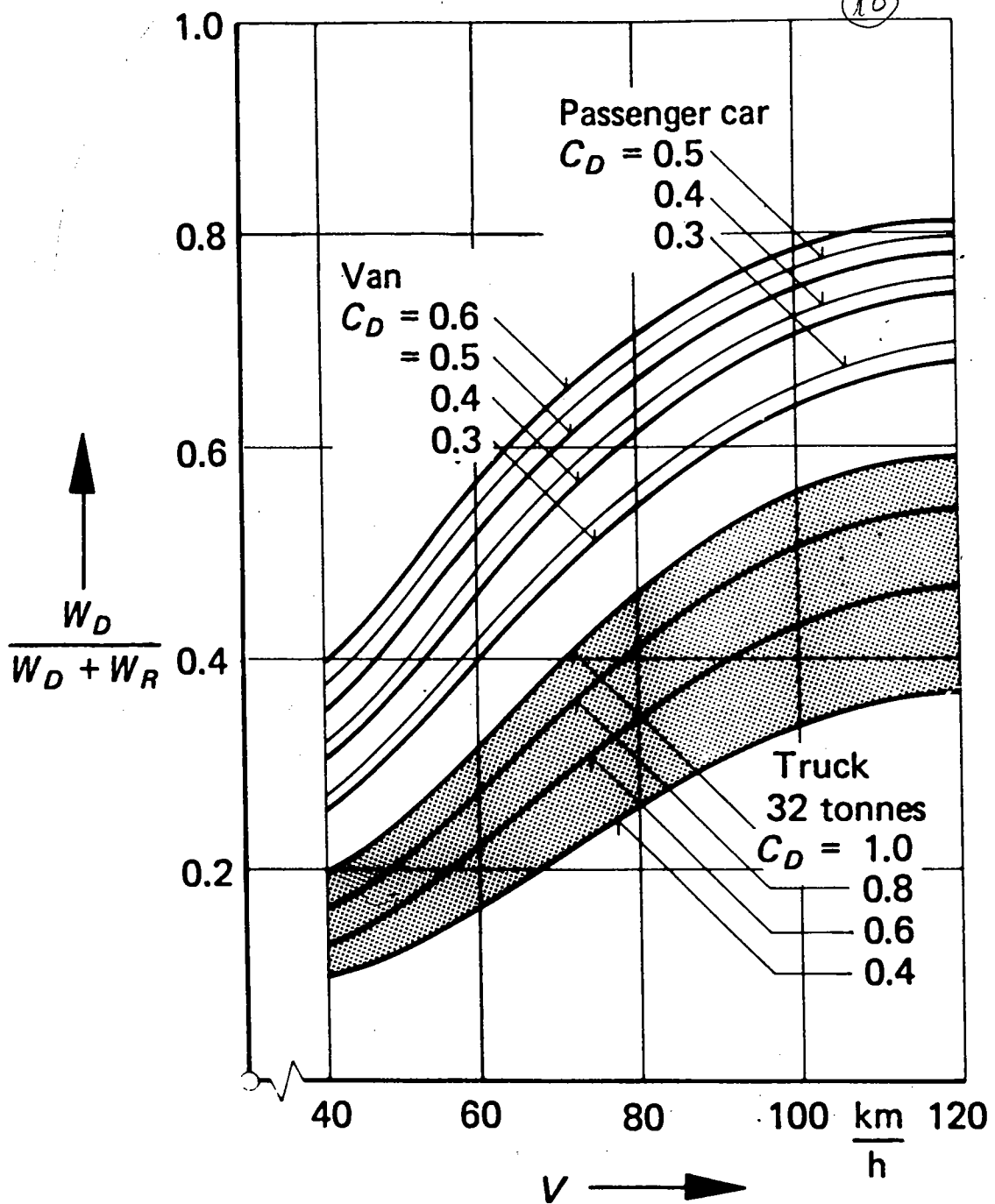


EPA Highway Cycle



$$B_{\text{Euromix}} = \frac{1}{3} (B_{\text{ECE}} + B_{90} + B_{120})$$

$$B_{\text{EPA composit}} = 0.55 B_{\text{urb}} + 0.45 B_{\text{high}}$$



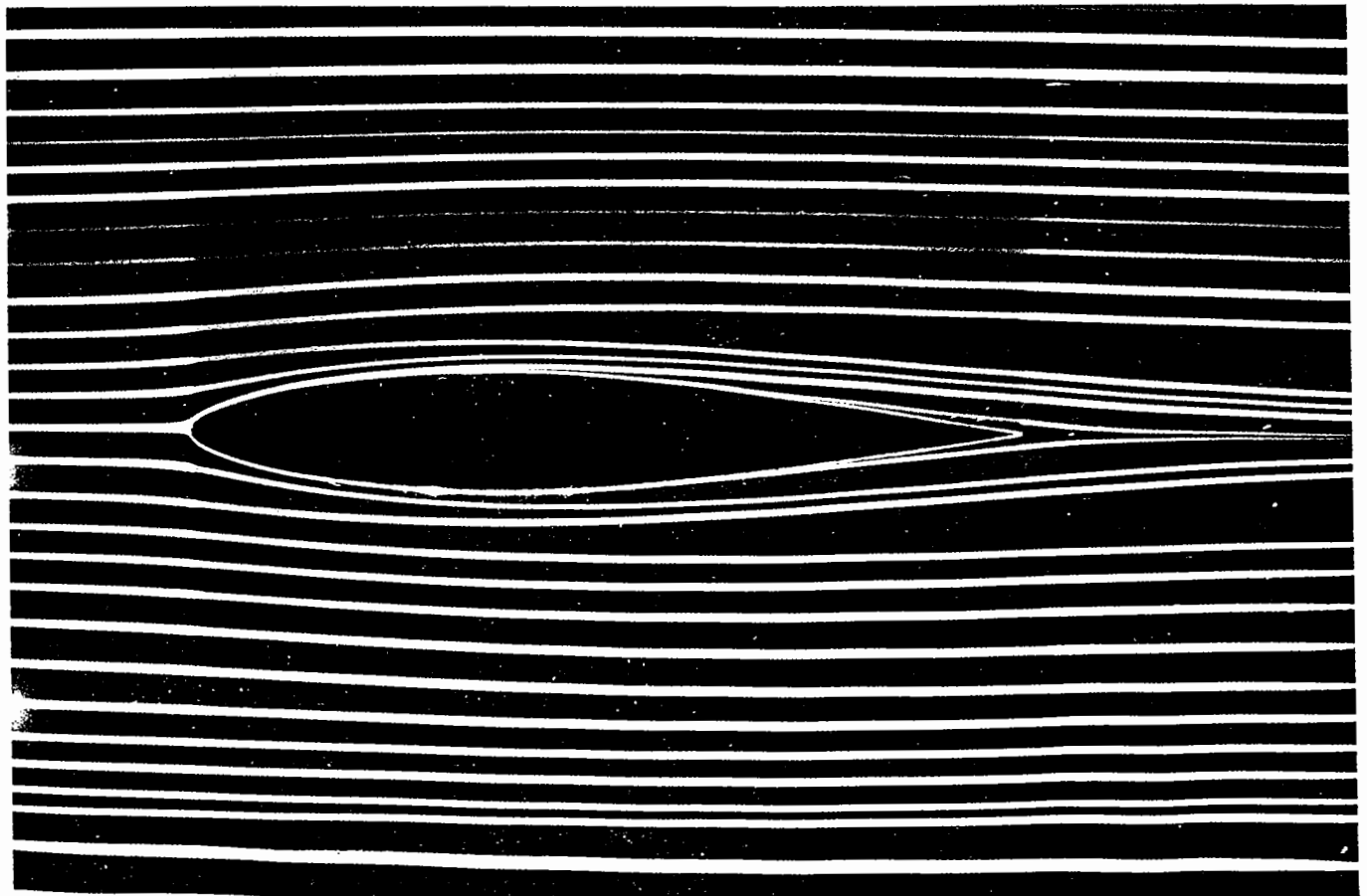
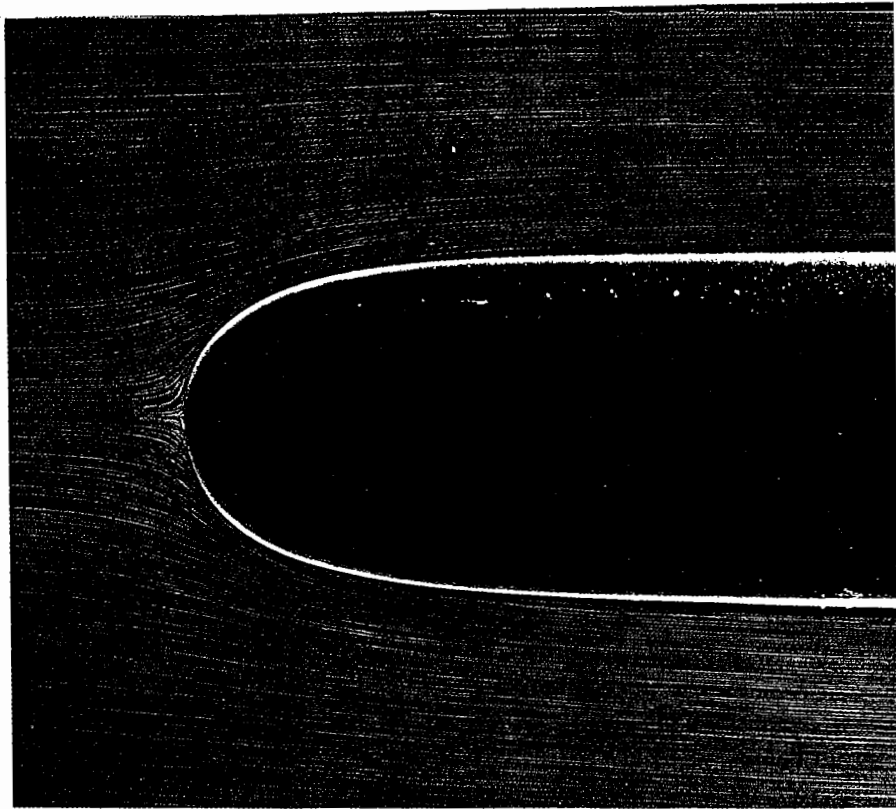
(15)

2.4/11

II/2

(23.1)

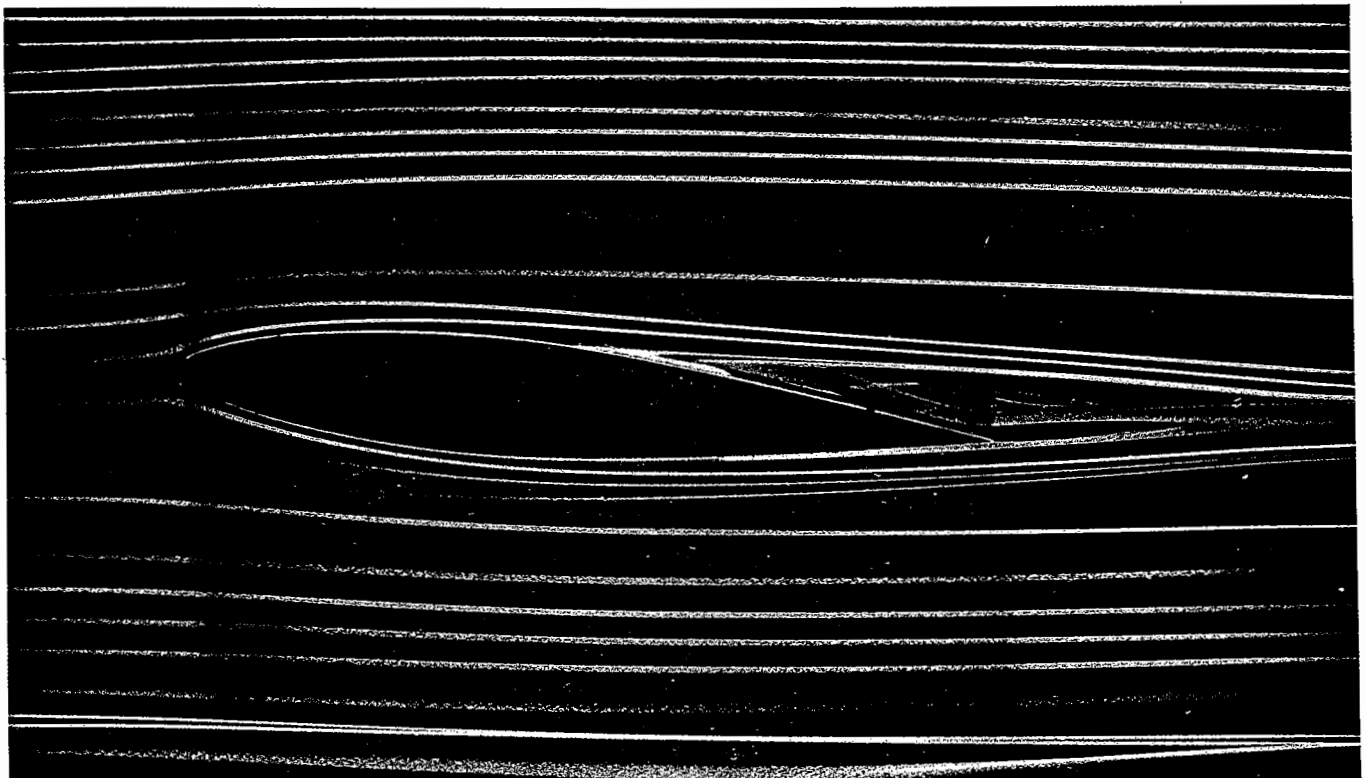
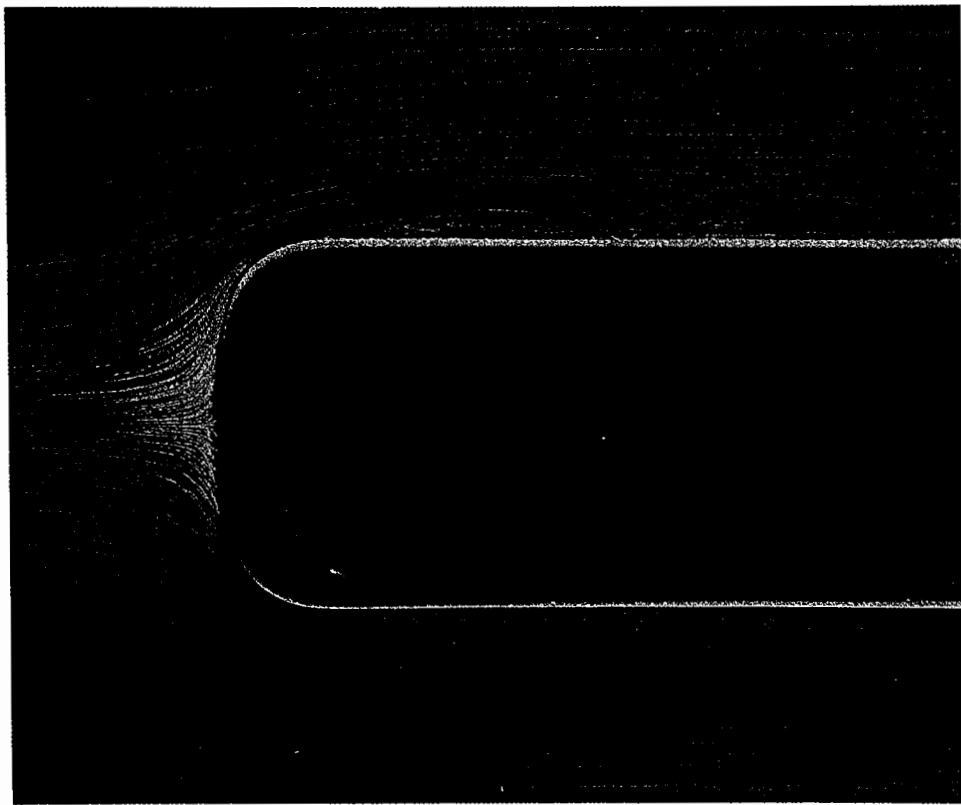
22. Axisymmetric flow past a Rankine ogive. This is the body of revolution that would be produced by a point potential source in a uniform stream—the axisymmetric counterpart of the plane half-body of figure 2. Its shape is so gentle that at zero incidence and a Reynolds number of 6000 based on diameter the flow remains attached and laminar. Streamlines are made visible by tiny air bubbles in water, illuminated by a sheet of light in the mid-plane. ONERA photograph, Werlé 1962



23. Symmetric plane flow past an airfoil. An NACA 64A015 profile is at zero incidence in a water tunnel. The Reynolds number is 7000 based on the chordlength. Streamlines are shown by colored fluid introduced up-

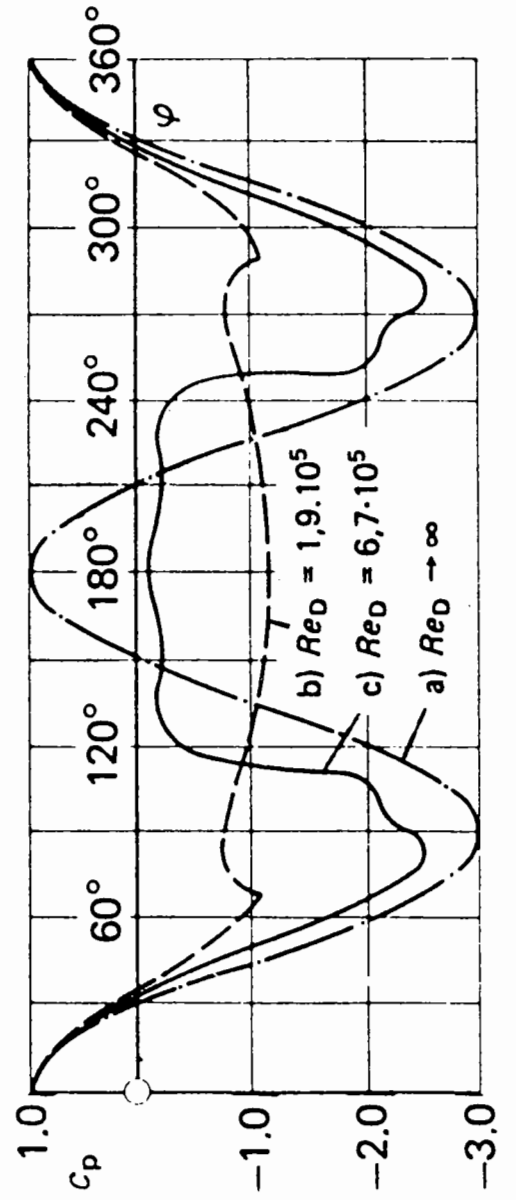
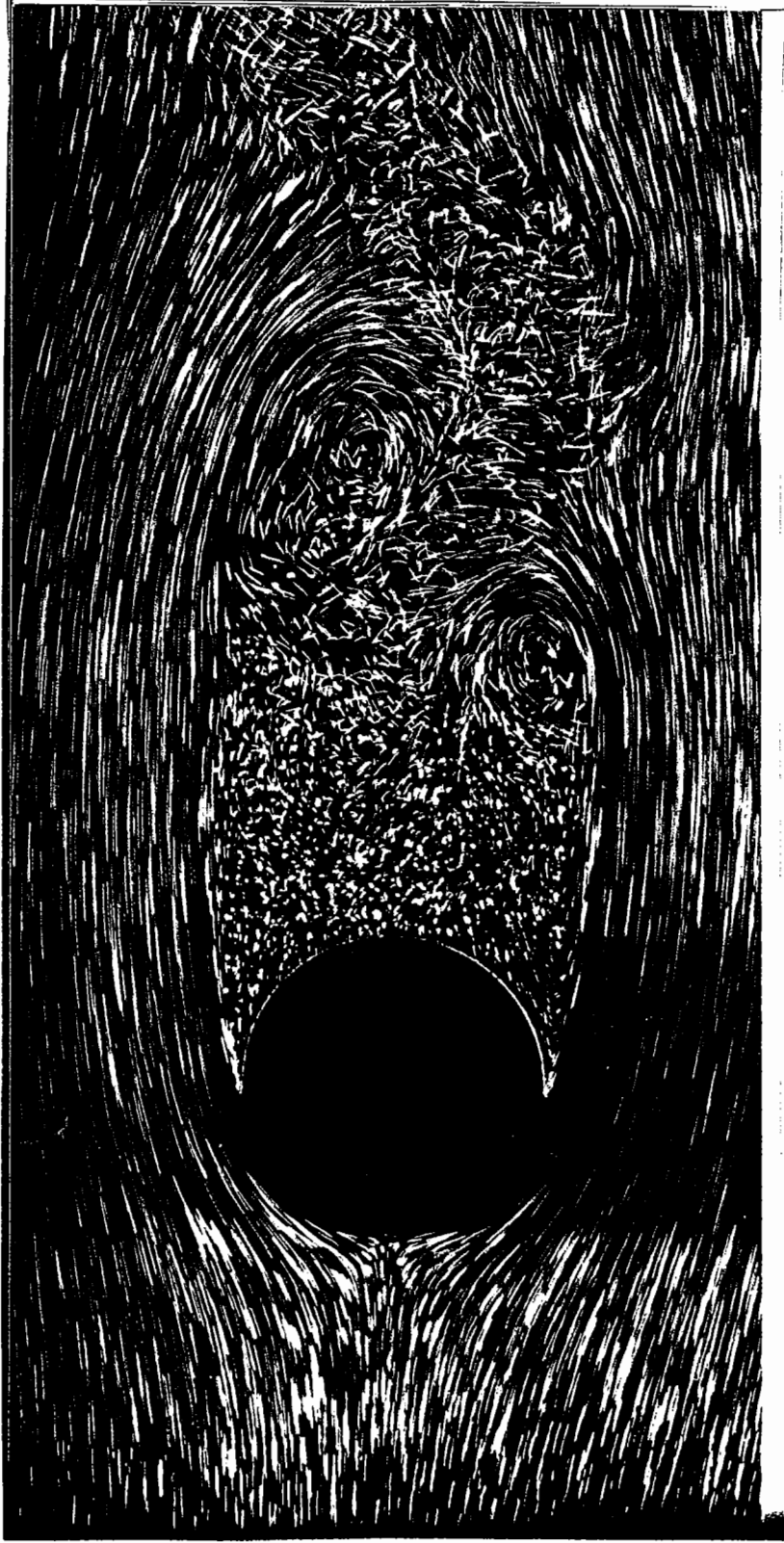
stream. The flow is evidently laminar and appears to be unseparated, though one might anticipate a small separated region near the trailing edge. ONERA photograph, Werlé 1974

33. Boundary-layer separation on a body of revolution. This shape is sufficiently blunter than the Rankine ogive of figure 22 that, at the same Reynolds number of 6000 based on diameter and zero incidence, the laminar boundary layer separates. It then quickly becomes turbulent and reattaches to the surface, enclosing a short thin region of recirculating flow. Visualization is by air bubbles in water. *ONERA photograph, Werlé 1962*



34. Boundary-layer separation on an inclined airfoil. When the NACA 64A015 airfoil of figure 23 is raised to 5° incidence the laminar boundary layer separates from the rear half of the upper surface. The flow remains attached

to the lower surface, from which it leaves tangentially at the trailing edge. Streamlines are shown by colored fluid filaments in water. *ONERA photograph, Werlé 1974*



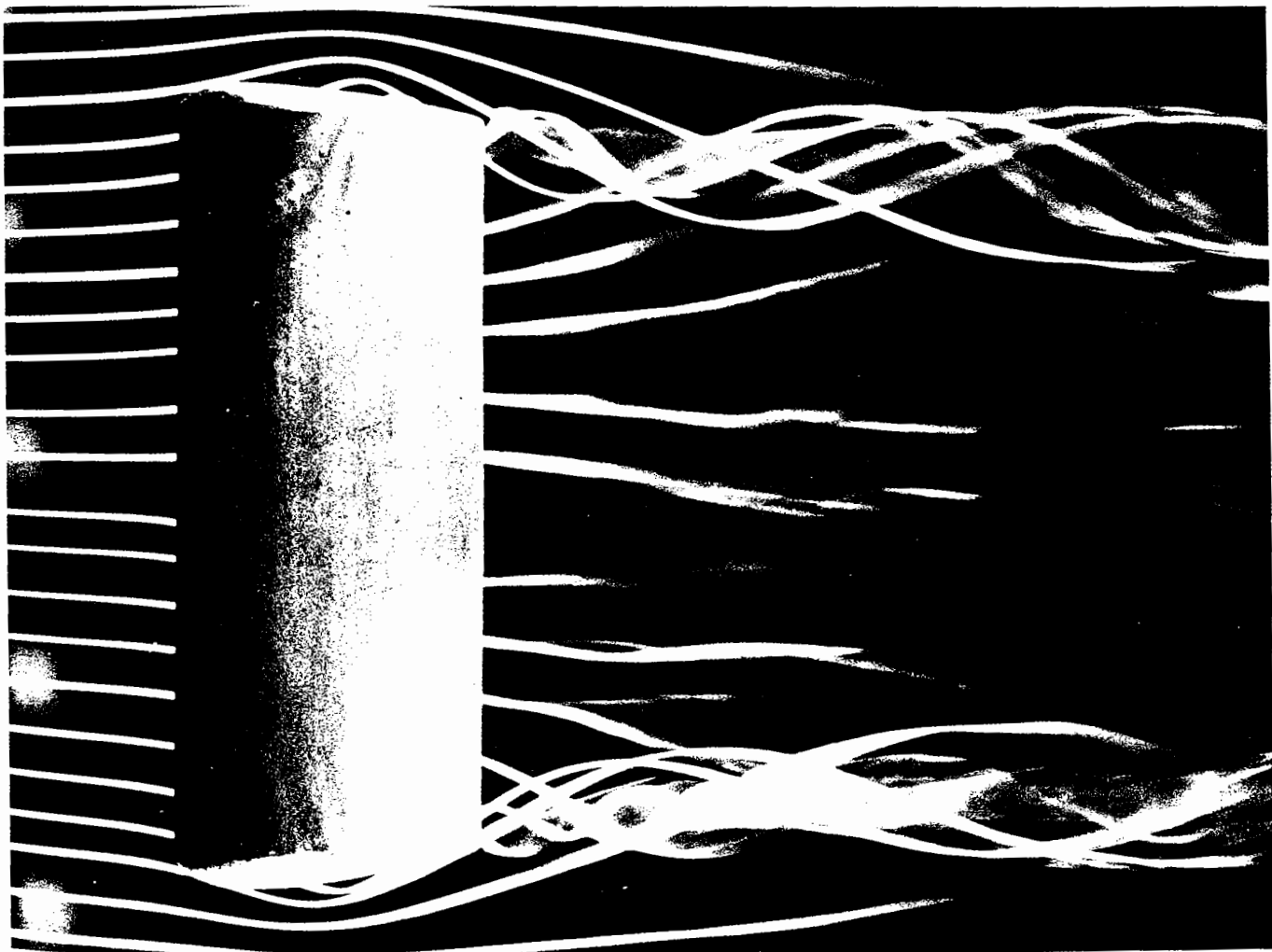
2.6/2

2.6



85. Trailing vortex from the tip of a rectangular wing. At 12.5° angle of attack the vortex is seen to separate well ahead of the trailing edge. The wing has an NACA 0012 profile and aspect ratio 4. At this Reynolds number of

10,000 the wake is laminar, in contrast to the opposite page. Visualization is by colored fluid in water. ONERA photograph, Werlé 1974



86. Trailing vortices from a rectangular wing. Suction is applied so that at 24° angle of attack the flow remains attached over the entire wing surface, in contrast to the preceding photograph. The centers of the vortex cores there-

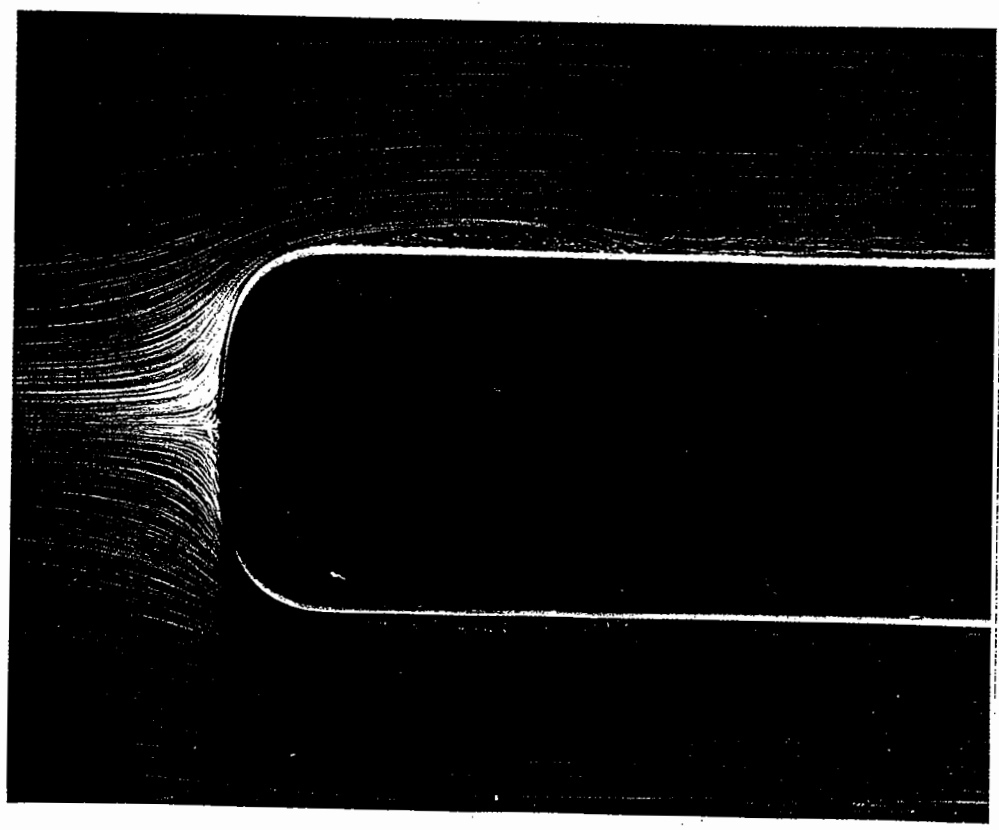
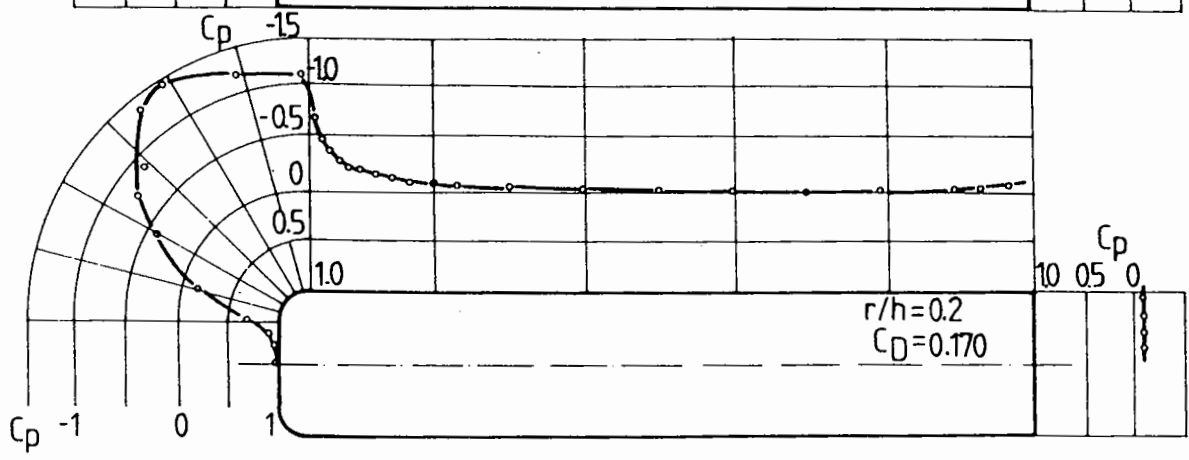
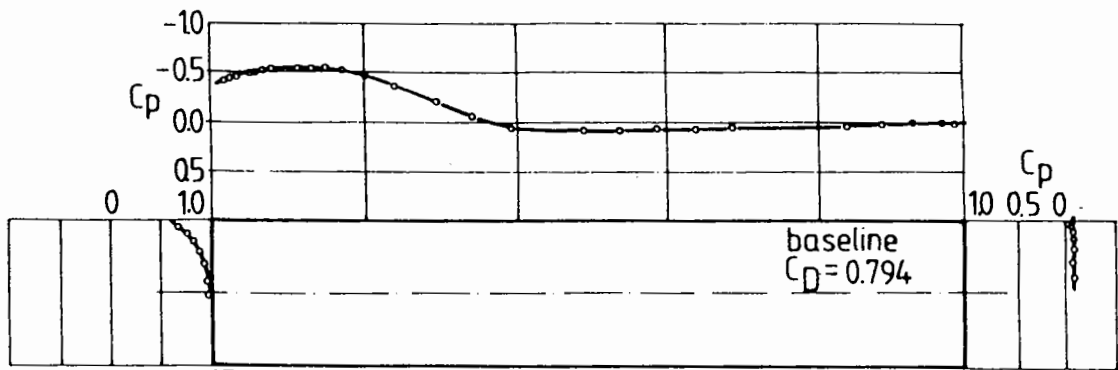
fore spring from the trailing edge at the tips. The model is made of perforated metal covered with blotting paper, and tested in a smoke tunnel at Reynolds number 100,000. Head 1982

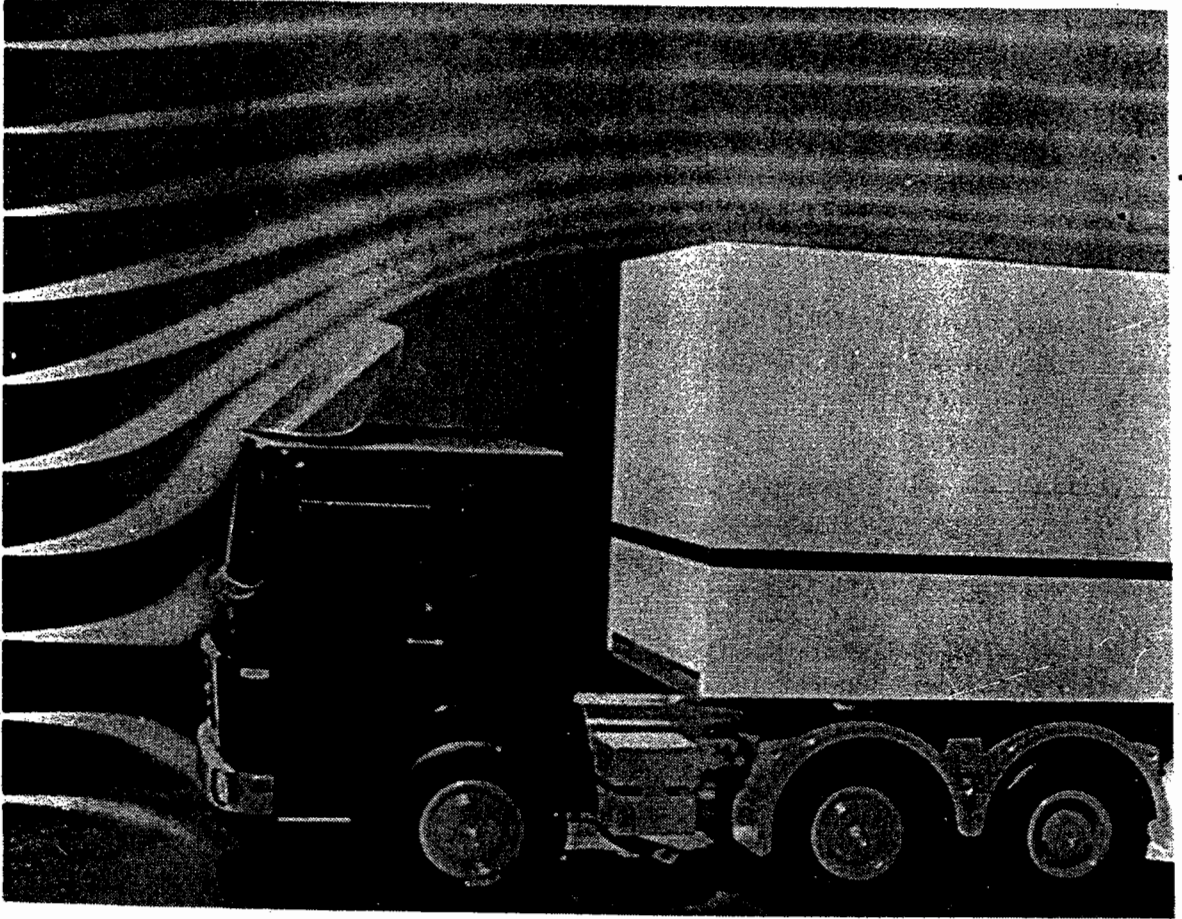
(17)

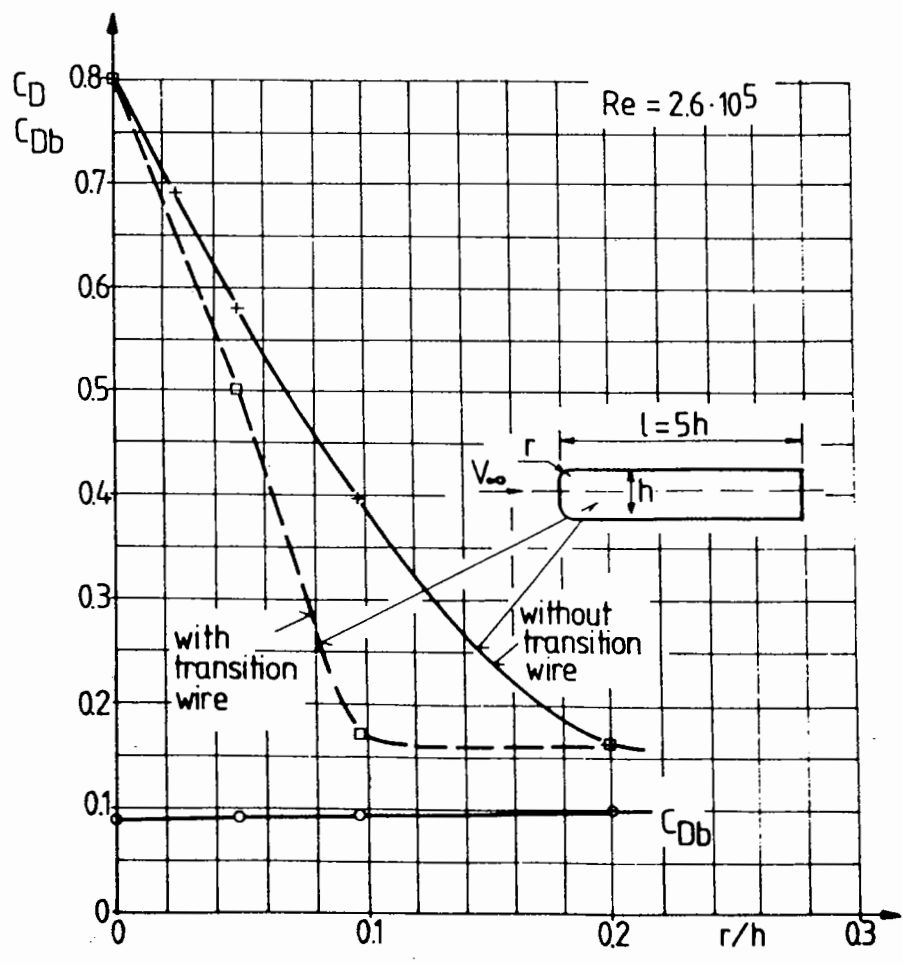
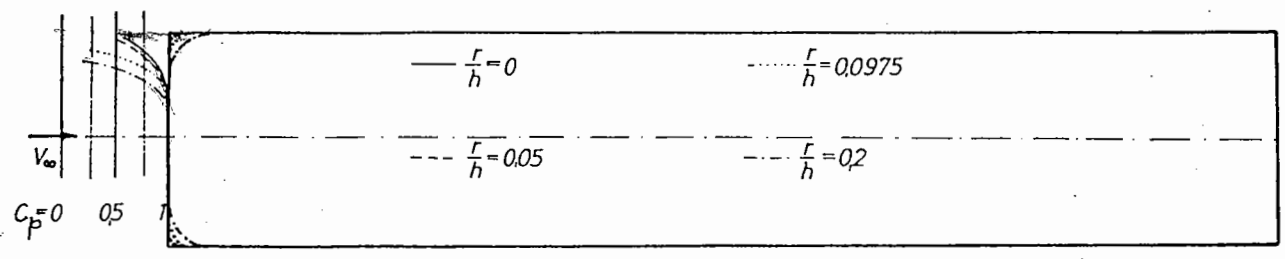
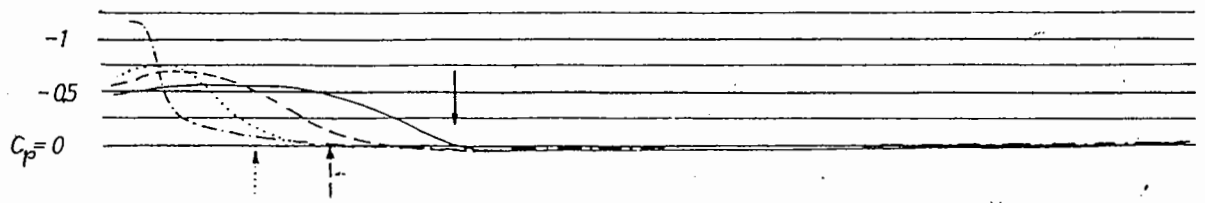
2.5/2

2.7

IV/5

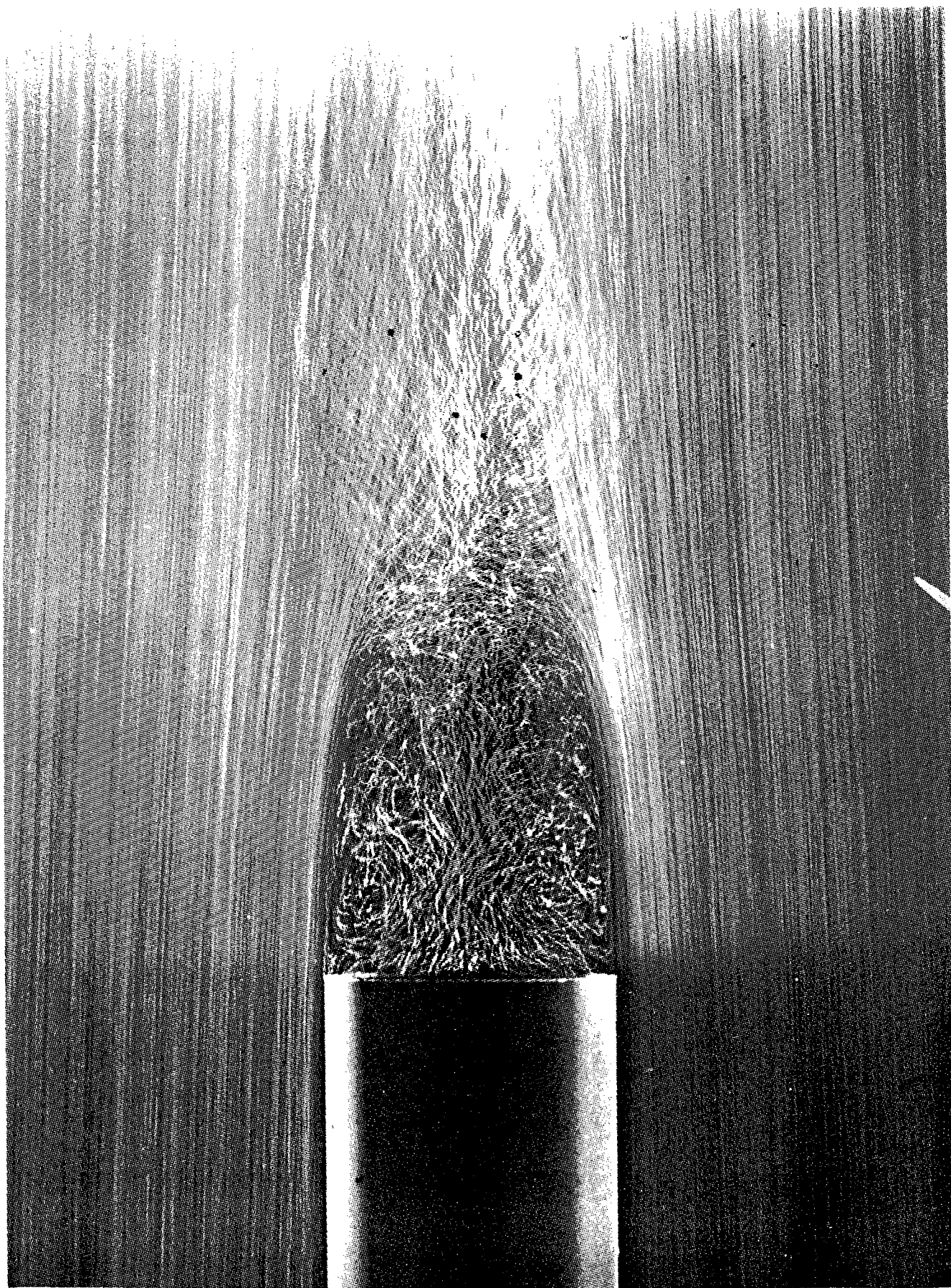






2.7/1

2.9³
III/₃

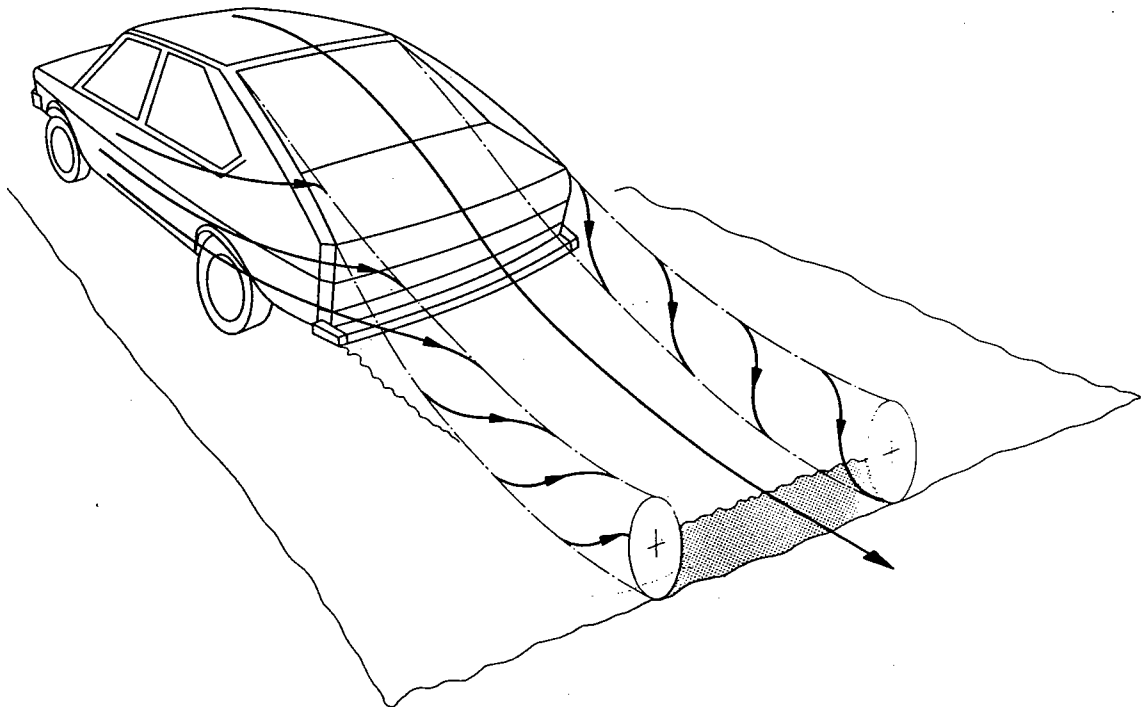
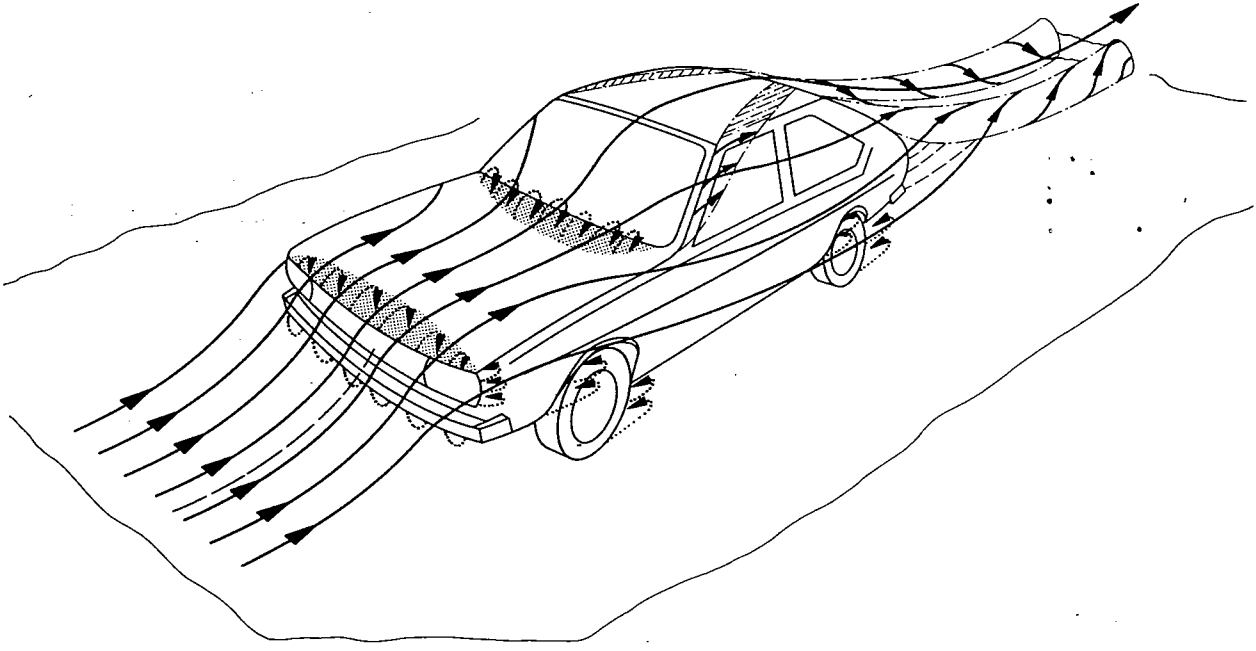


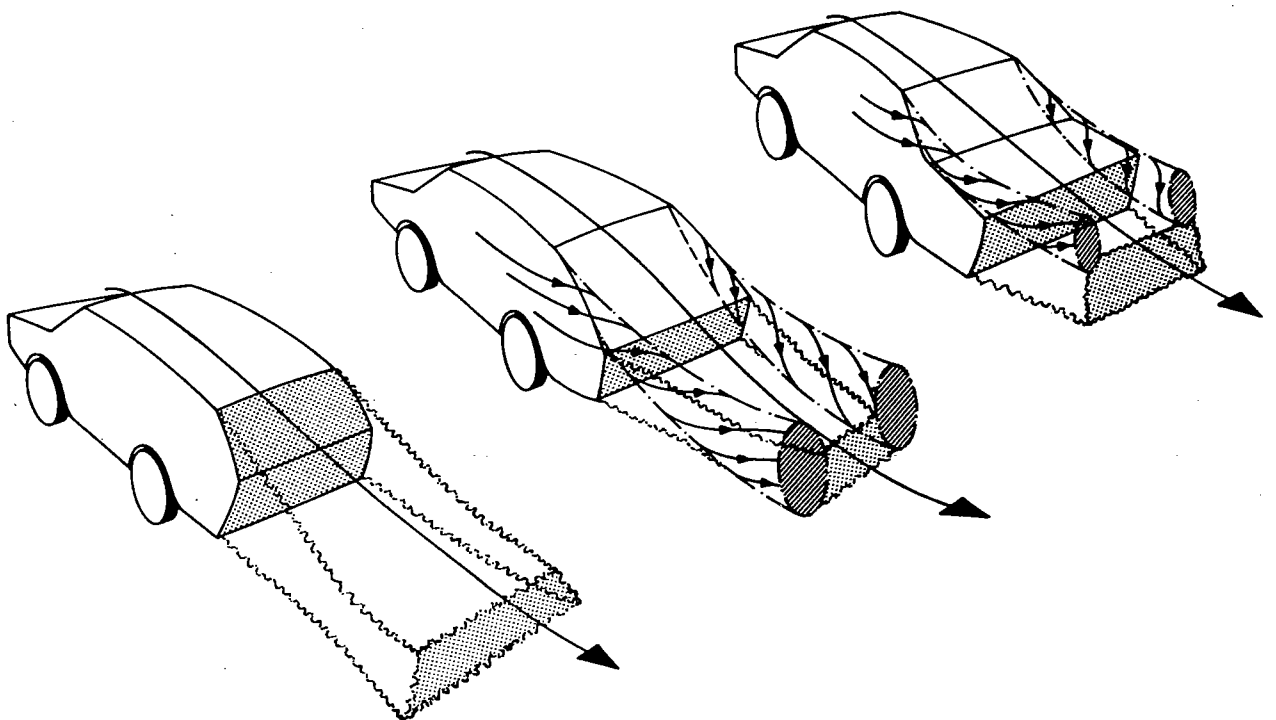
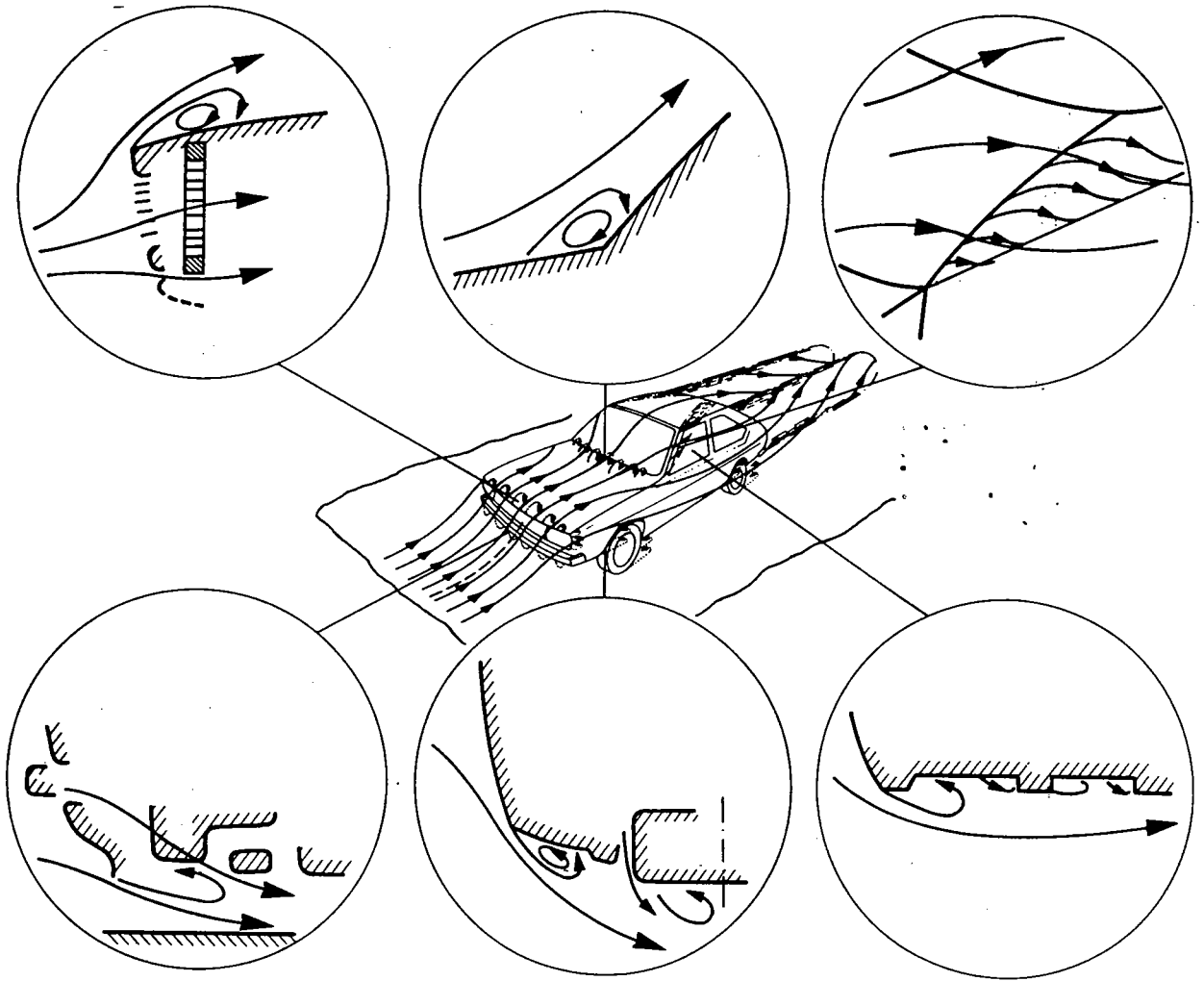
4 -

3.1/1

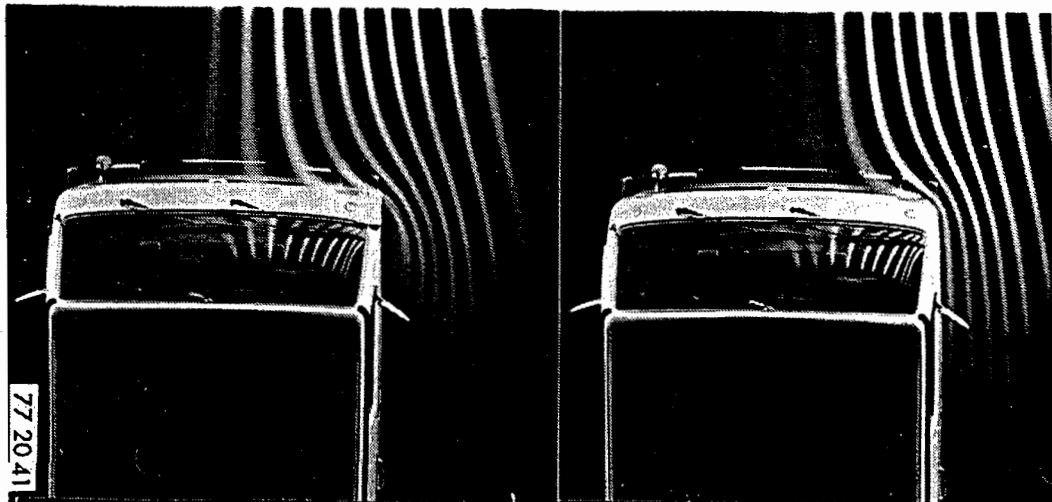
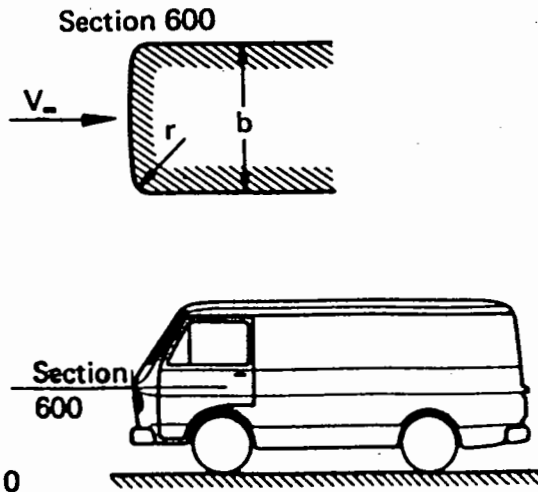
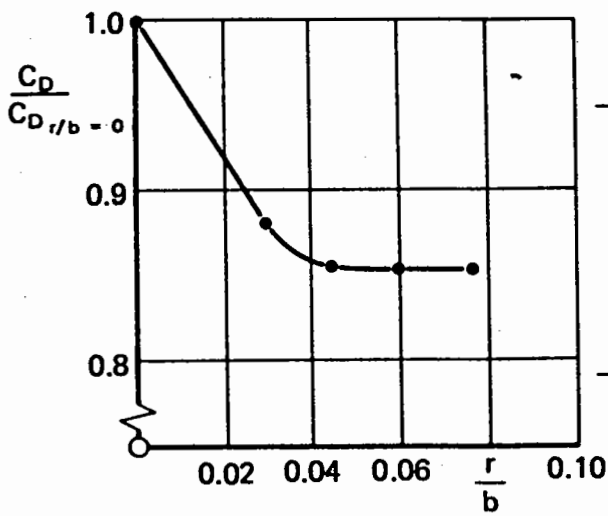
2.13³

IV/2

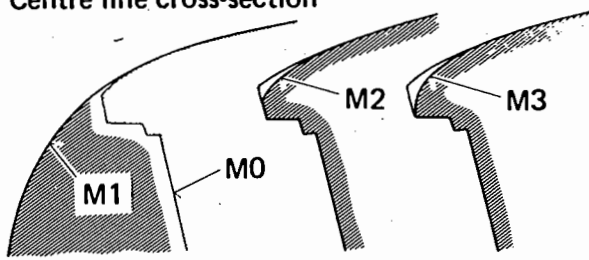




| | | | |
|--|------------------------------|--|--------------------------------|
| | <p>a) Sharp-edged front</p> | <p style="text-align: center;">Separated</p> | <p>$c_D = 0.76$</p> |
| | <p>b) Rounded edge front</p> | <p style="text-align: center;">Attached</p> | <p>0.42</p> |



Centre line cross-section

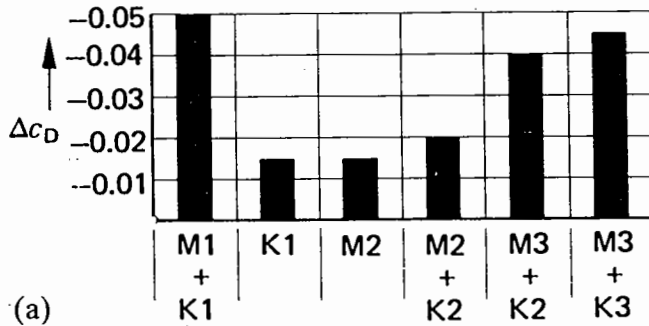
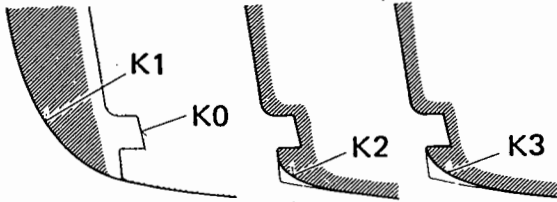


17

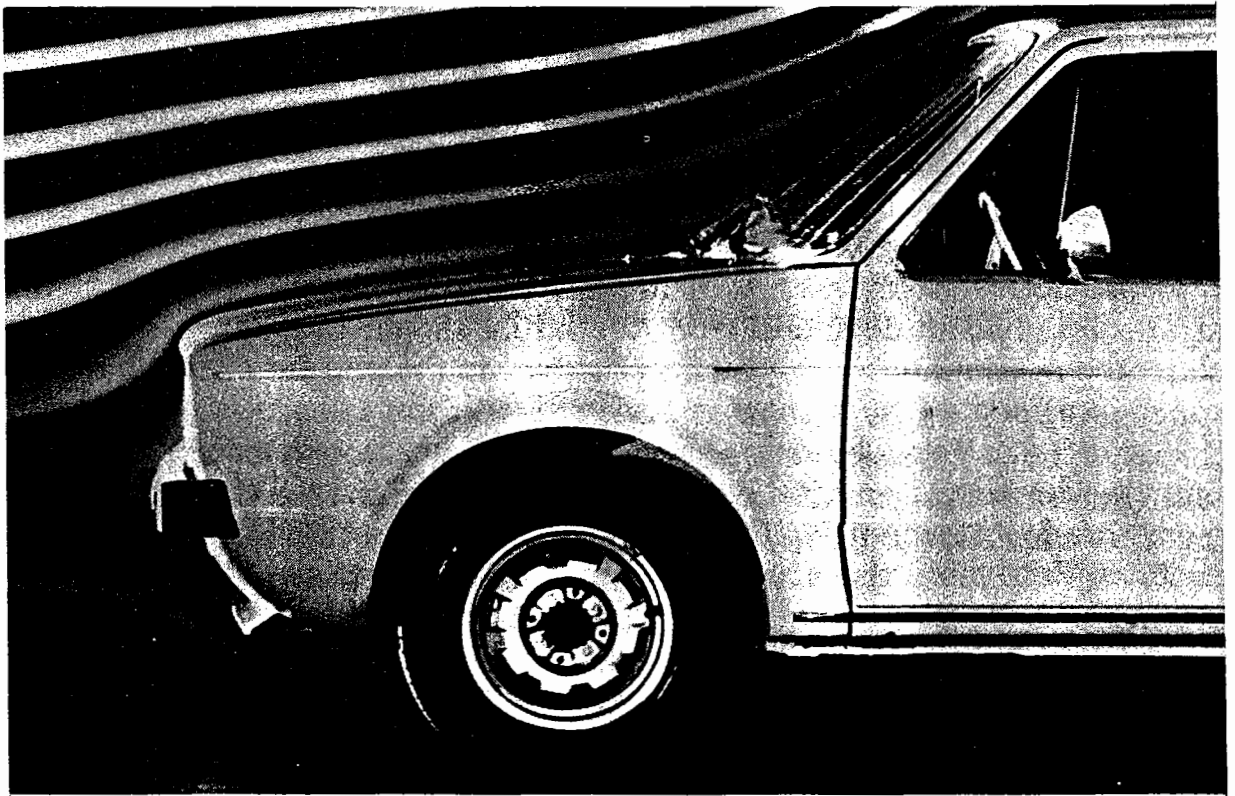
3.2/2

3/1/2

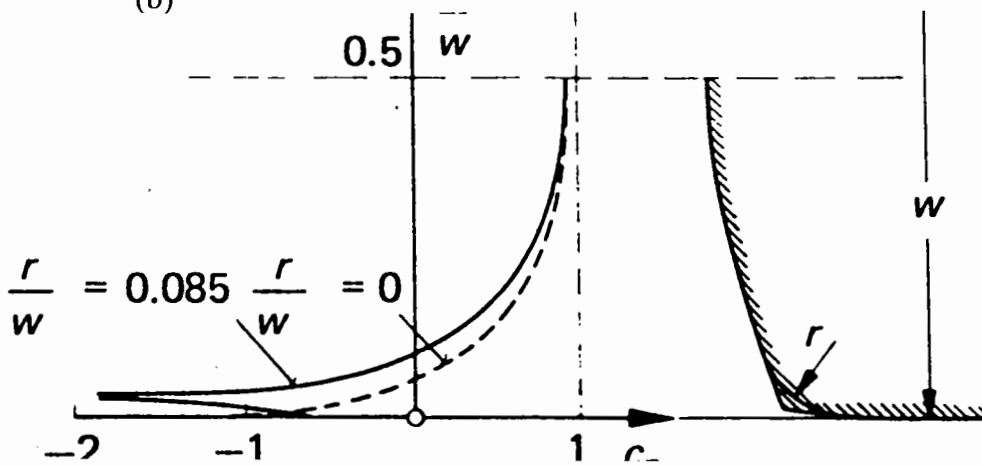
Horizontal section, height of headlamps

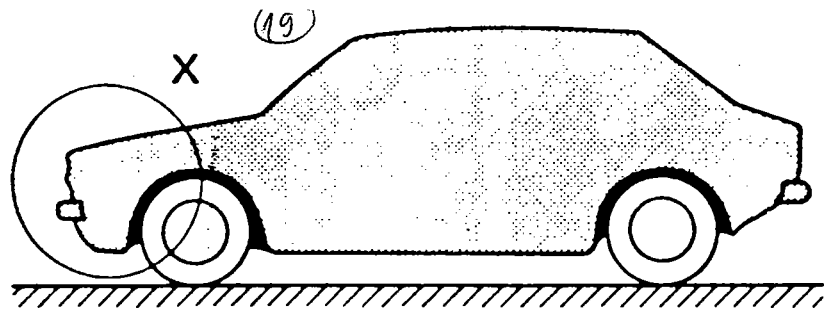


(a)



(b)

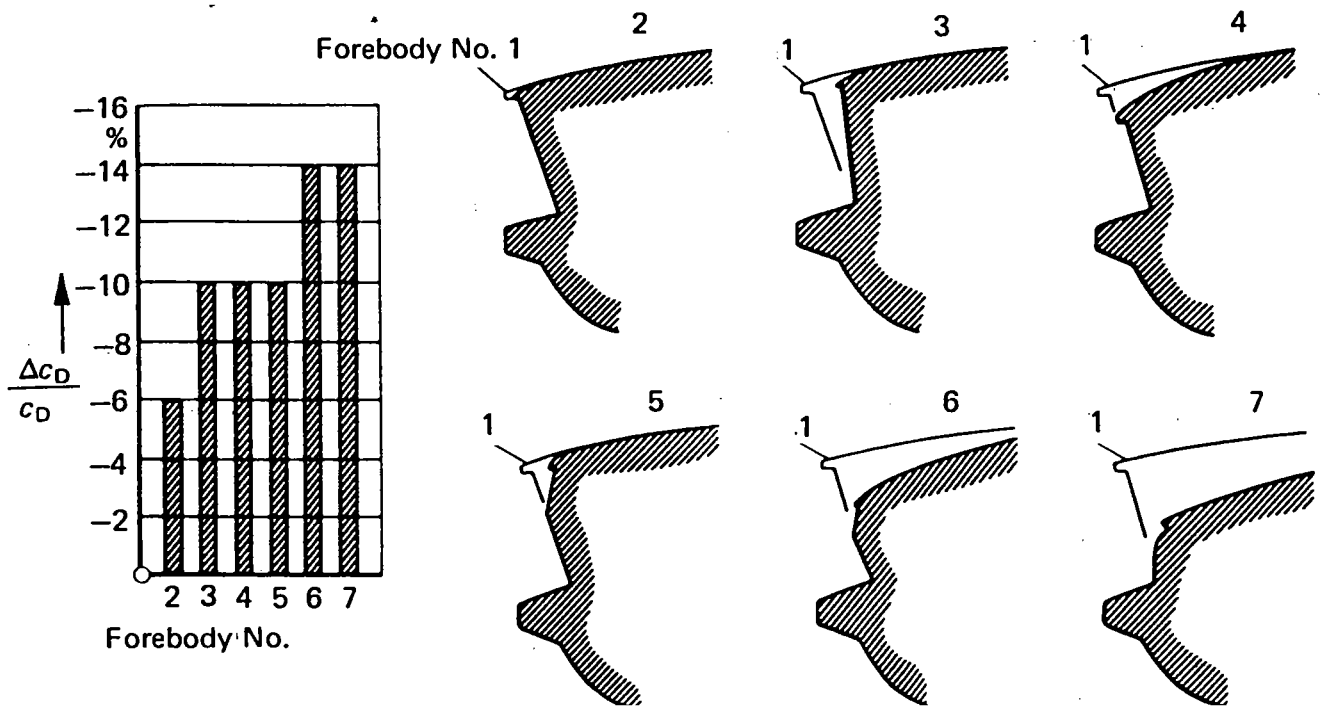
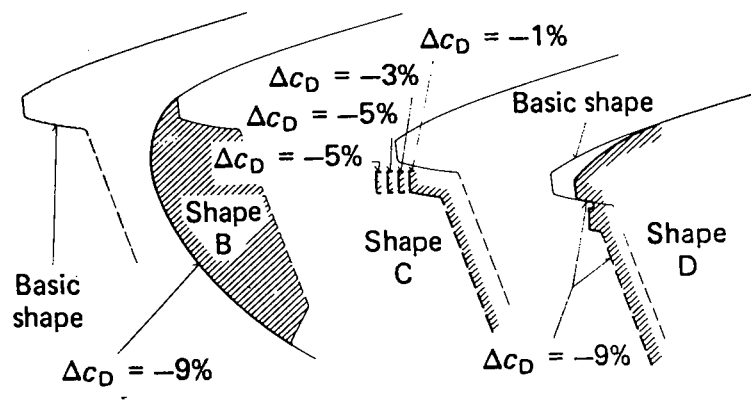
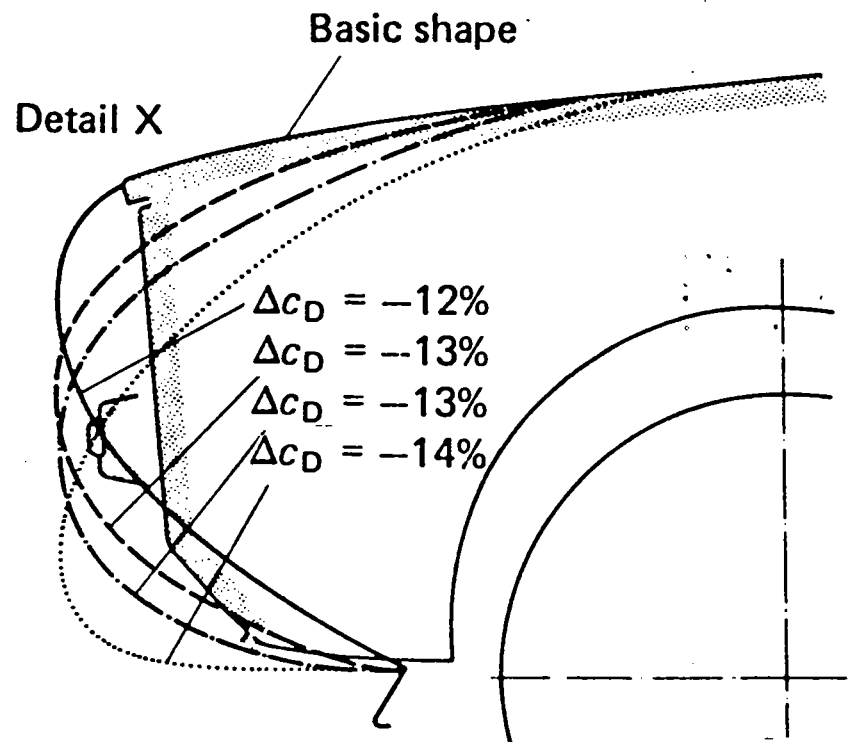


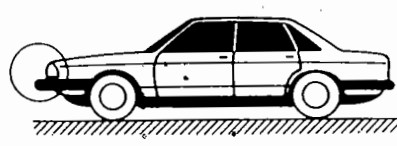
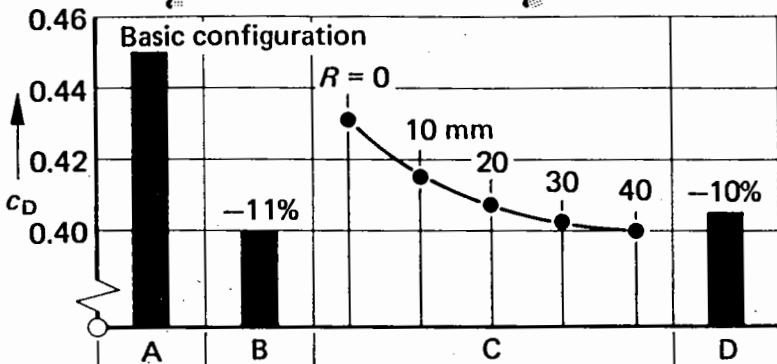
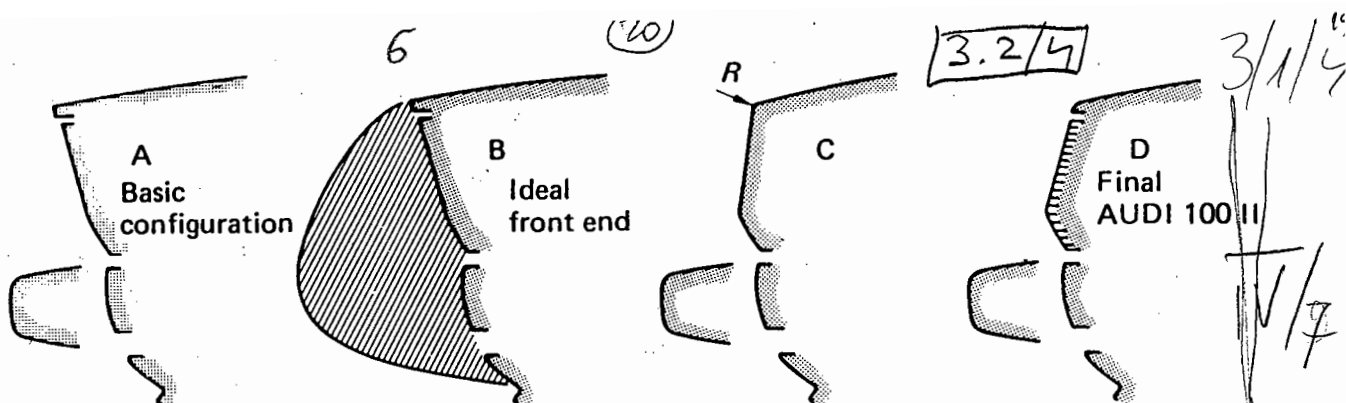


3/1/3

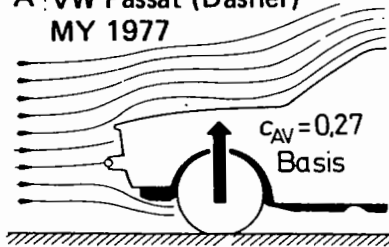
I/5

3.2/3

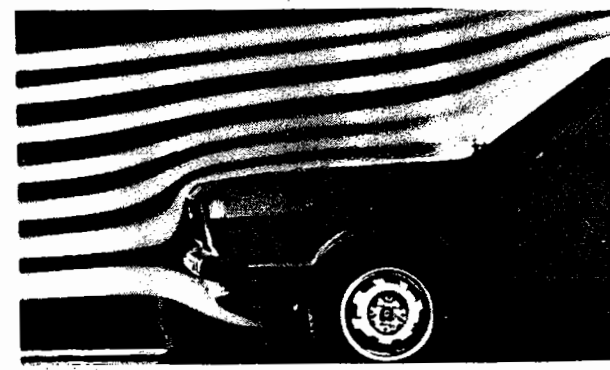
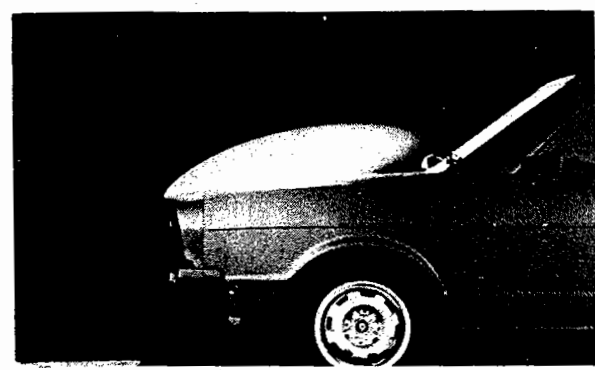
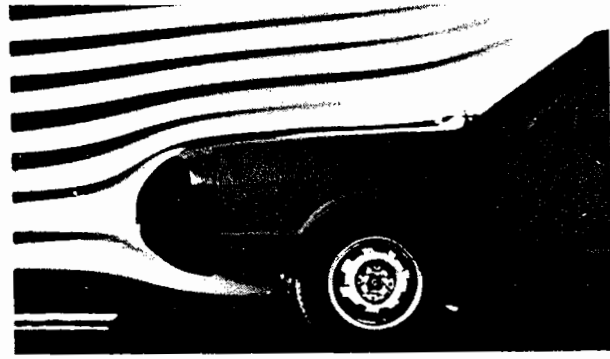
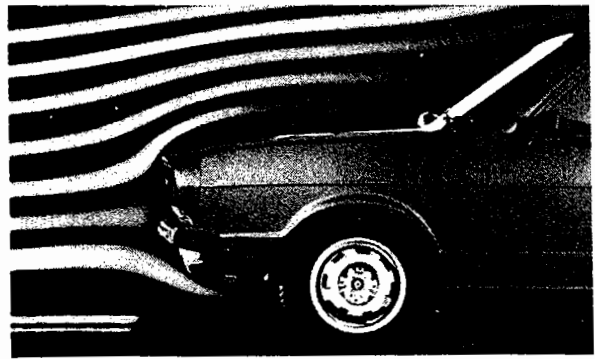
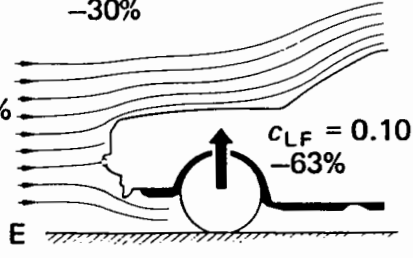
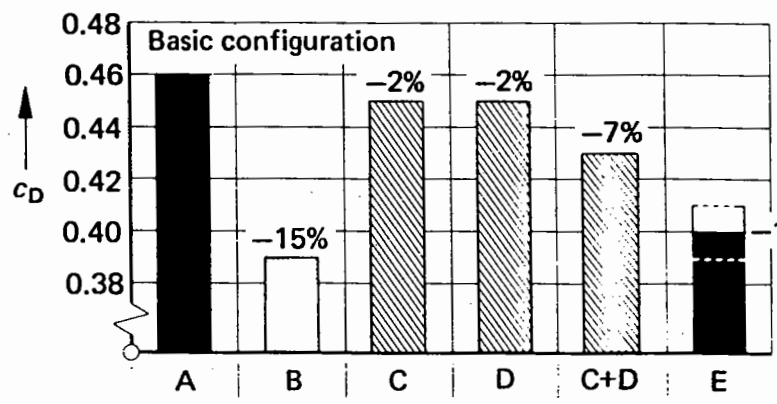
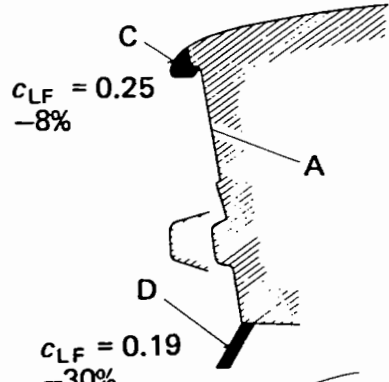
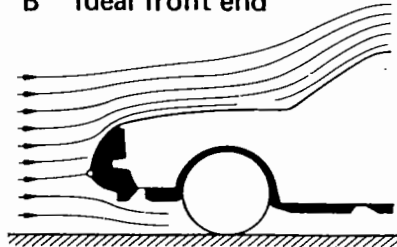




A VW Passat (Dasher) MY 1977



B Ideal front end

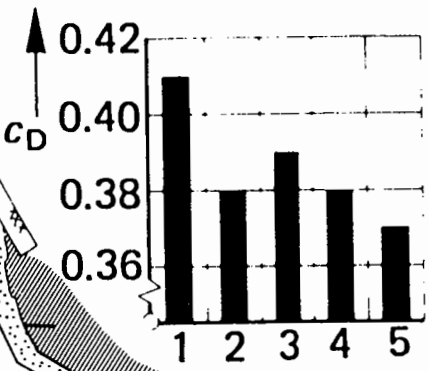
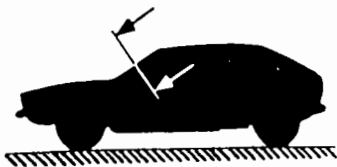


8

(22)

3/1/5^u

3.3/1



Windscreen

Side window 5

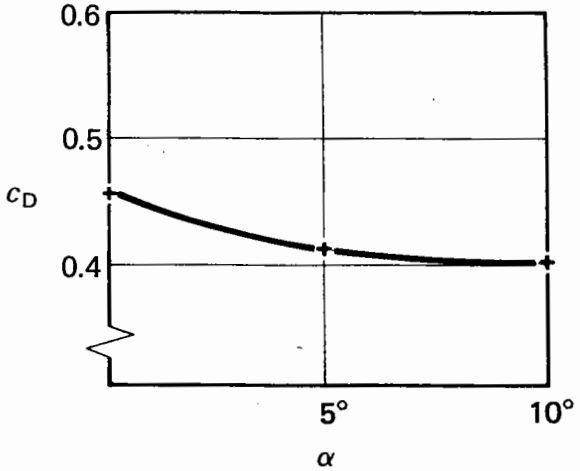
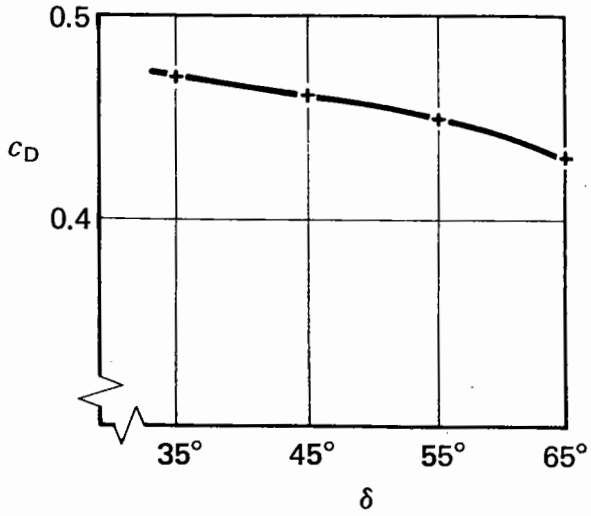
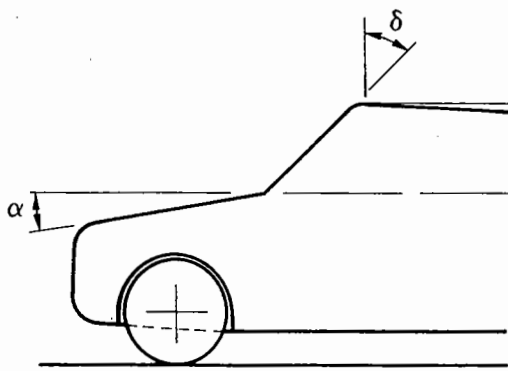
A-pillar 4

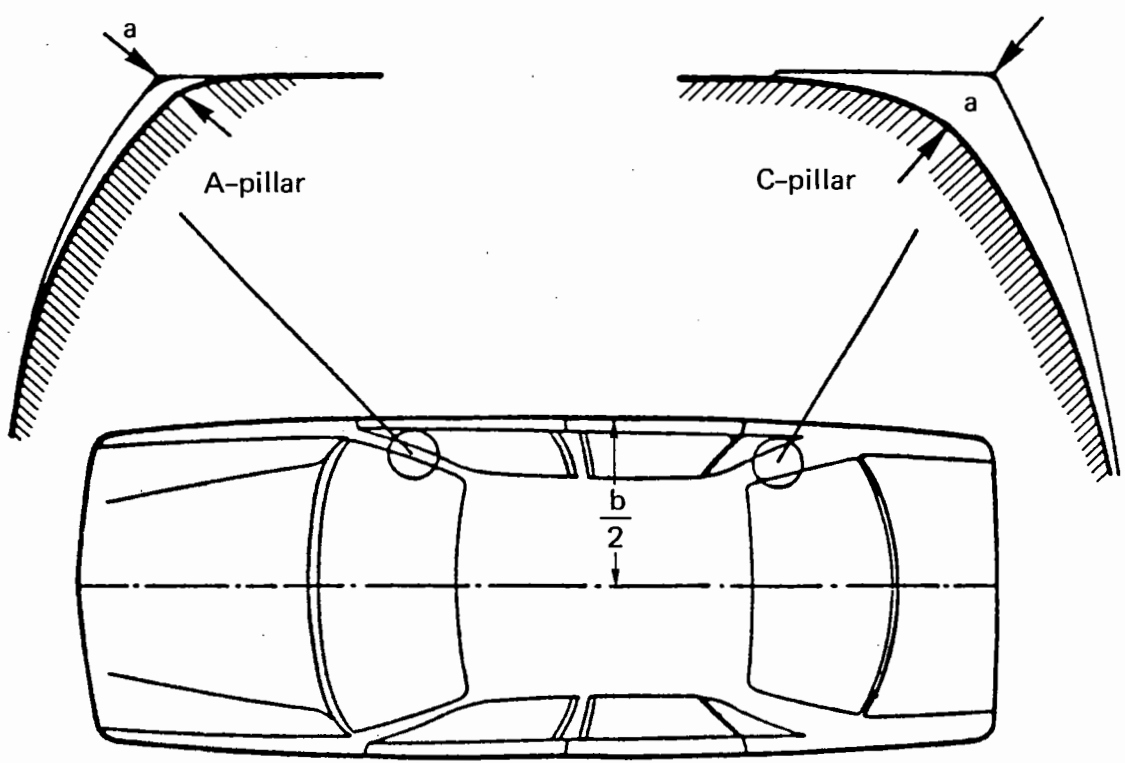
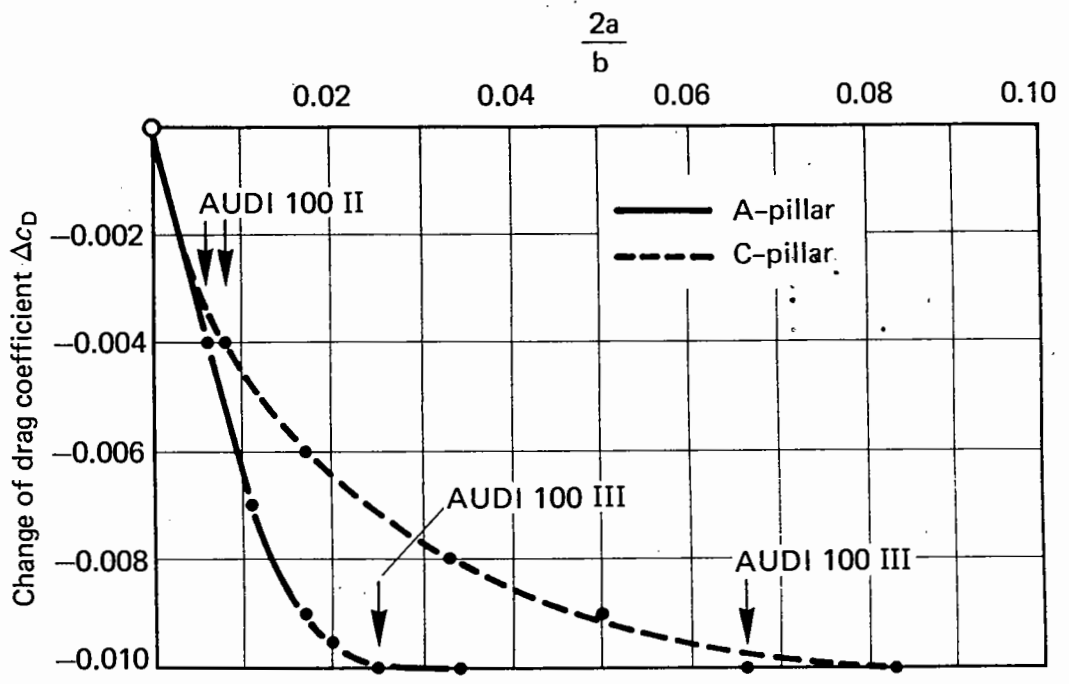
3

2

Rain water

1 Separation



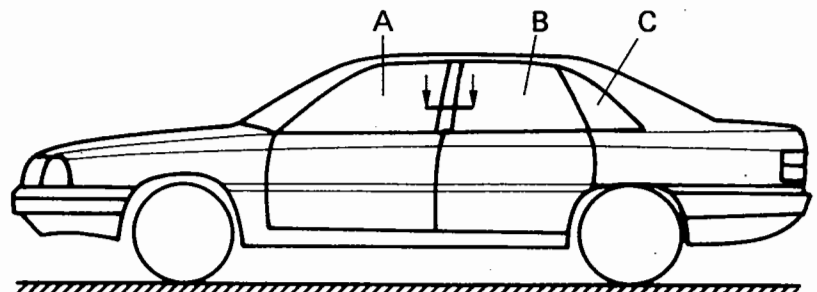
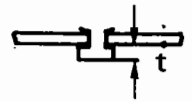
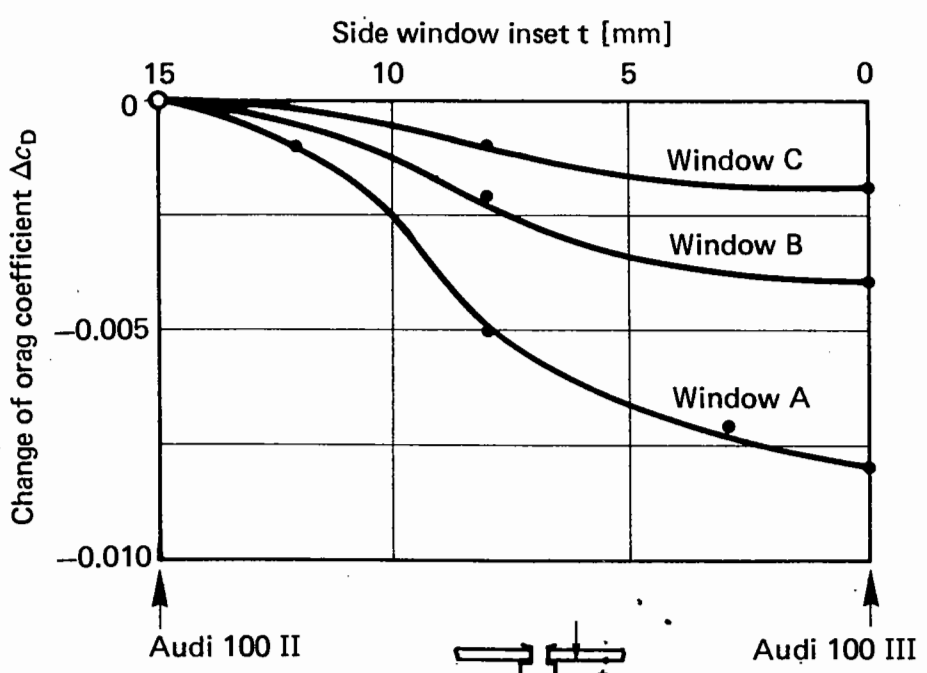
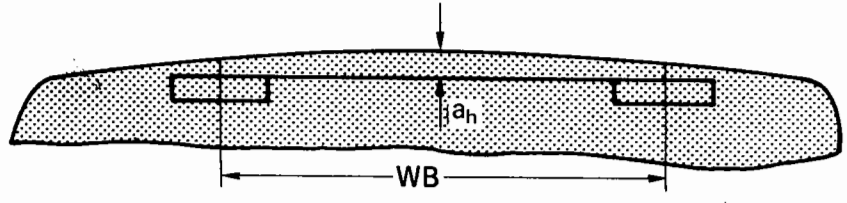
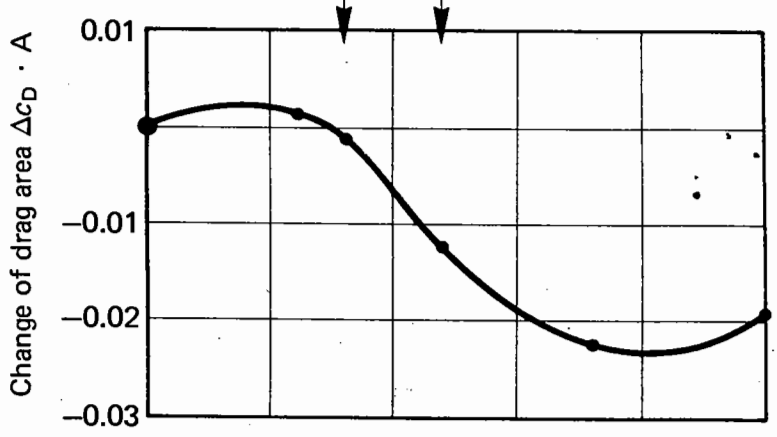
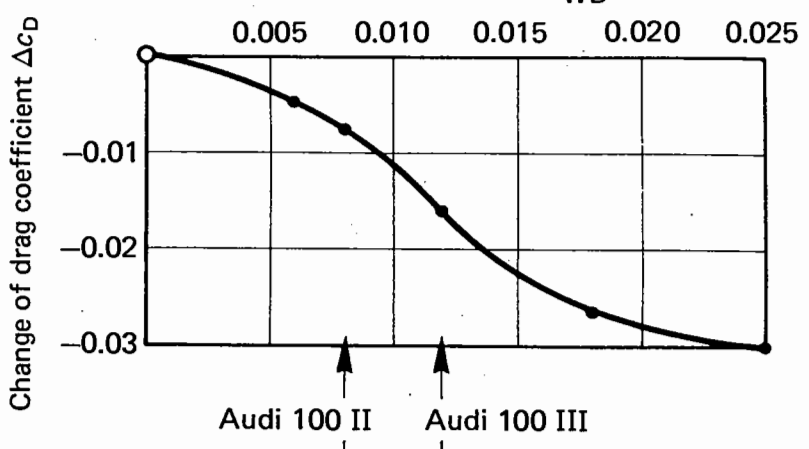


10

(25) Plan view camber $\frac{a_h}{WB}$

3/2/2

3.4/1



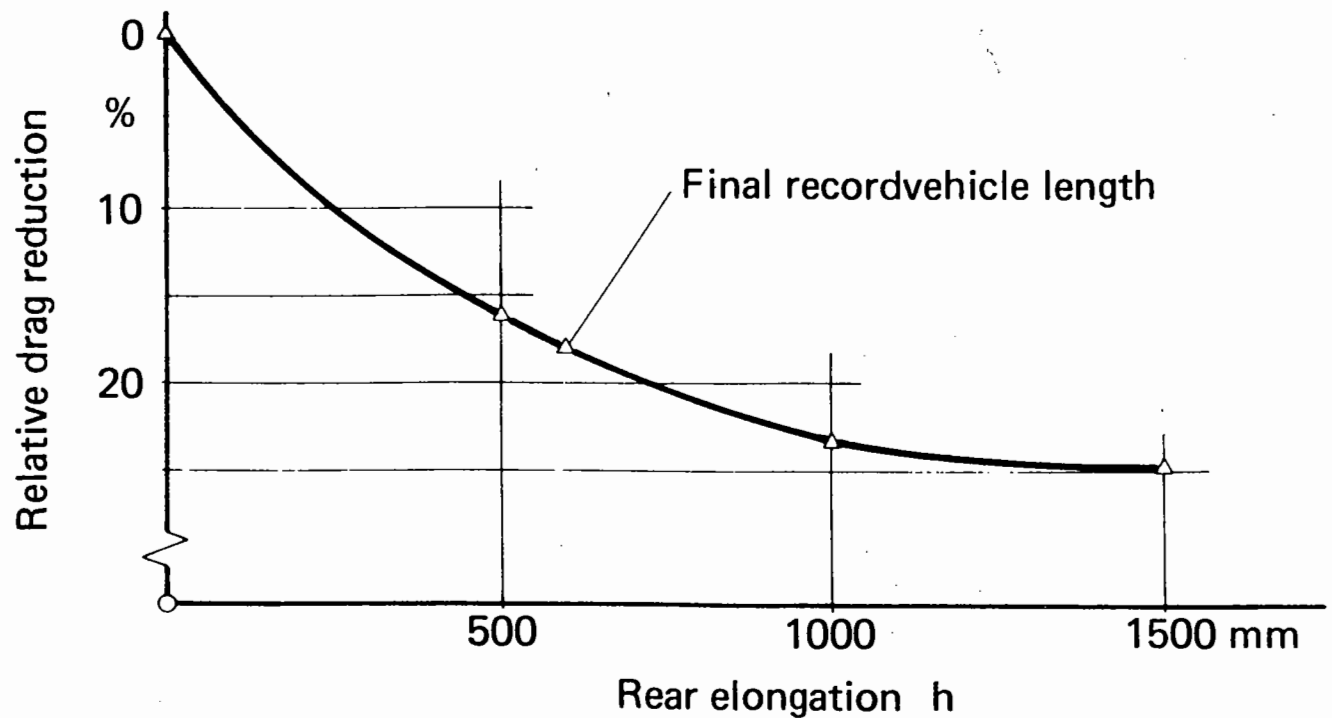
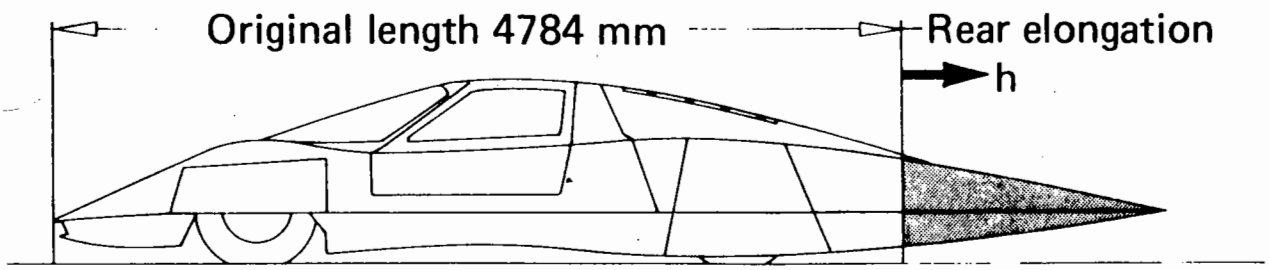
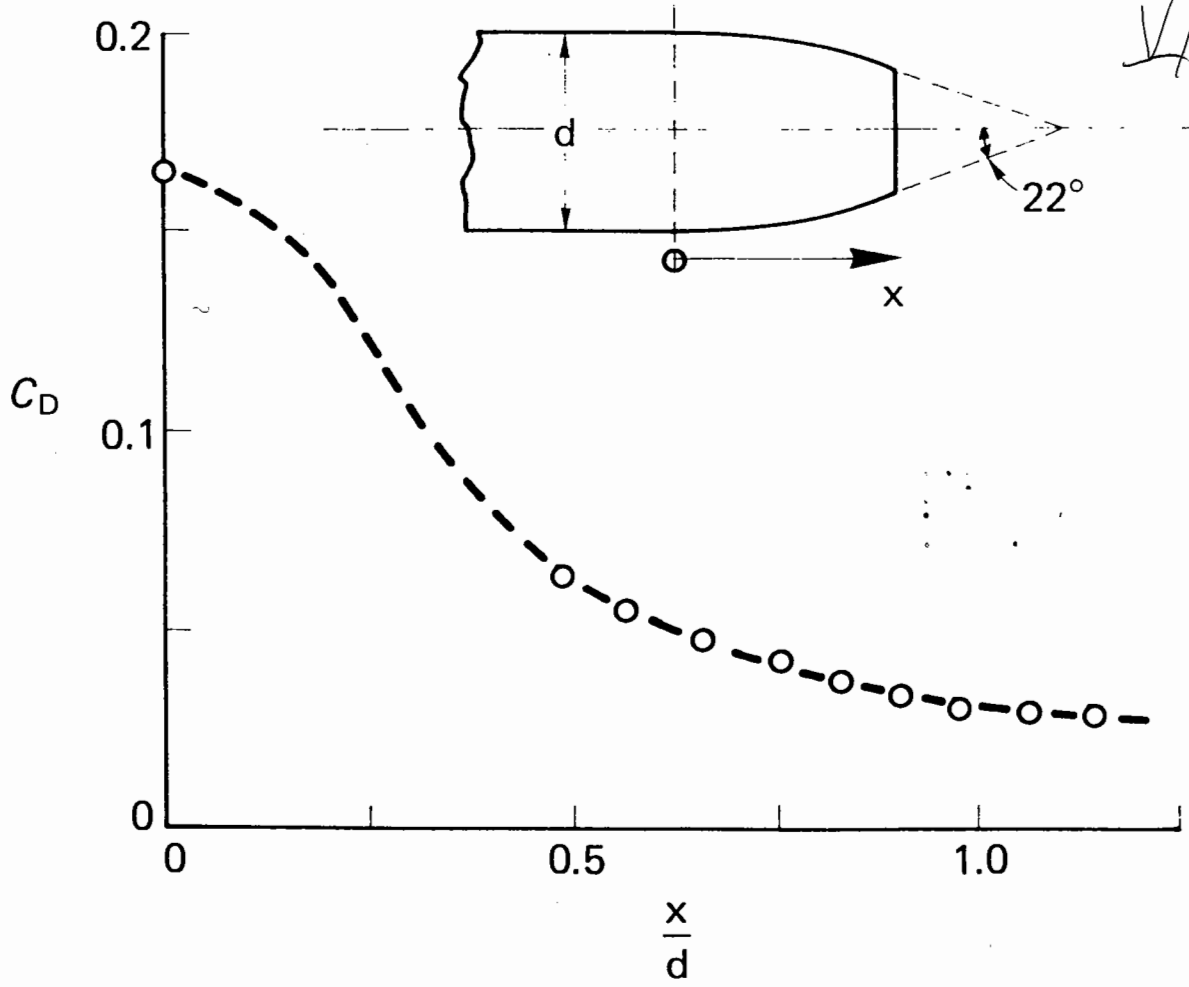
12

(27)

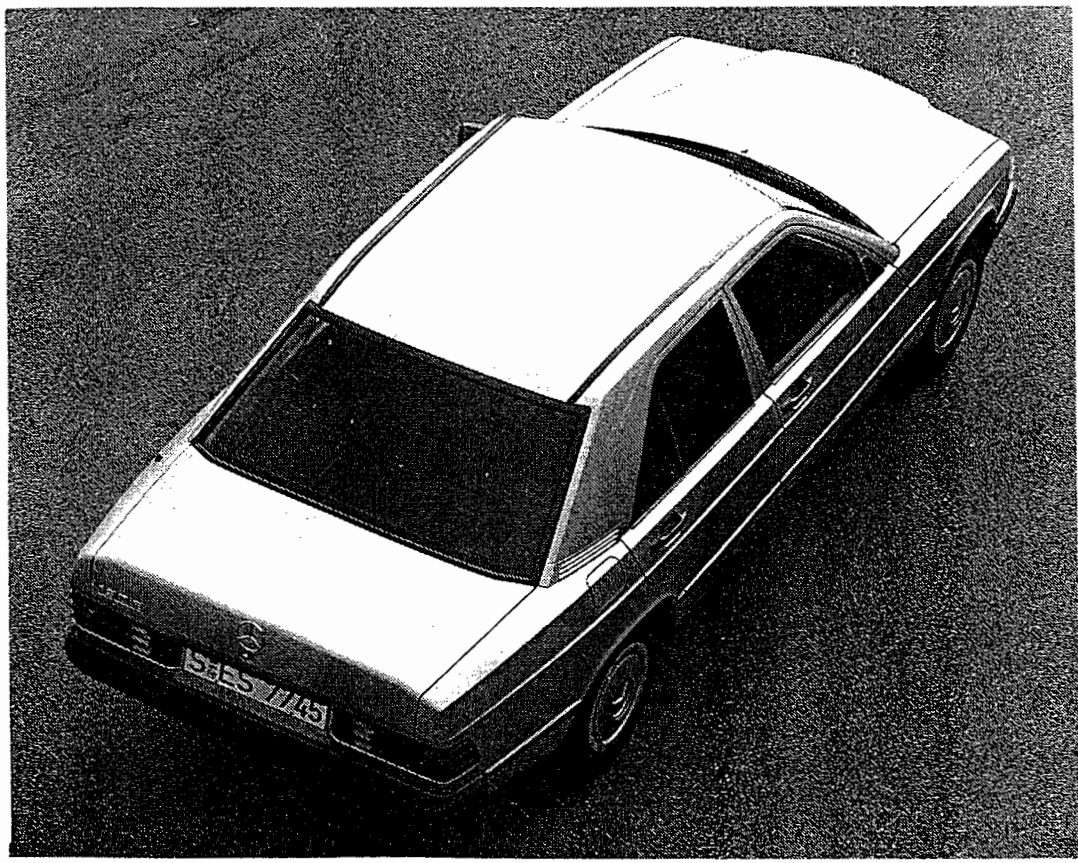
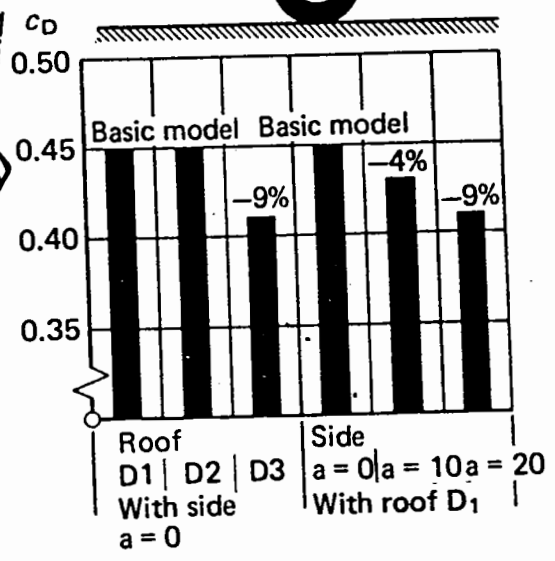
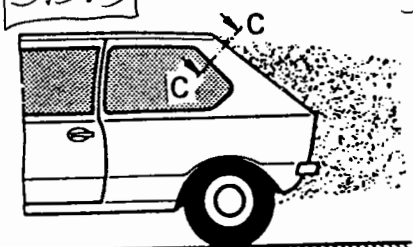
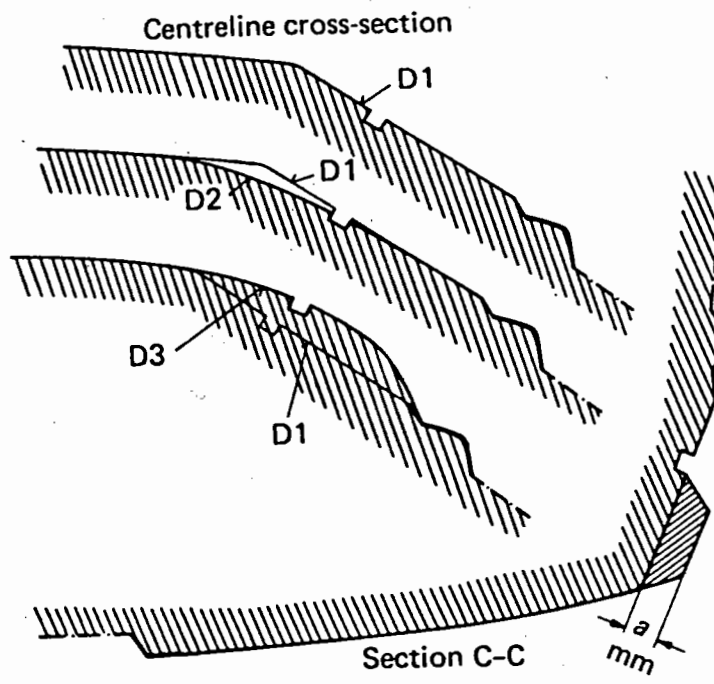
2.7/2

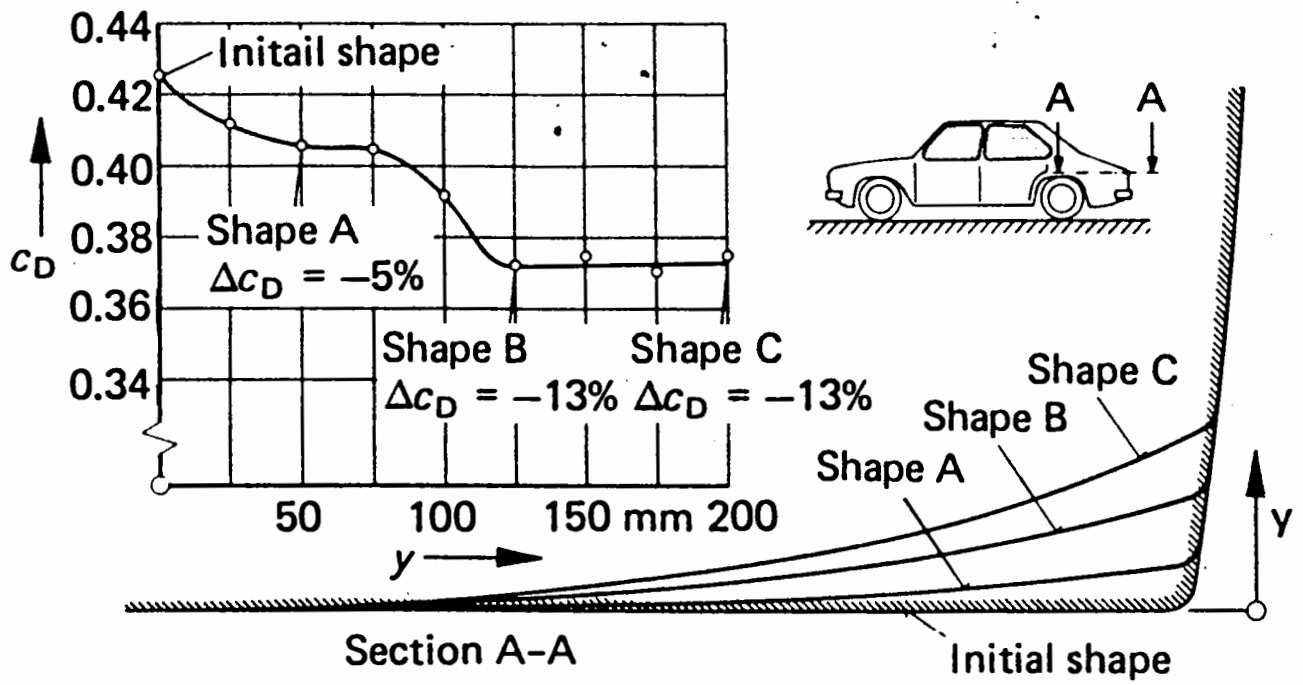
(2.10)³

√/2



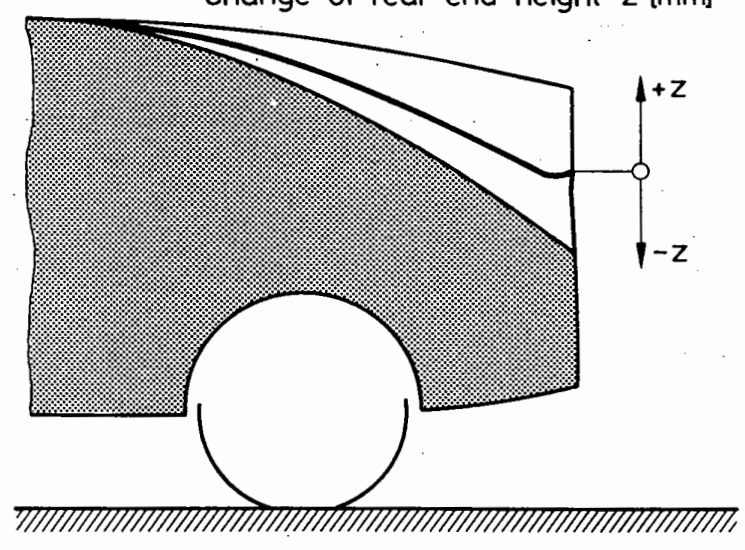
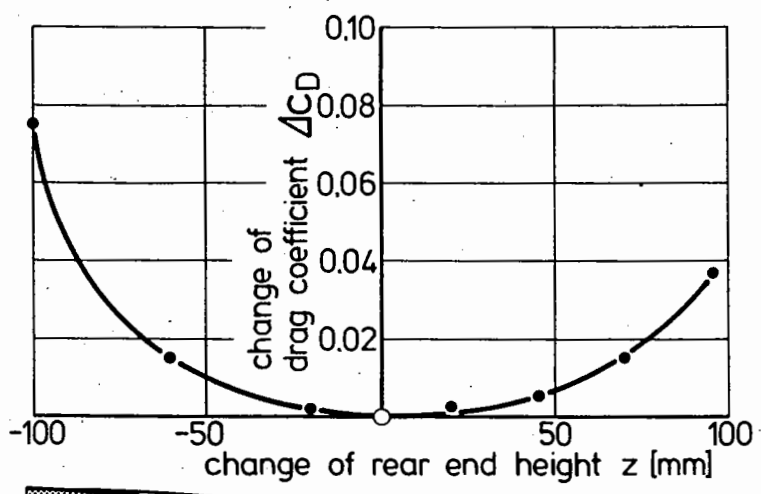
3/3/1³
V/4





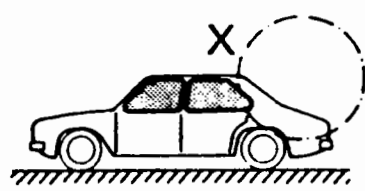
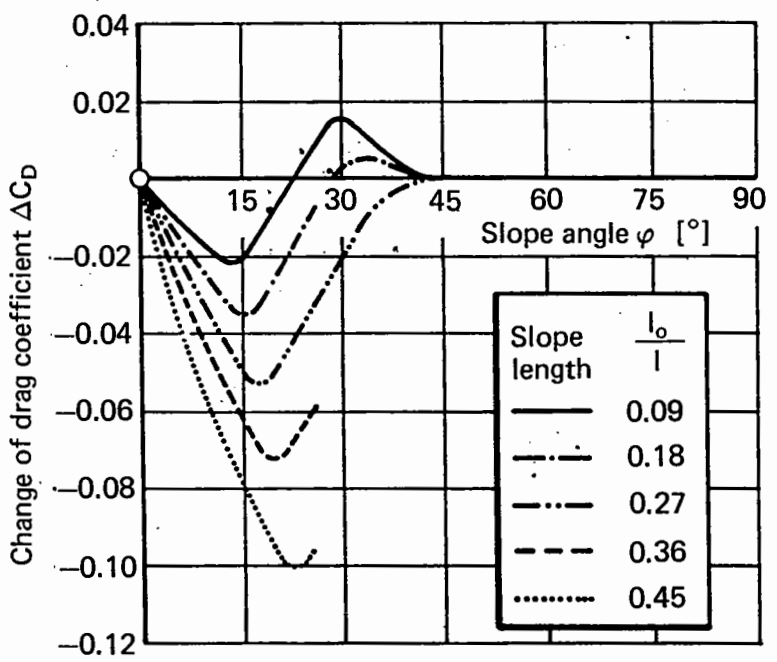
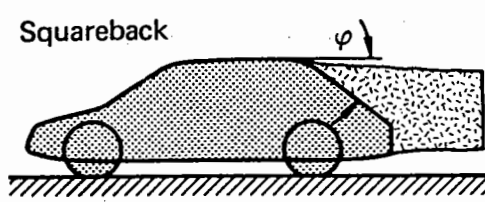
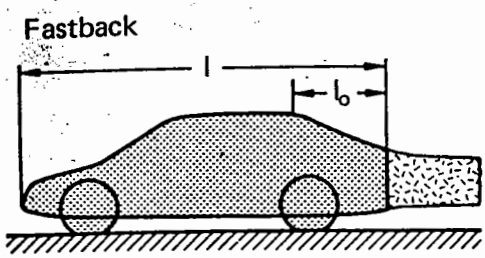
3.5.6

3/3/3

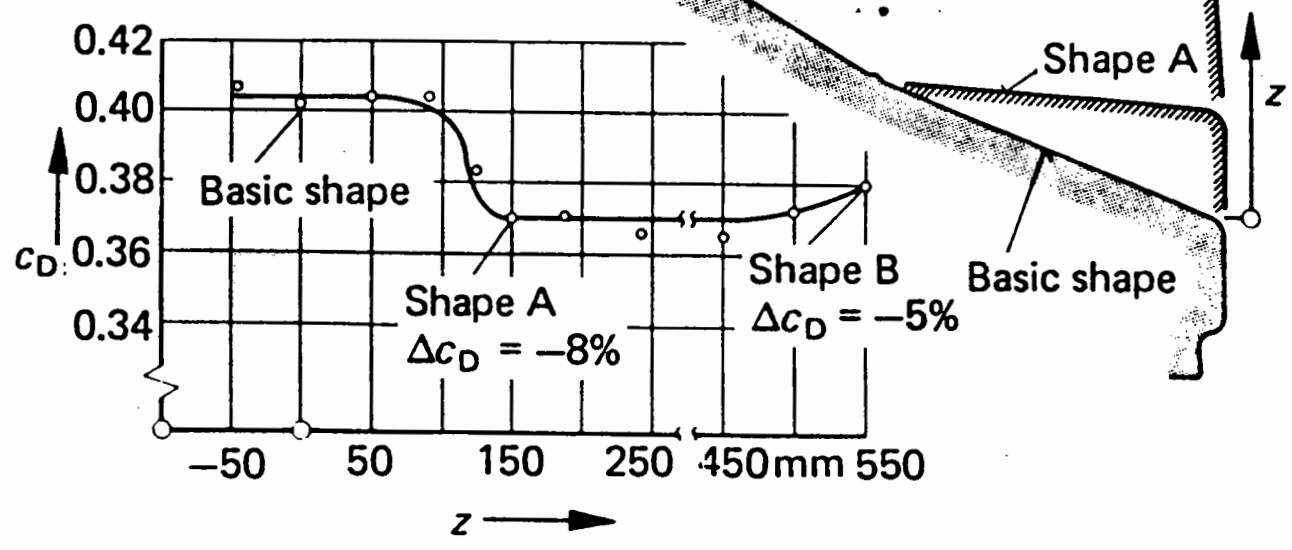


3.5.5

3/3/24



Detail X

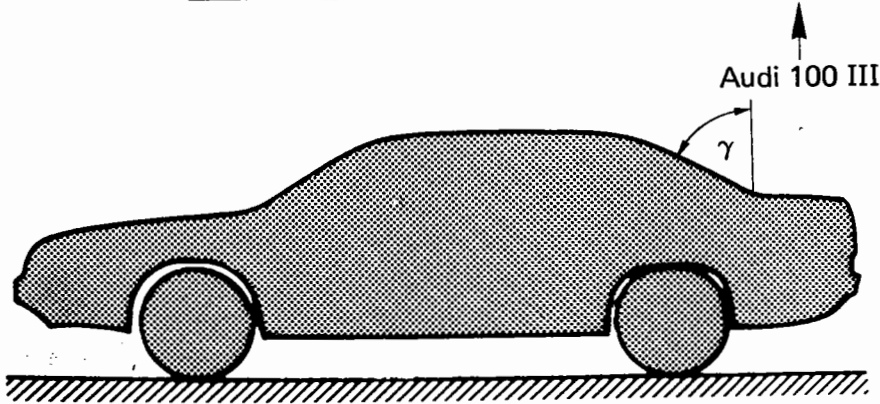
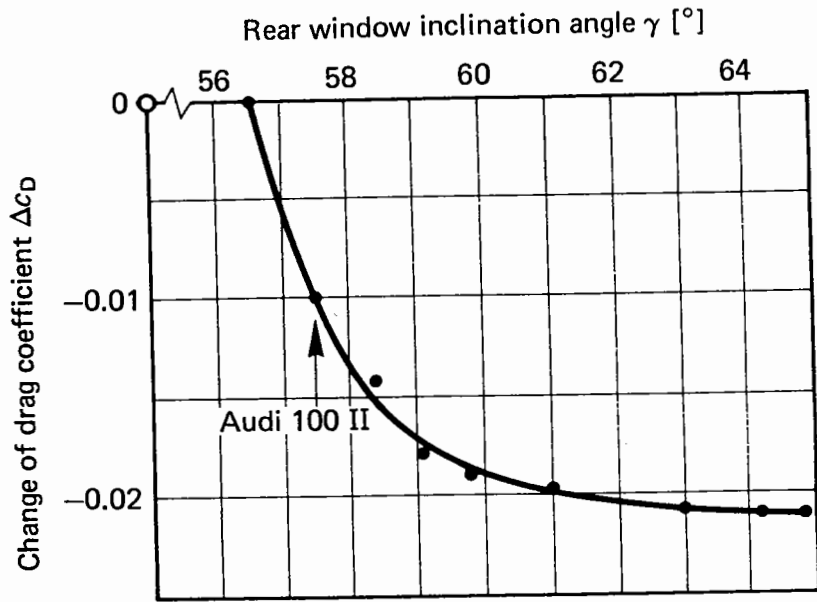


11

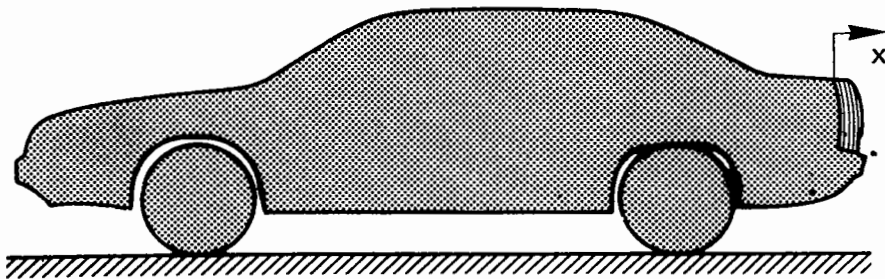
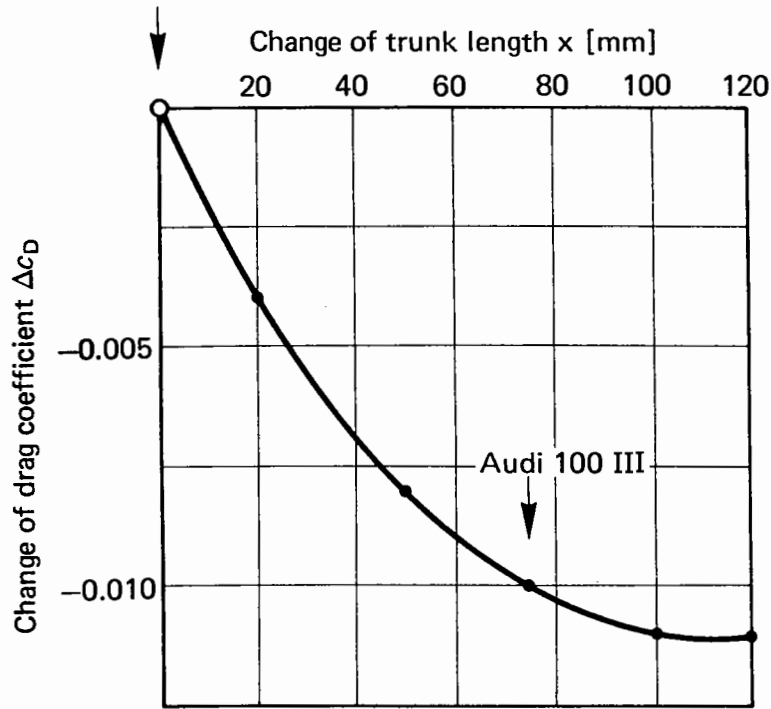
26

3.5.7

3/3/5⁴¹

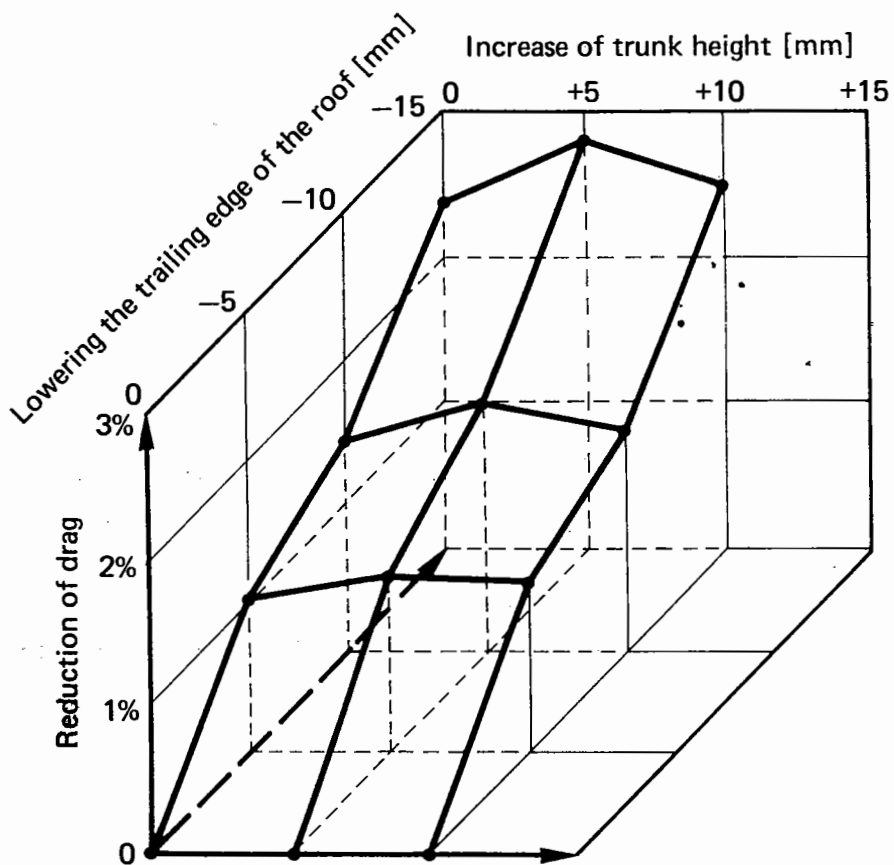
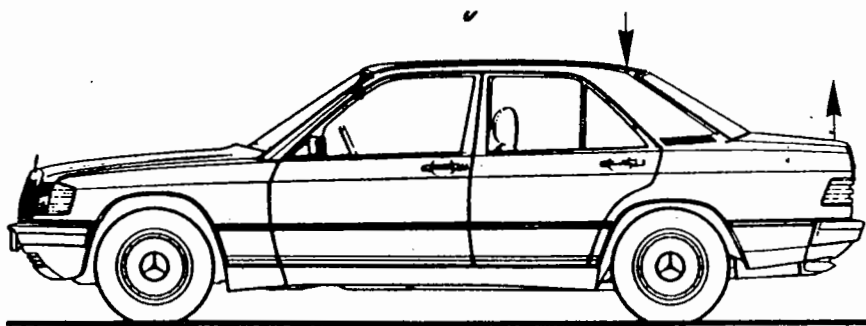


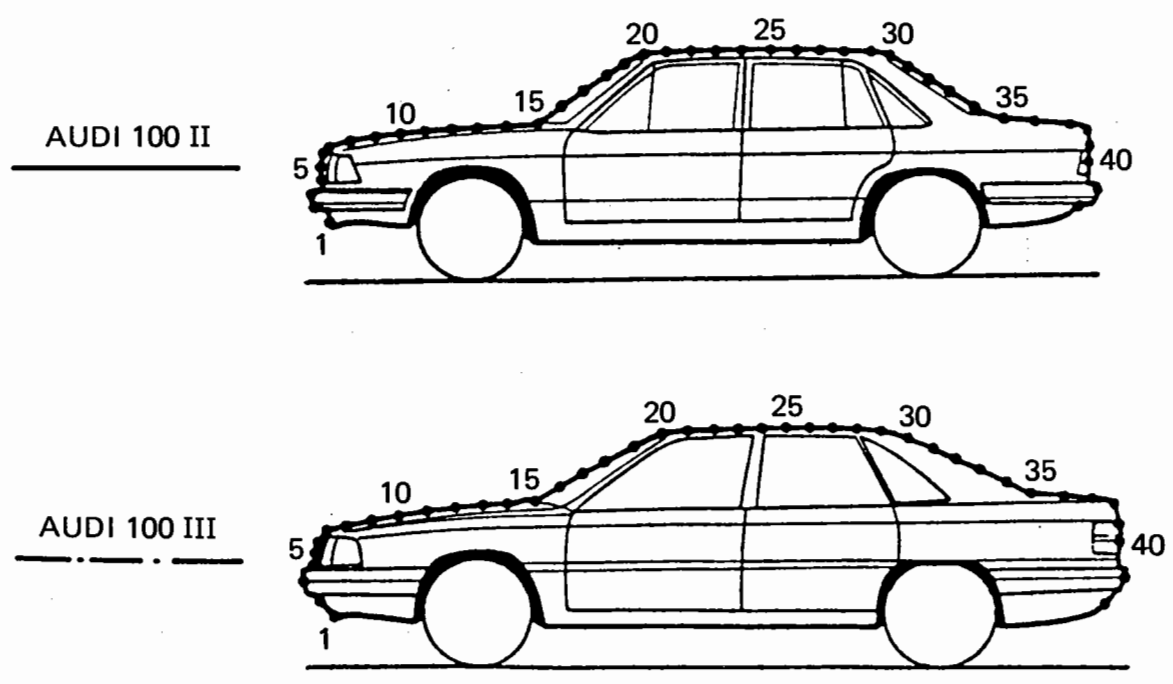
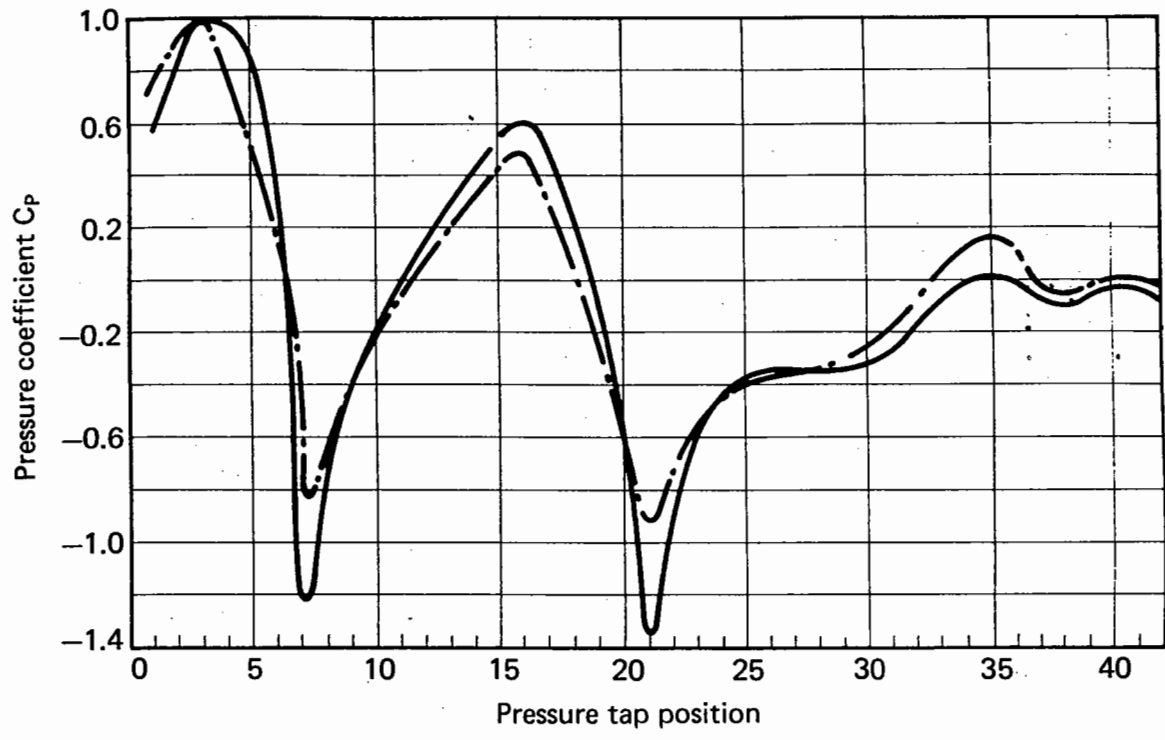
Audi 100 III



3.5.8

3/3/6





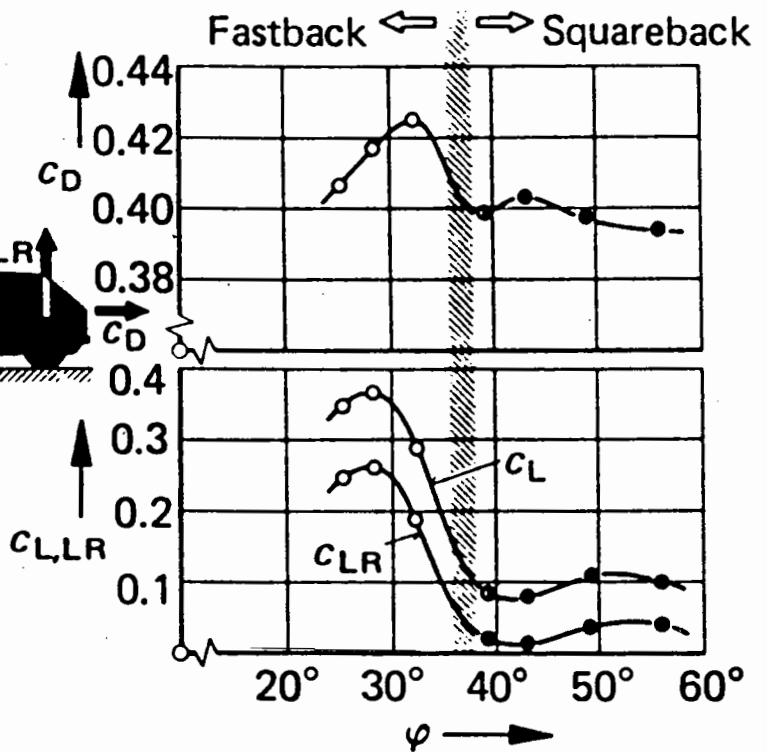
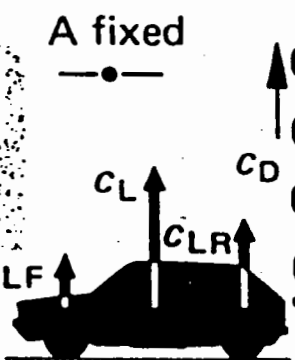
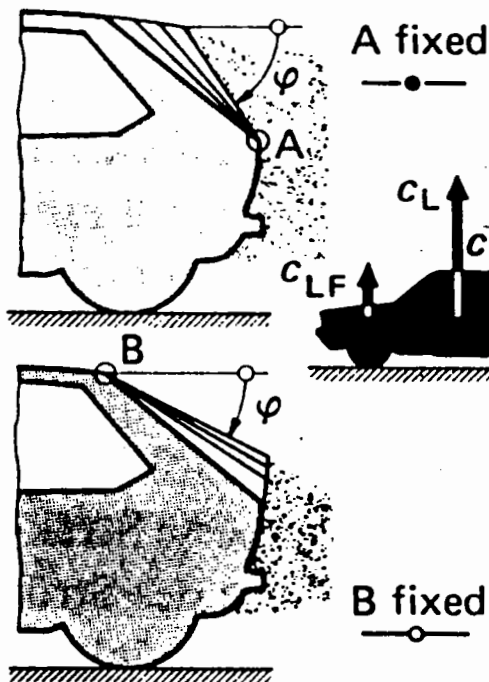
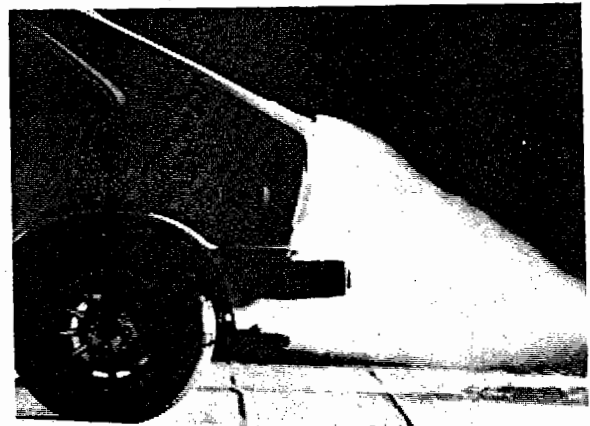
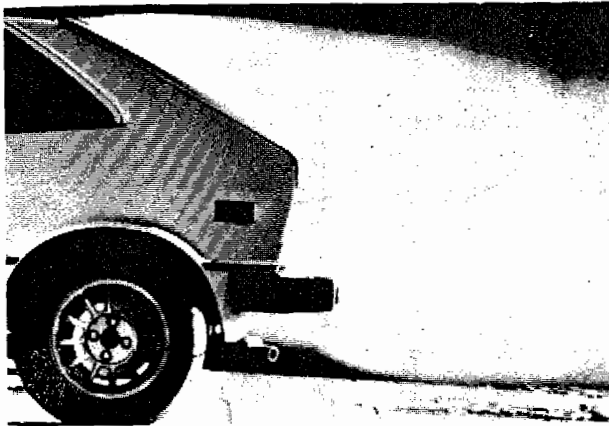
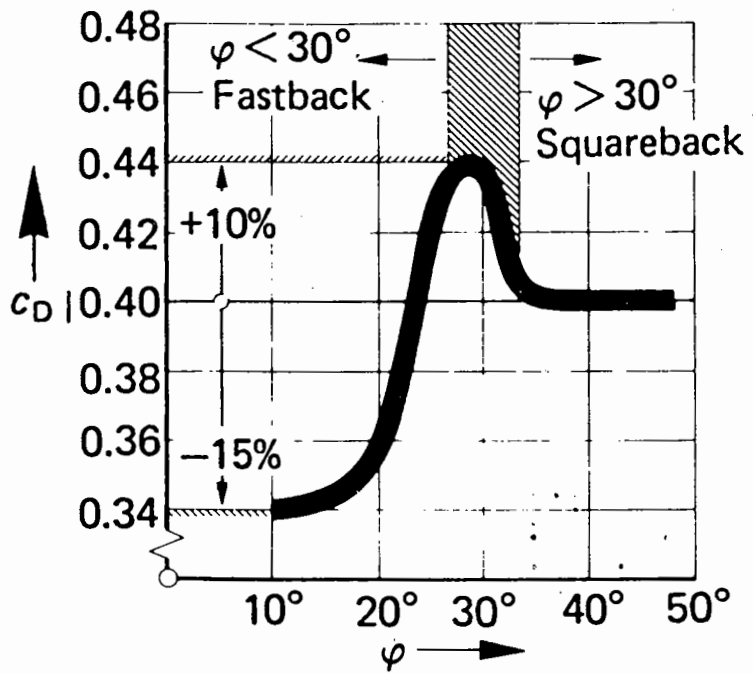
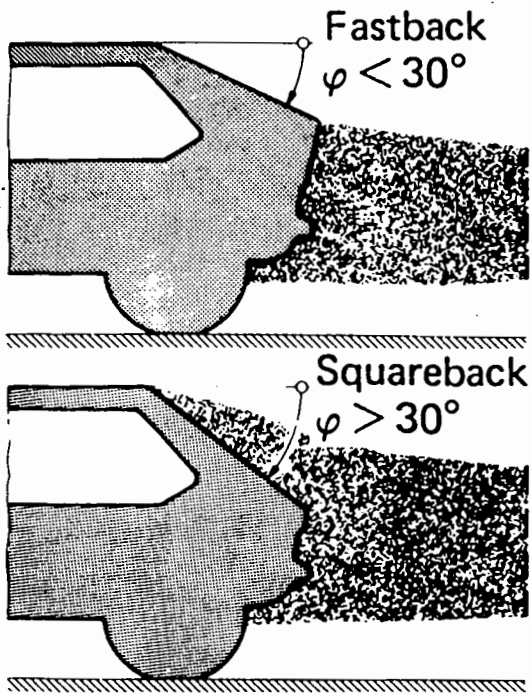
13

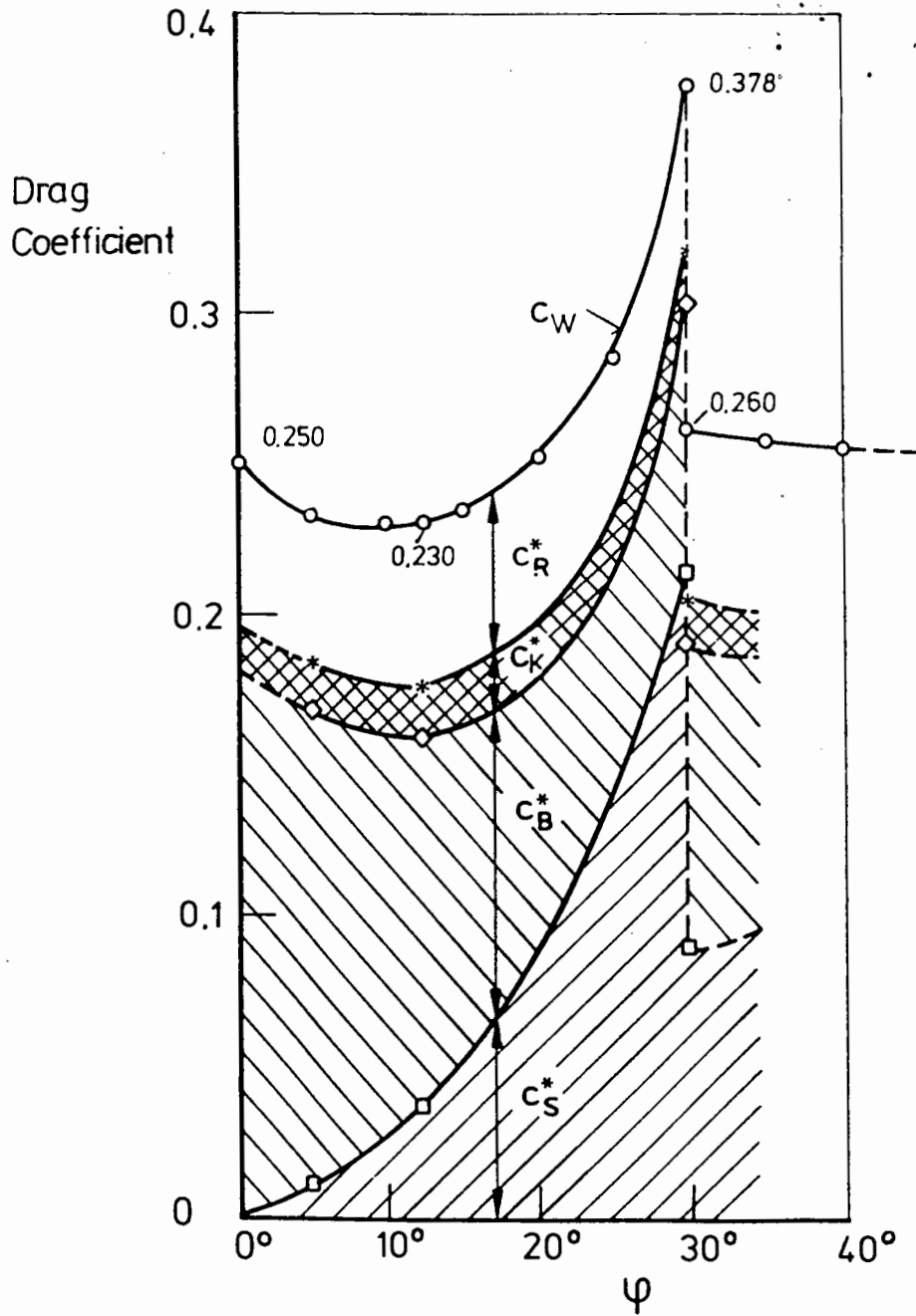
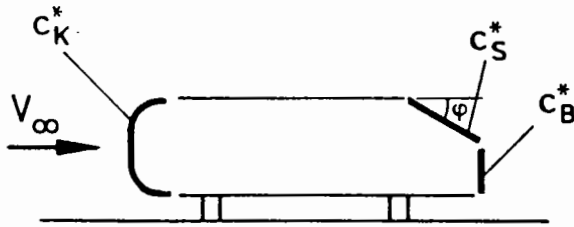
30

3.5.10

3/3/89

$\sqrt{7}$



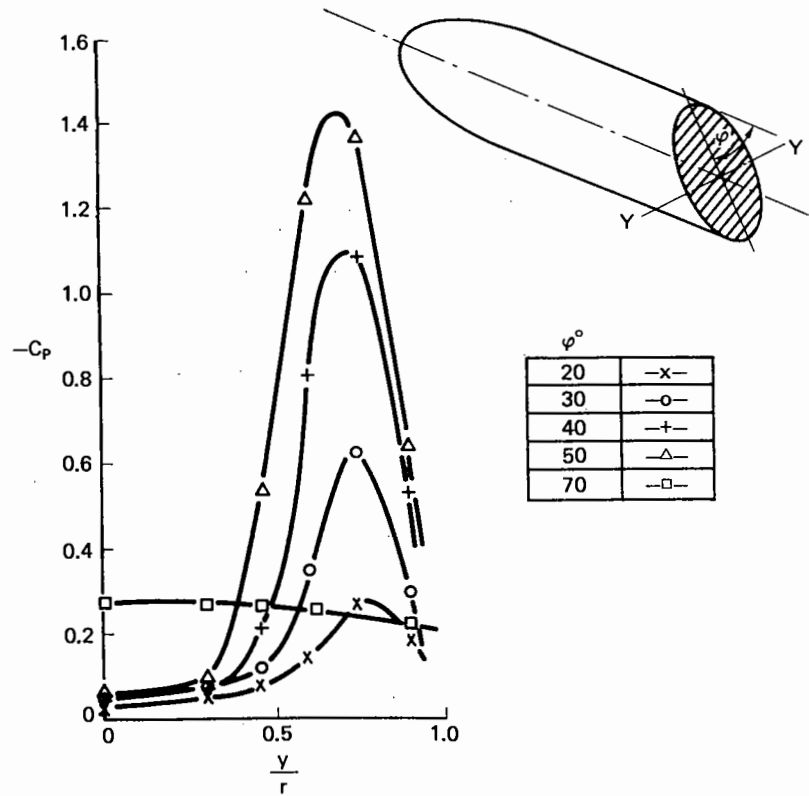
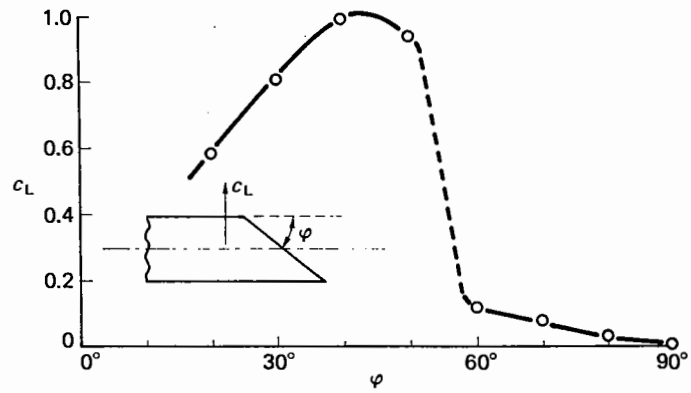
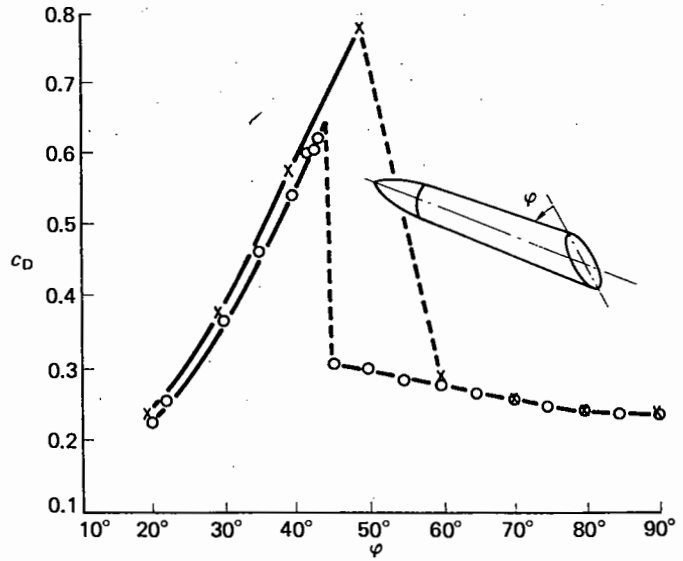


15

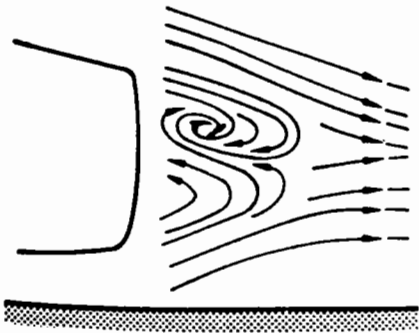
(32)

2.7/3

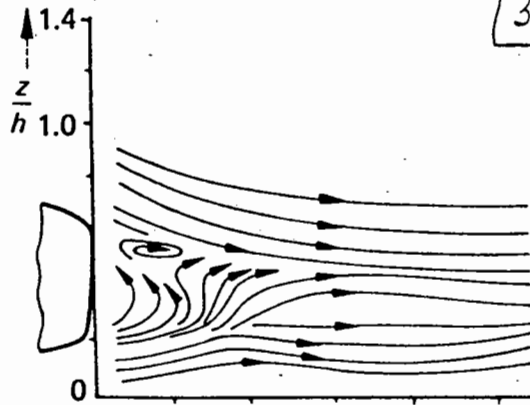
2.12



notchback

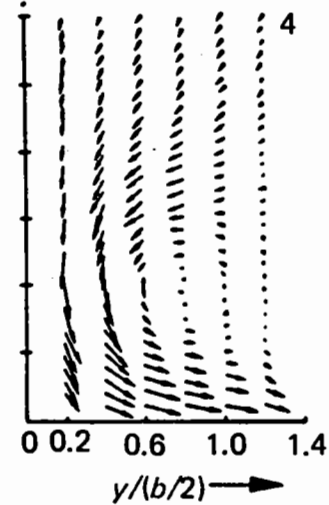
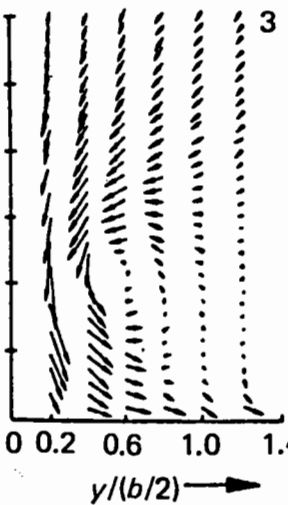
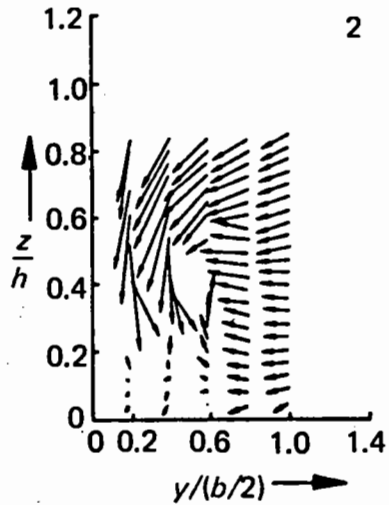
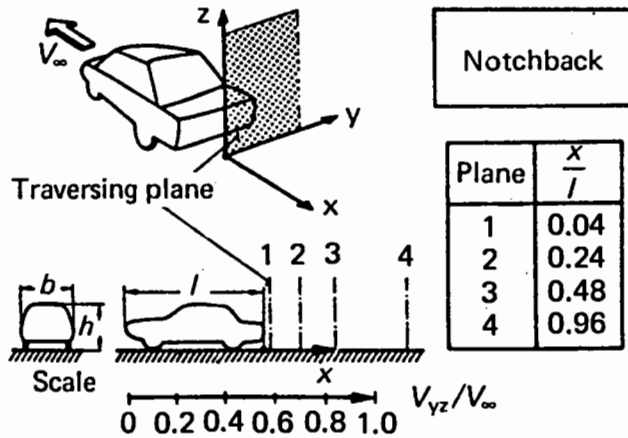
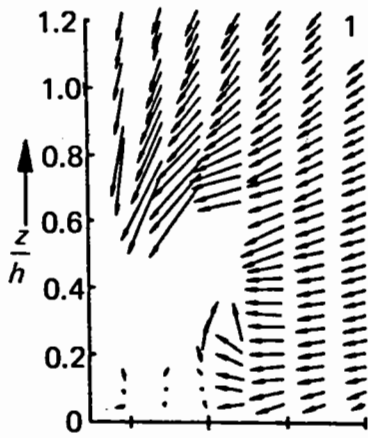
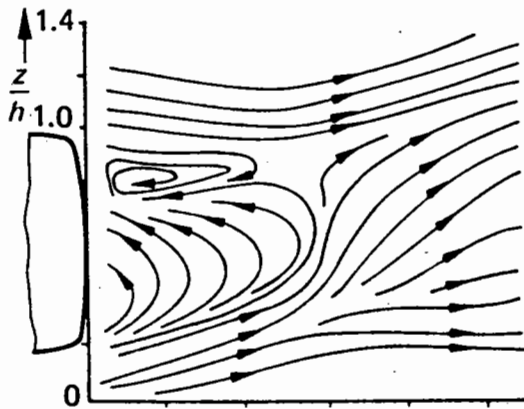


fastback



3.5/1

squareback

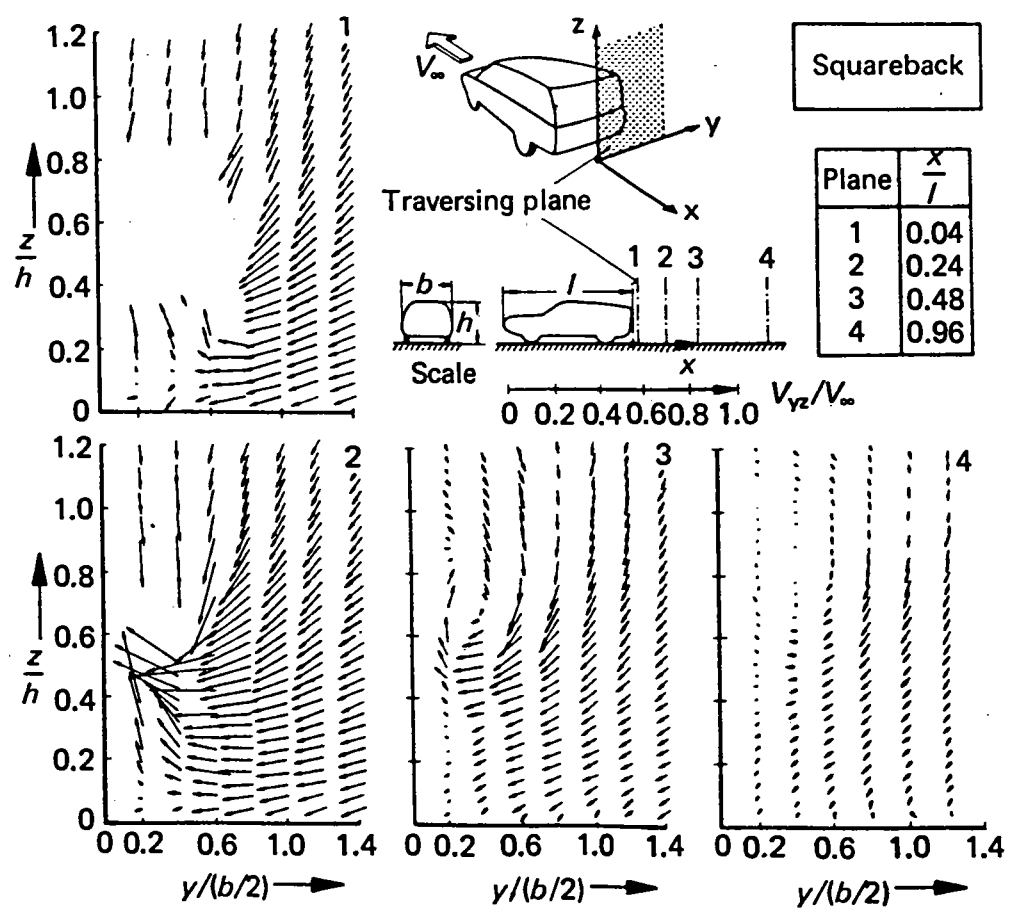
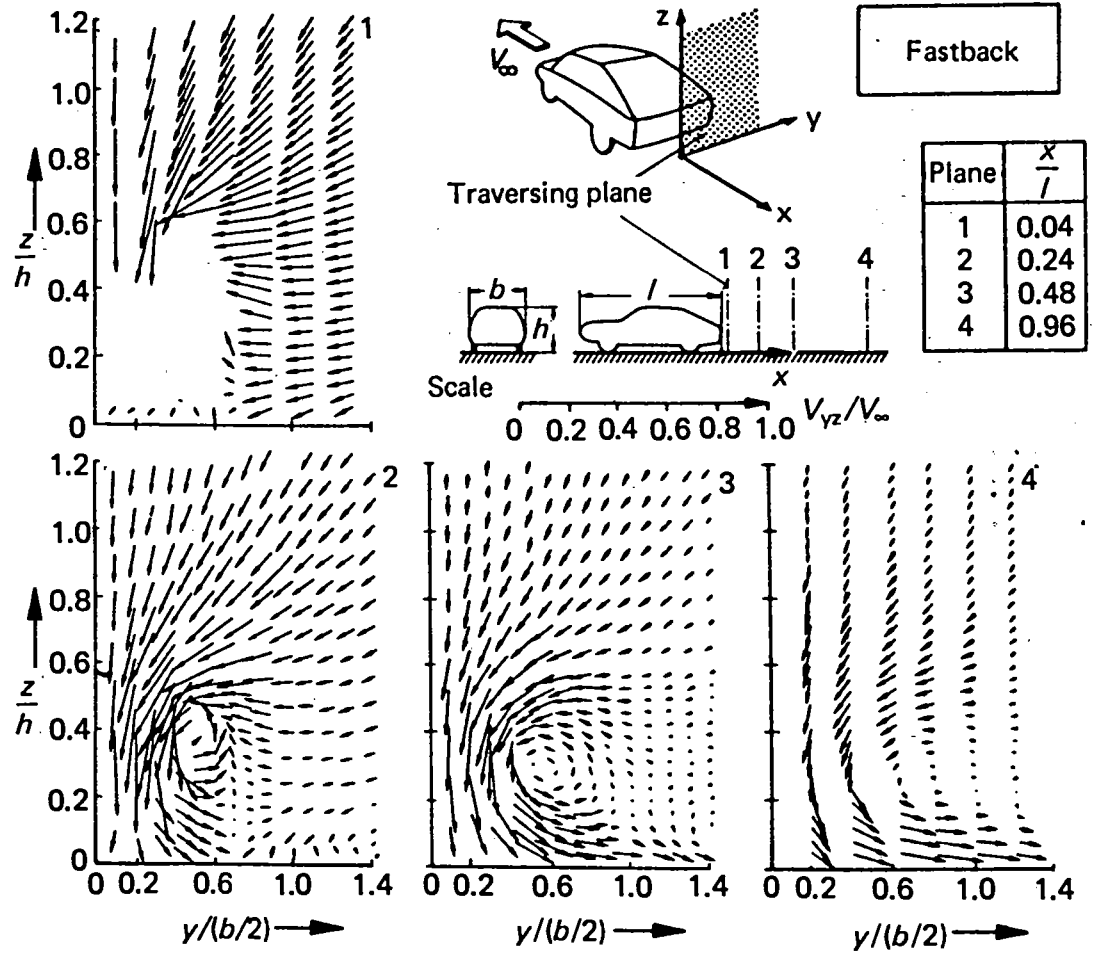


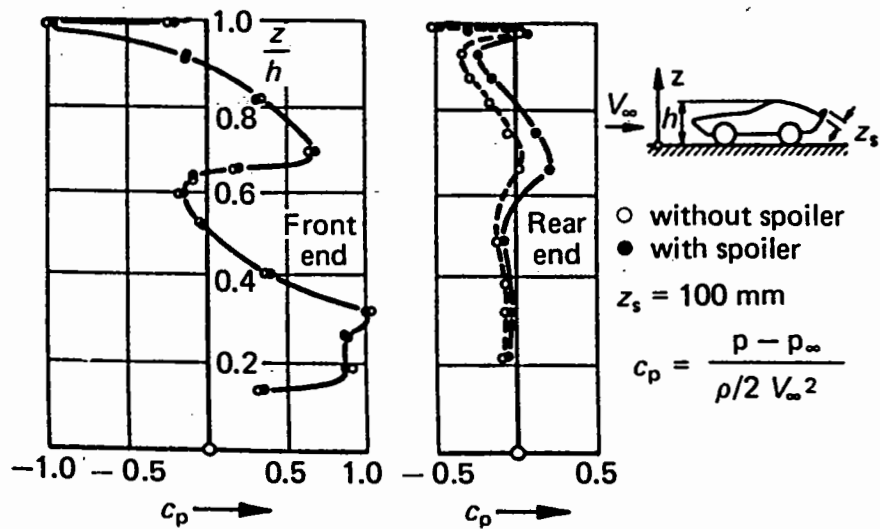
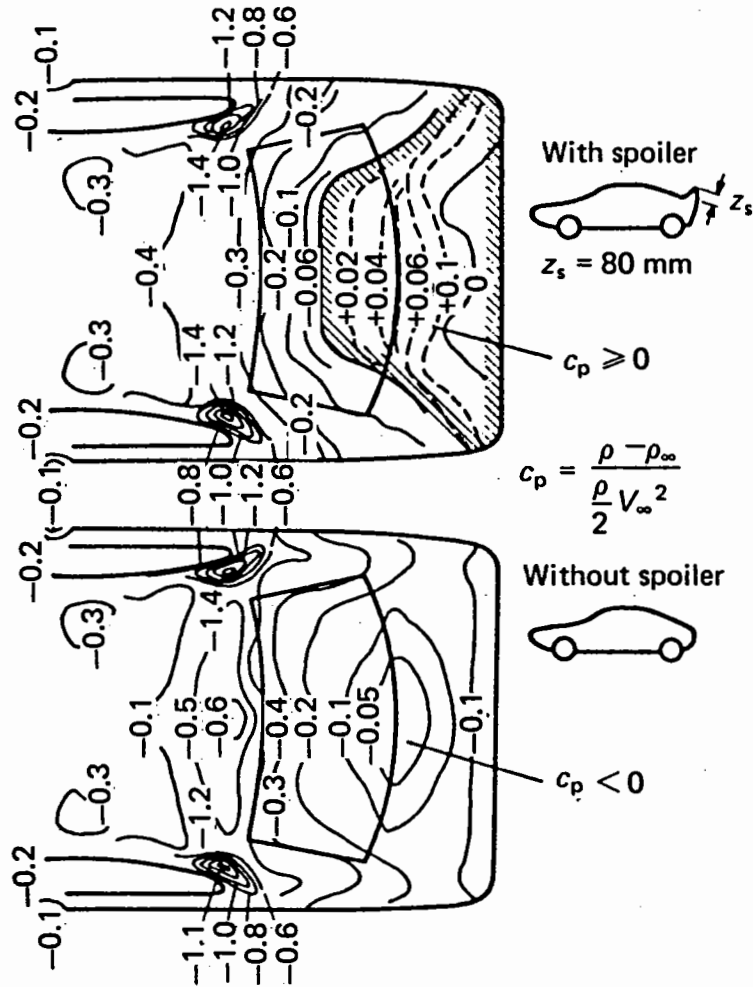
4

3.5/2

3/3/80

V/6





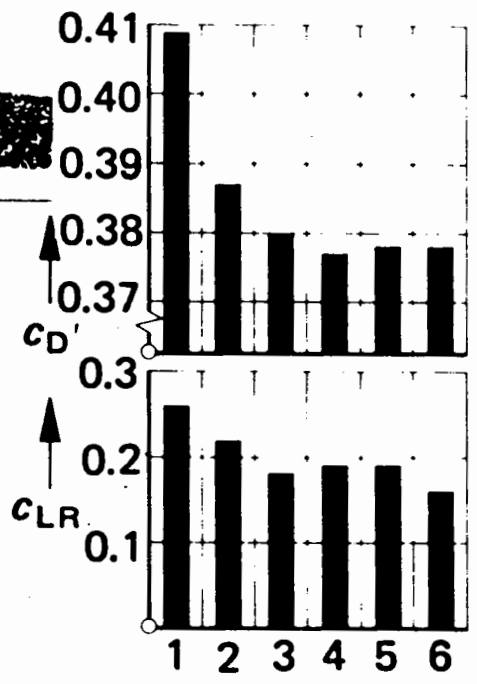
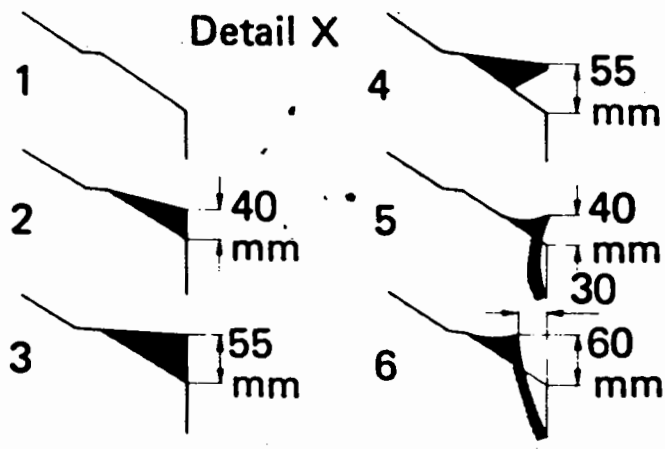
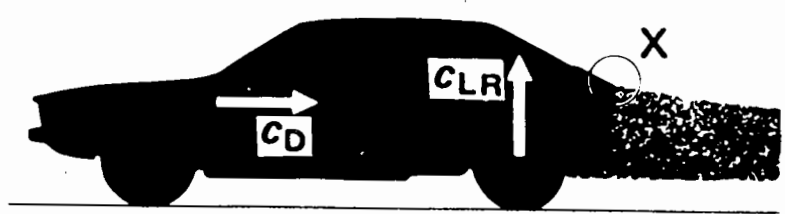
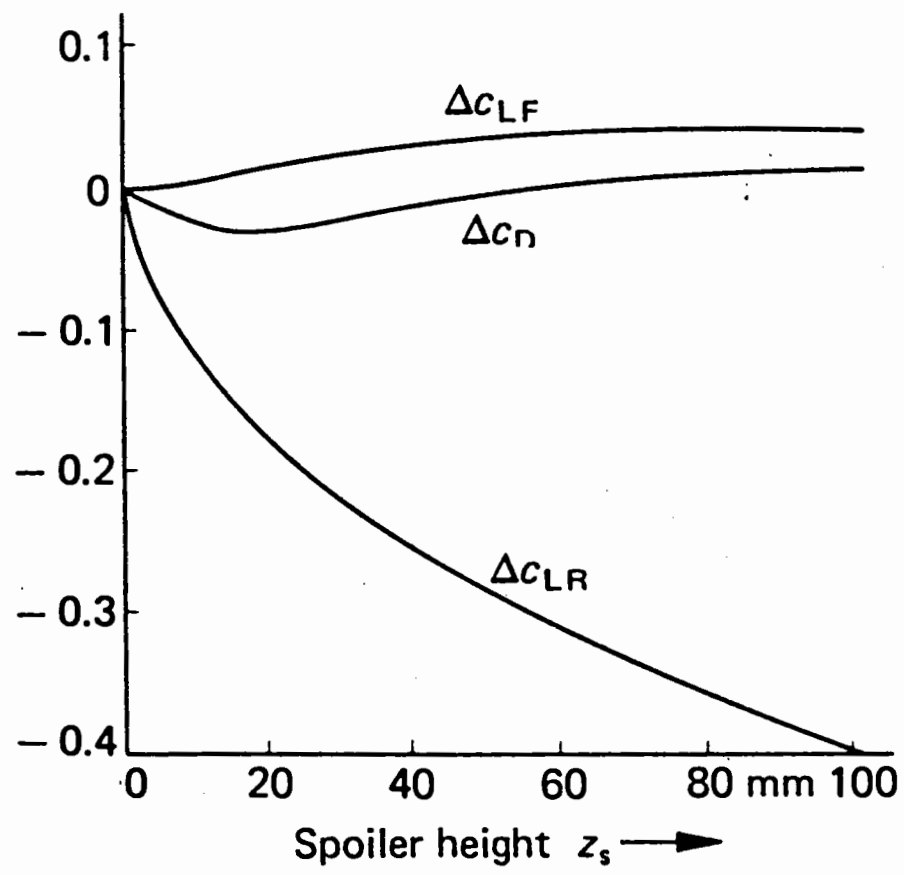
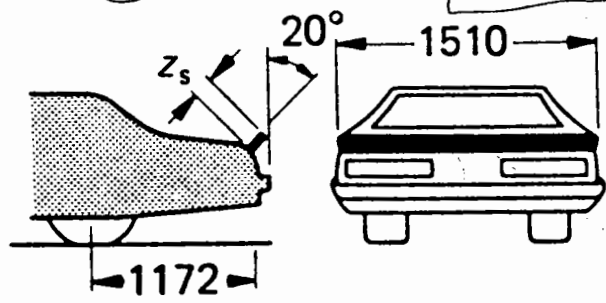
18

(35)

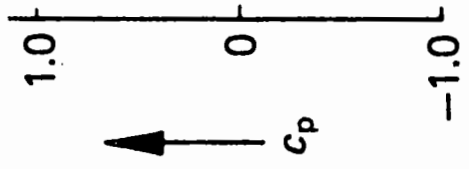
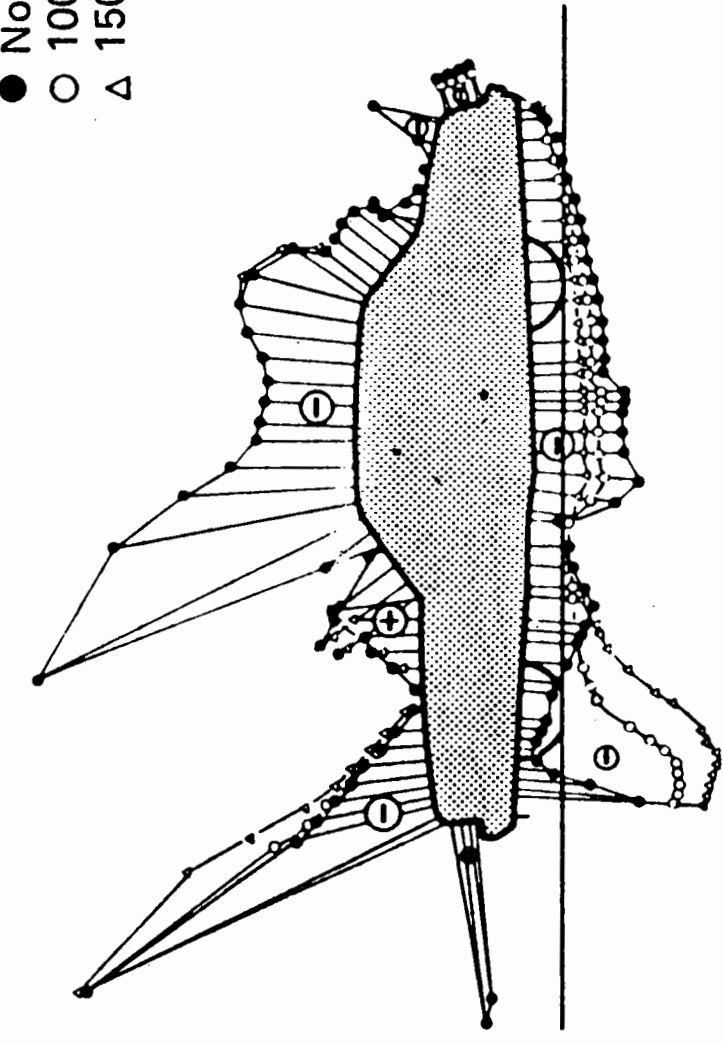
3.5.12

3/3/12

V/8



- No spoiler
- 100 mm spoiler height
- △ 150 mm spoiler height



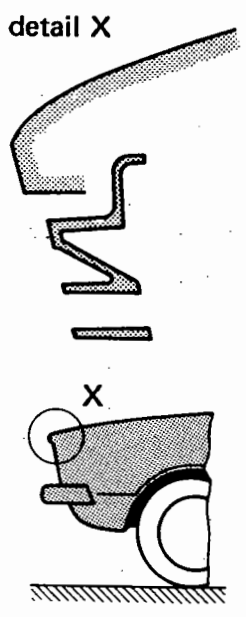
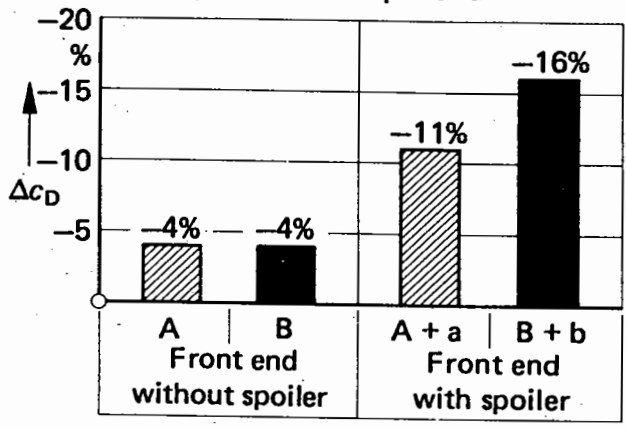
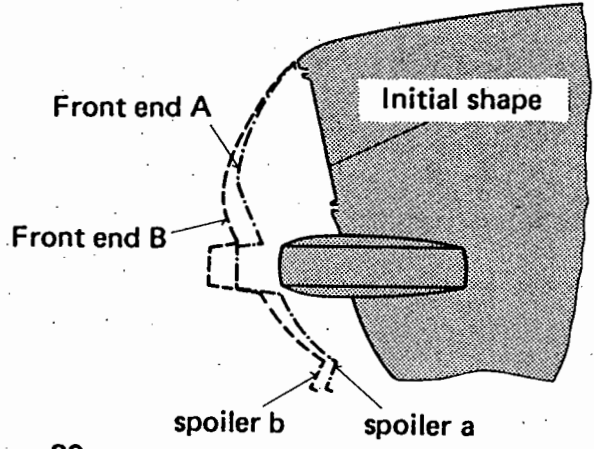
17

18

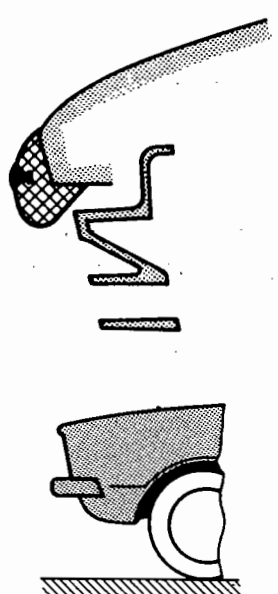
3.2/5

3/4/4

IV 8

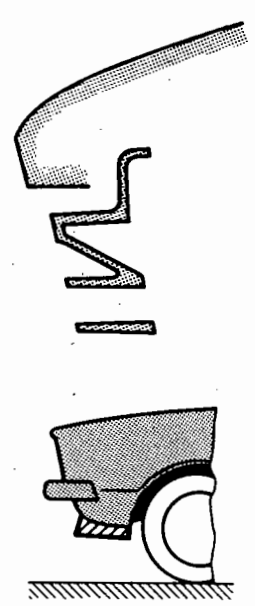


Initial shape



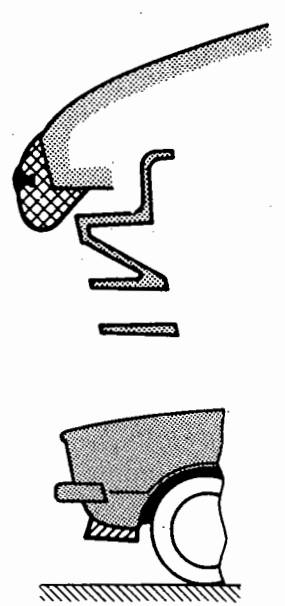
Shape B

$\Delta c_D = -2\%$
 $\Delta c_{LF} = -8\%$



Shape C

$\Delta c_D = -2\%$
 $\Delta c_{LF} = -30\%$

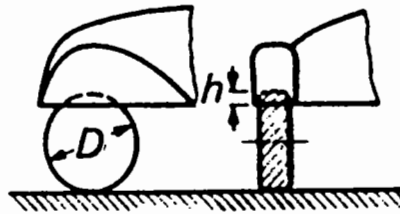
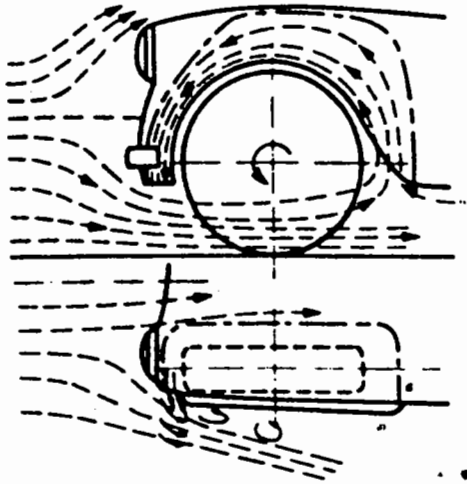


Shape D

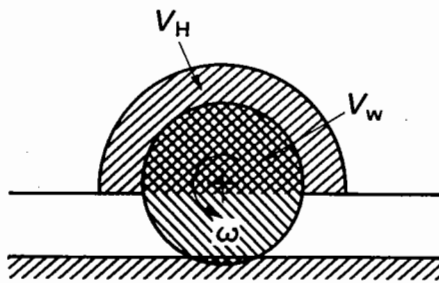
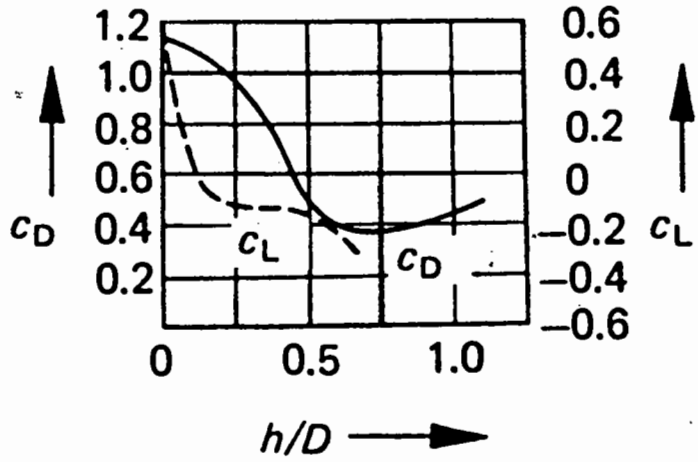
$\Delta c_D = -8\%$
 $\Delta c_{LF} = -32\%$

3.6.7

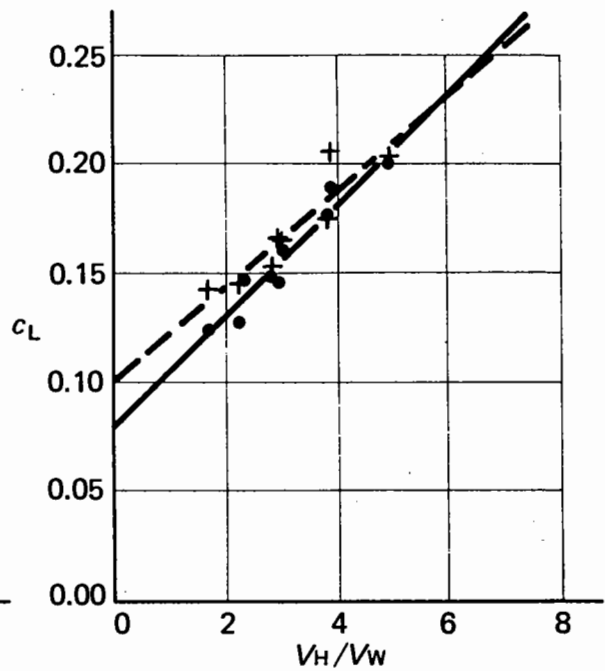
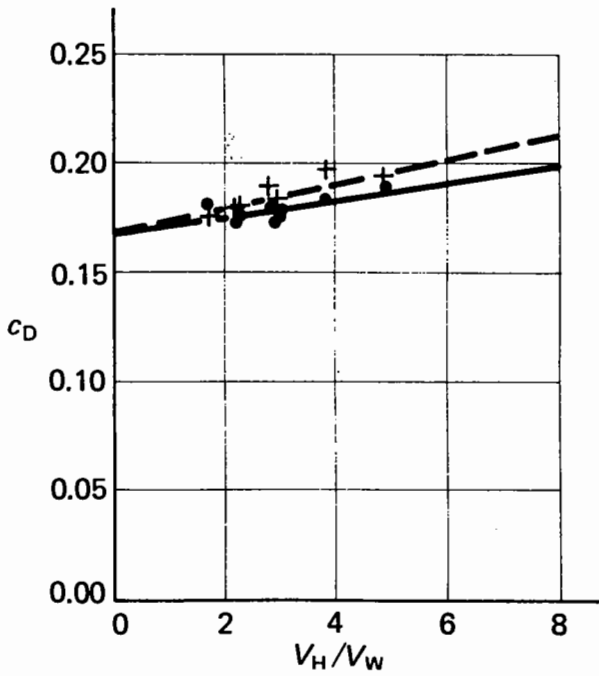
3/4/5

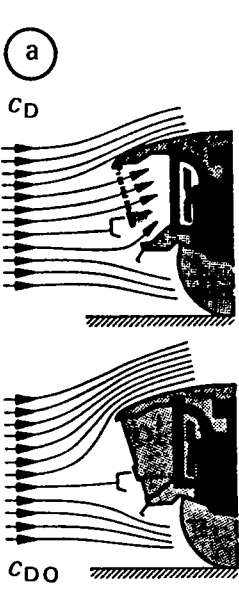


$C_e = 0,6$
 $C_f = 0,4$



| | |
|------------------------|--|
| $\omega = 0$ | |
| $\omega = \frac{V}{R}$ | |

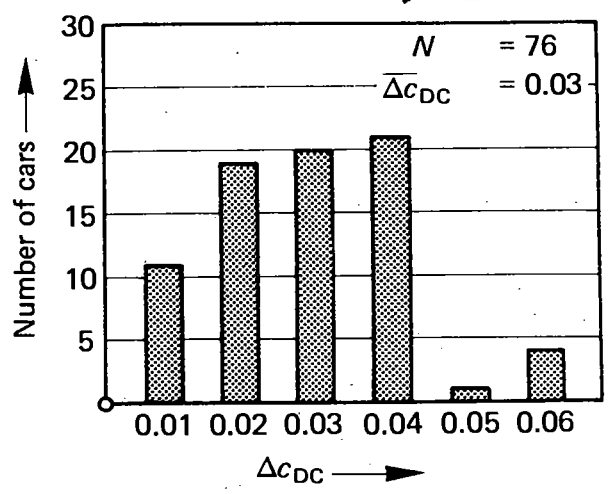




(23)

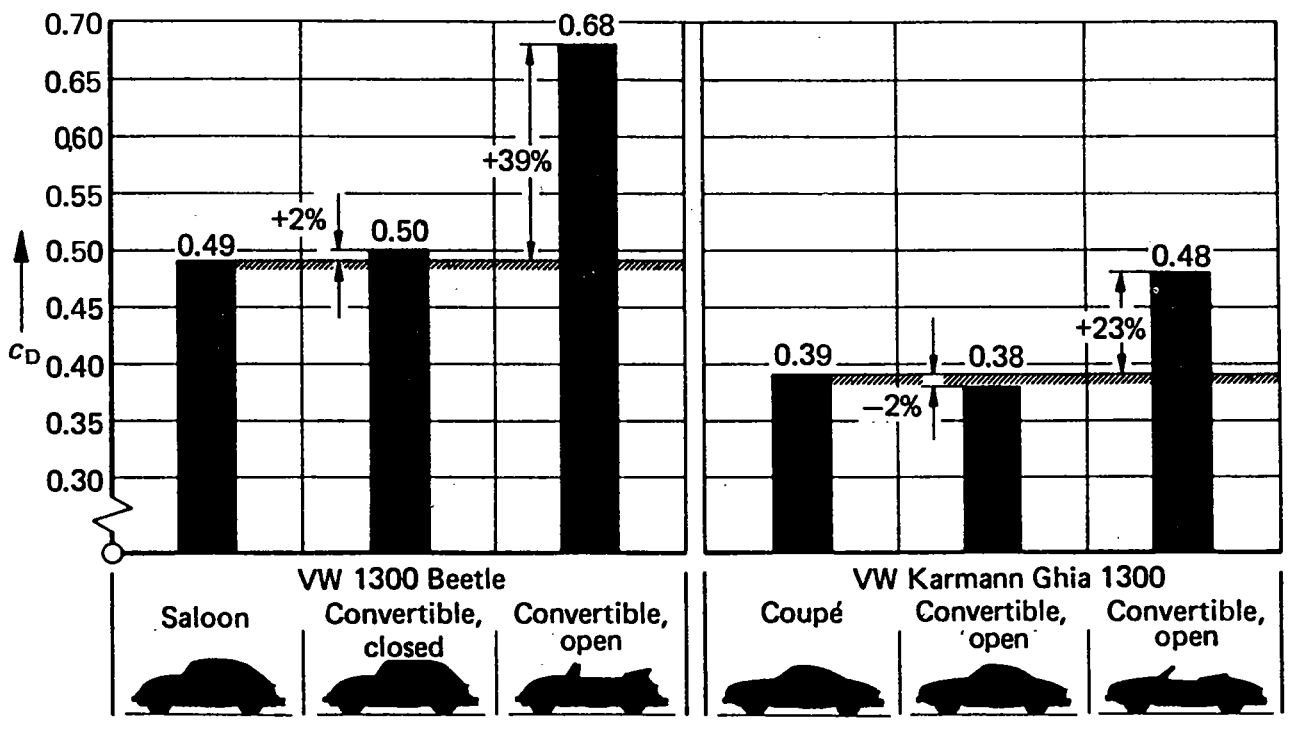
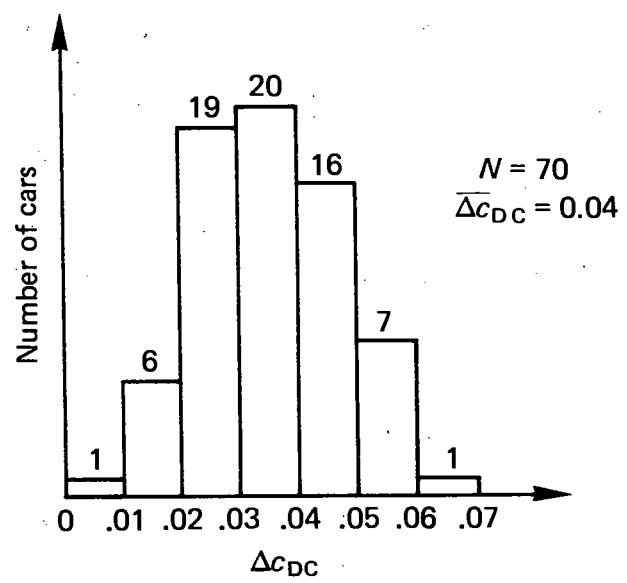
3.2/6

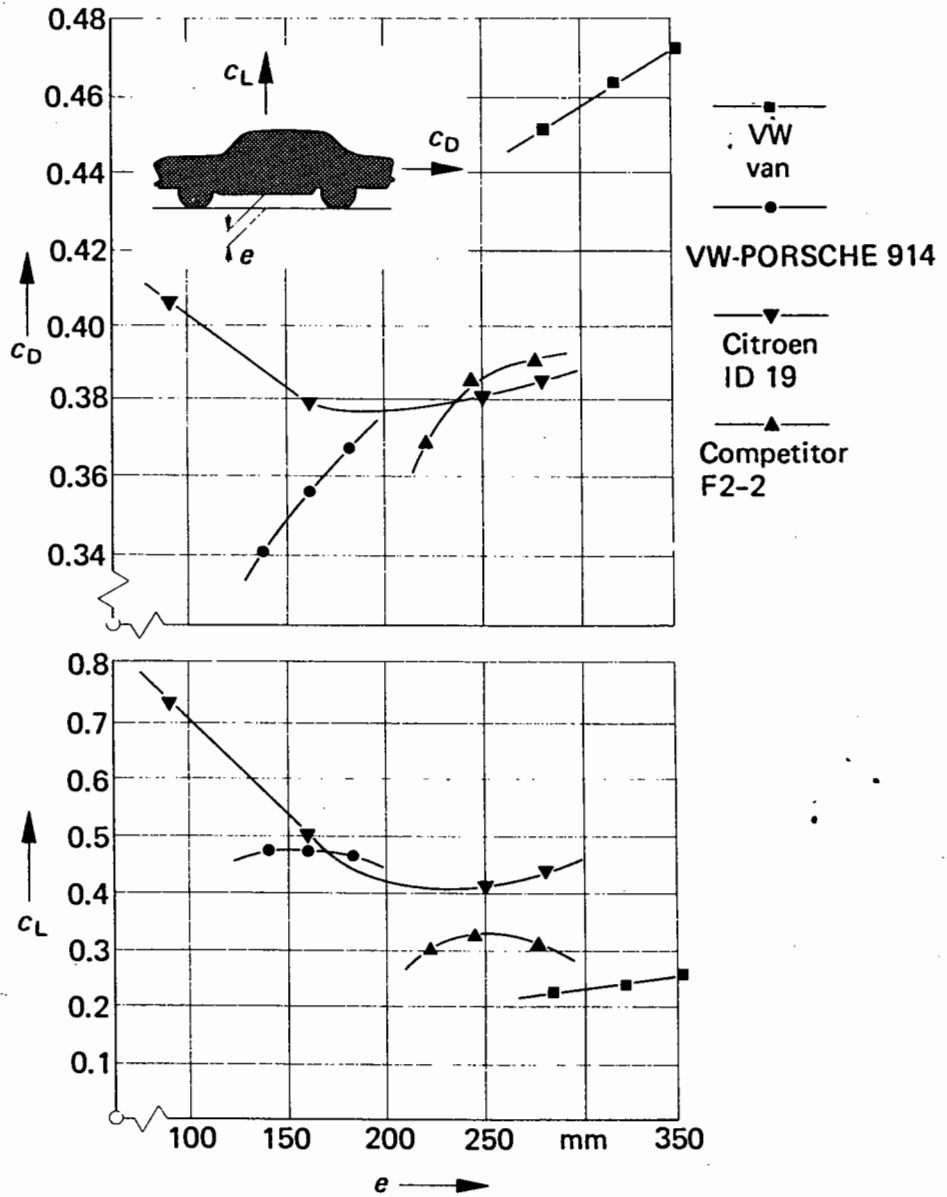
3/5/1

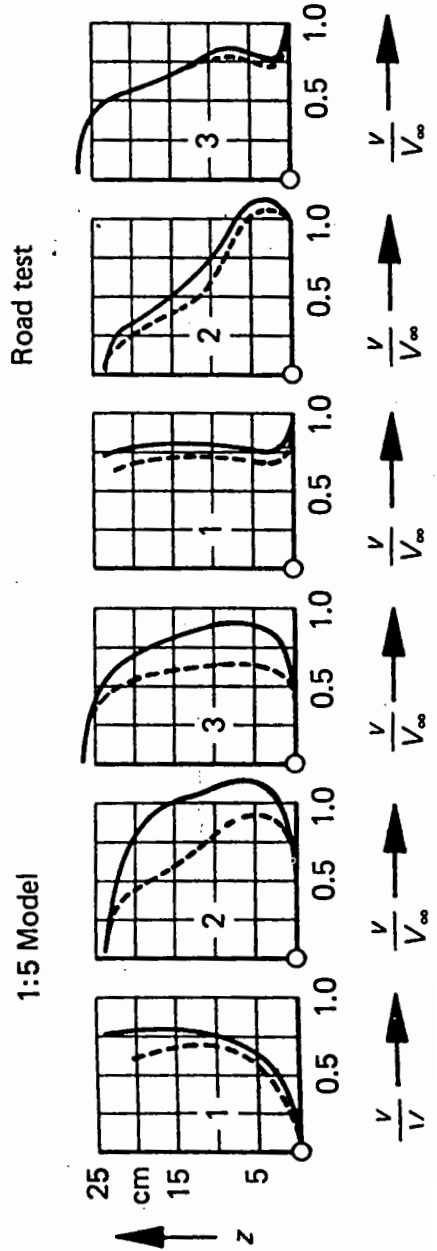
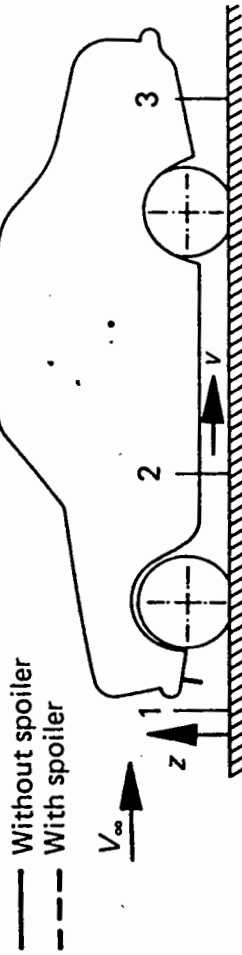
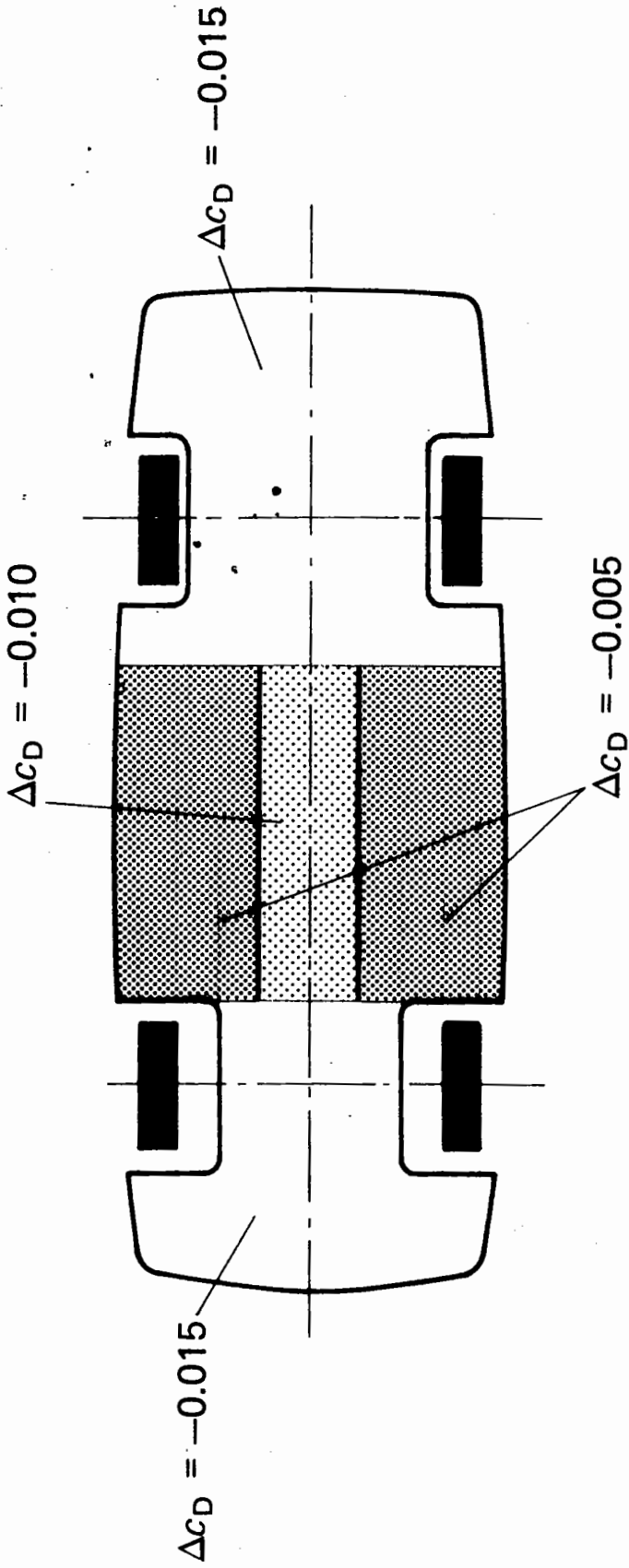


$\Delta c_{DC} = c_D - c_{DO}$

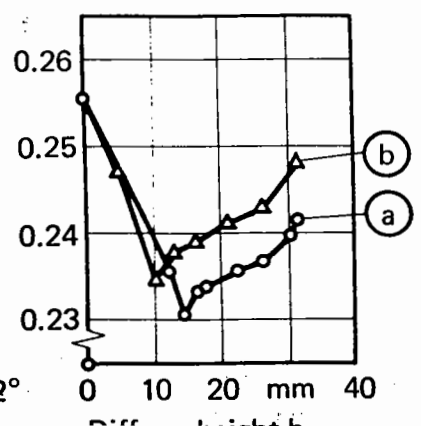
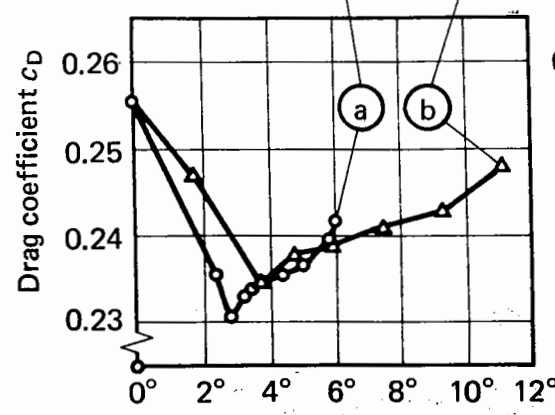
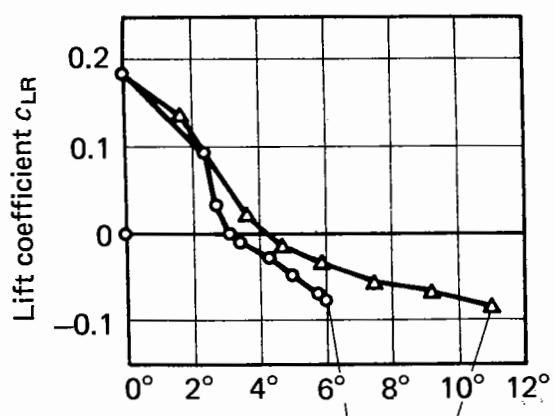
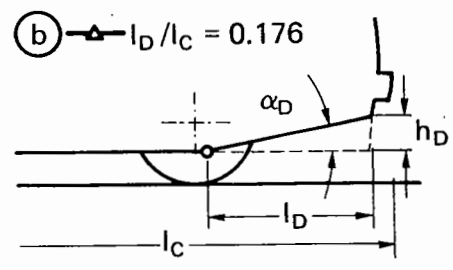
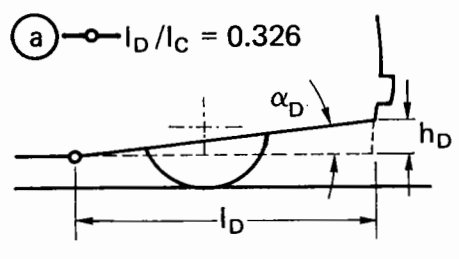
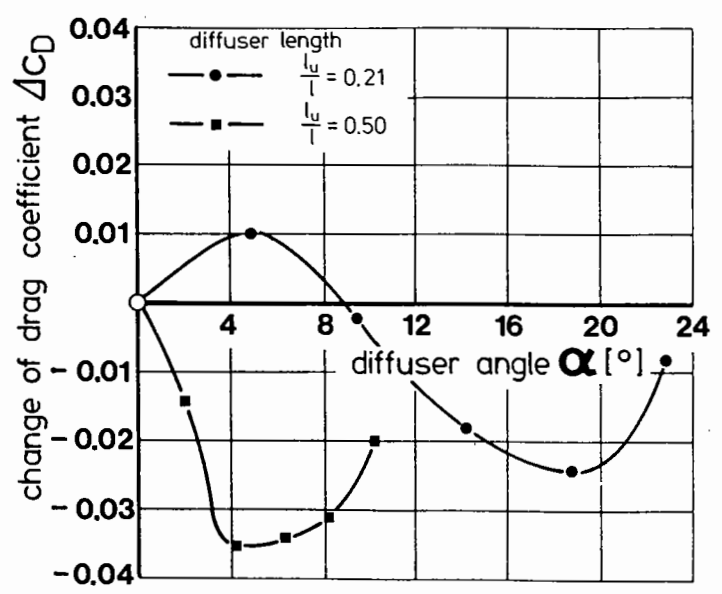
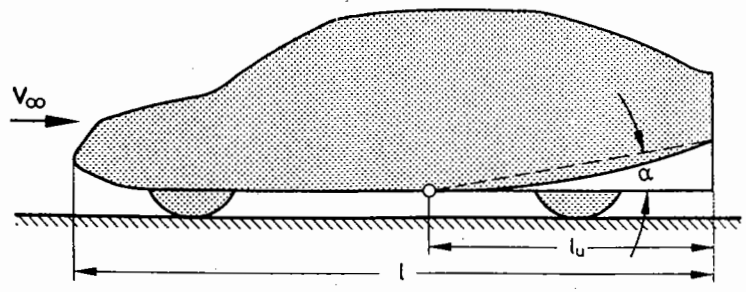
(b)





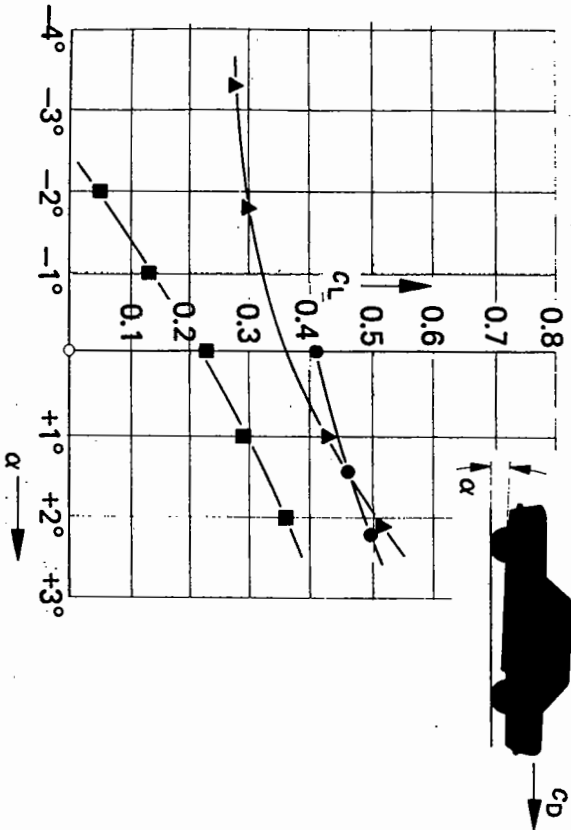
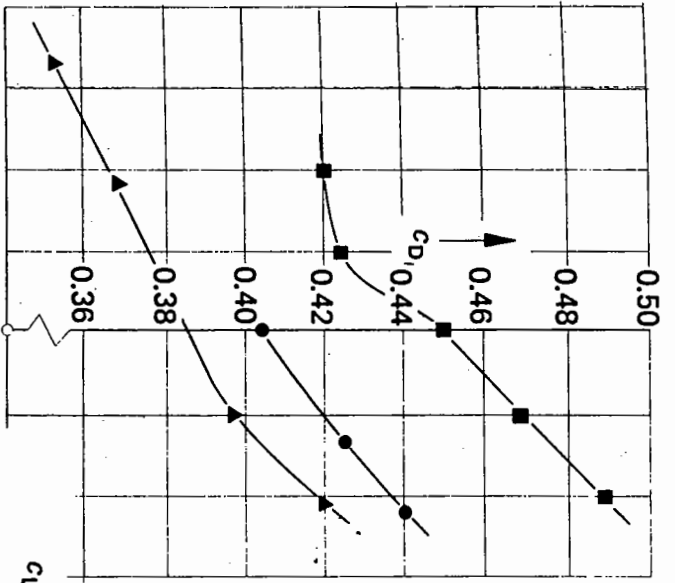


4/11

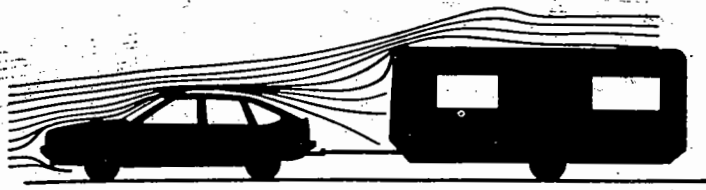
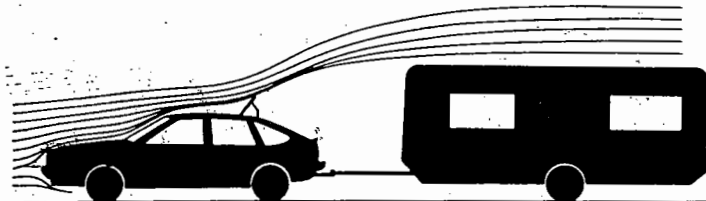
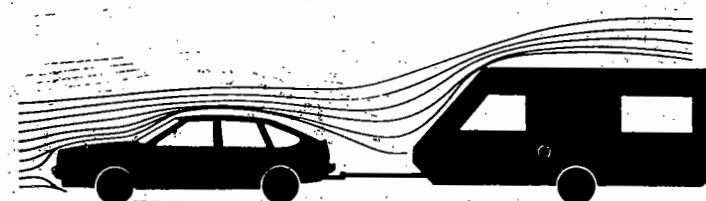


3/5/2 48

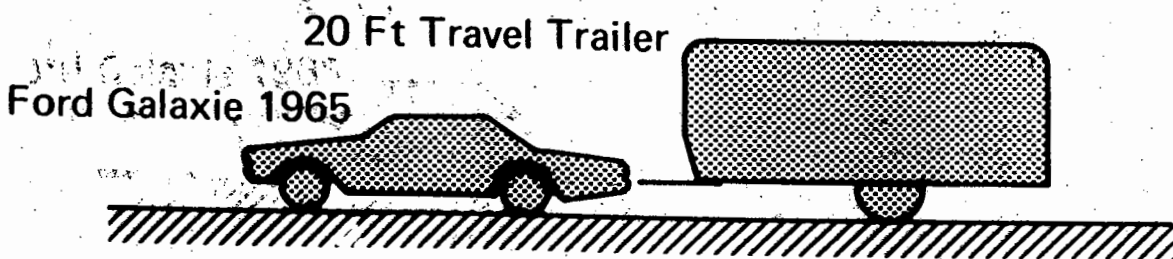
3.6.2 41

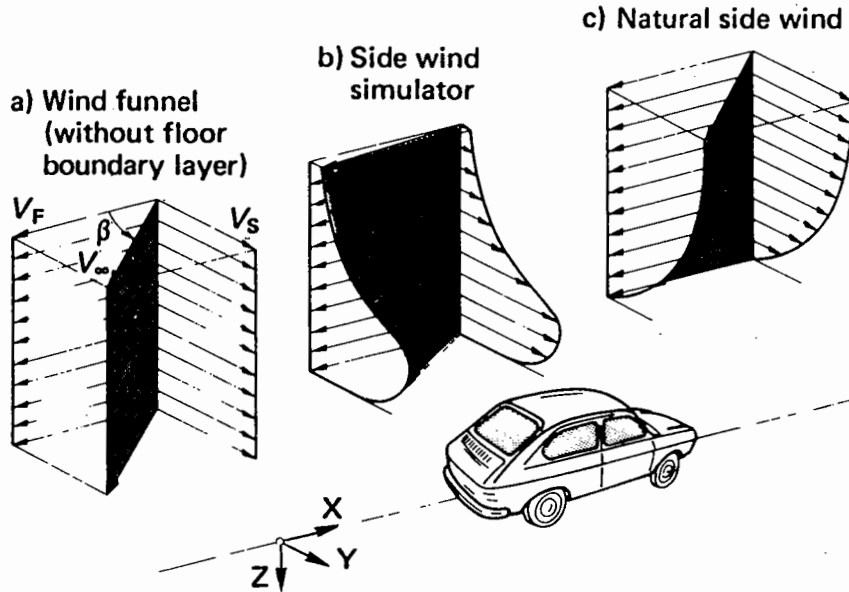


| | |
|--|------------------------|
| <p>(A)</p> <p>$\frac{\Delta c_D}{c_D} = 0.10$</p> | <p>(E)</p> <p>0.28</p> |
| <p>(B)</p> <p>0.13</p> | <p>(F)</p> <p>0.33</p> |
| <p>(C)</p> <p>0.28</p> | <p>(G)</p> <p>0.38</p> |
| <p>(D)</p> <p>0.18</p> | |

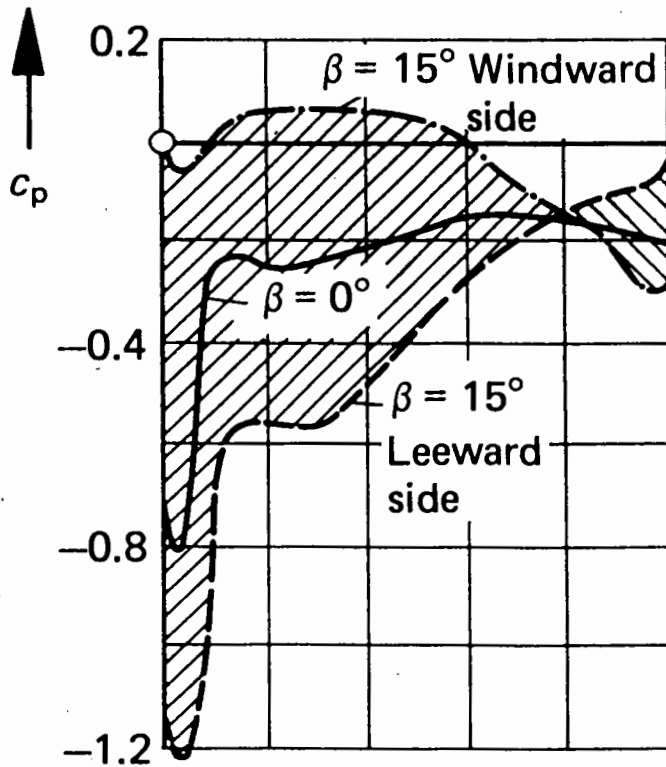
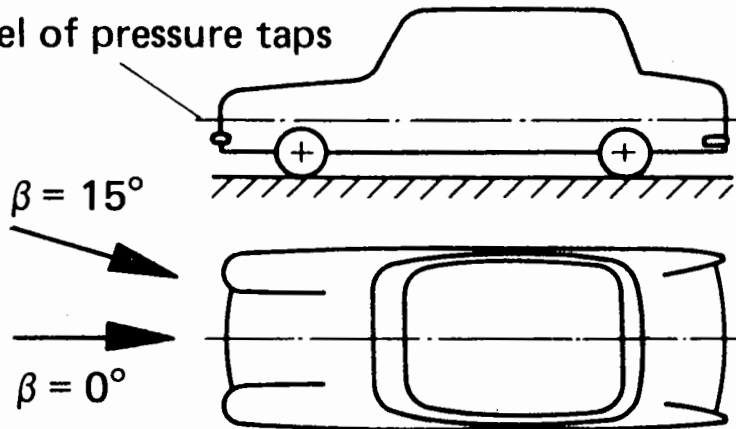
| | c_D car + trailer ¹ | Load change at the hitch (N) at $V = 80$ km/h (50 mph) |
|---|----------------------------------|--|
|  | 0.53 | -340 ² |
|  | 0.45 | -315 ² |
|  | 0.53 | ±0 |

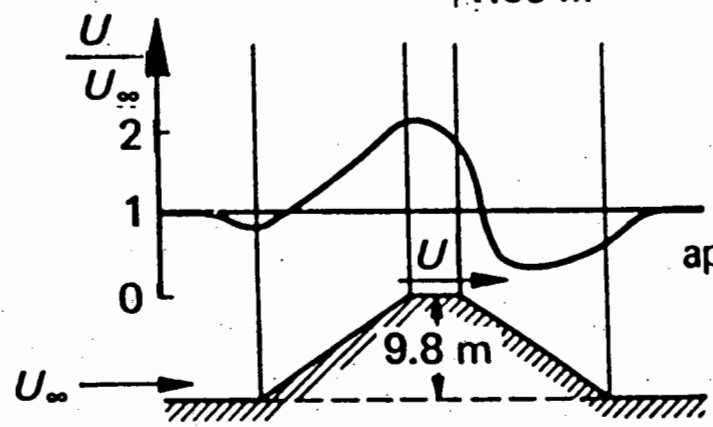
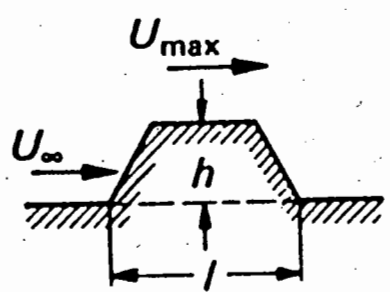
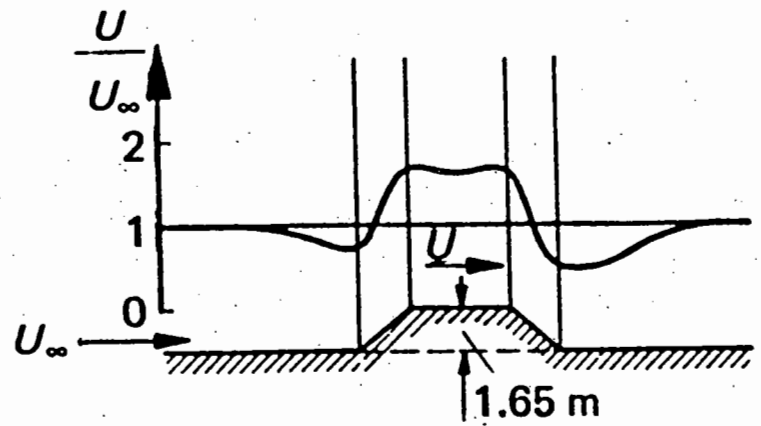
| | A [ft ²] | c_D | $c_D \cdot A$ | $c_{DA} \text{ Car}$ |
|-------------------------|----------------------|-------|---------------|----------------------|
| Car without trailer | 24.6 | 0.53 | 13.0 | = 1.9 |
| Car in front of trailer | 24.6 | 0.30 | 7.4 | |
| Trailer without car | 54.2 | 0.62 | 33.6 | = 1.6 |
| Trailer behind car | 54.2 | 0.59 | 32.0 | |



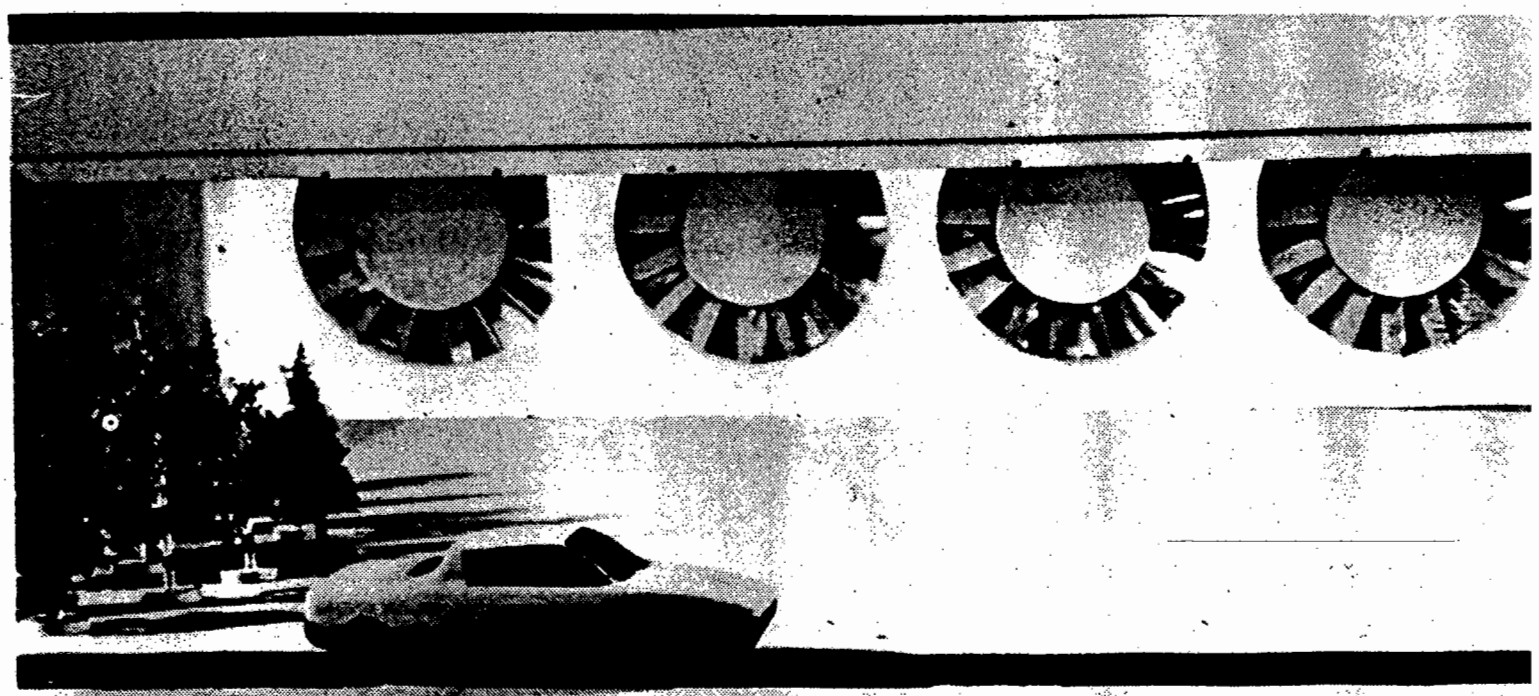


Level of pressure taps

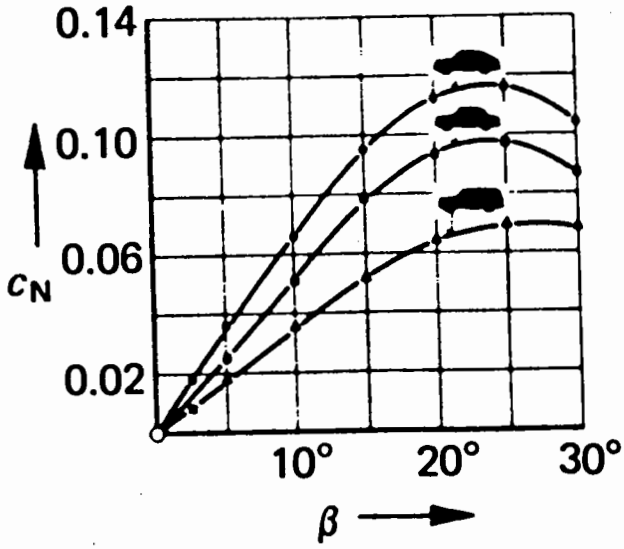




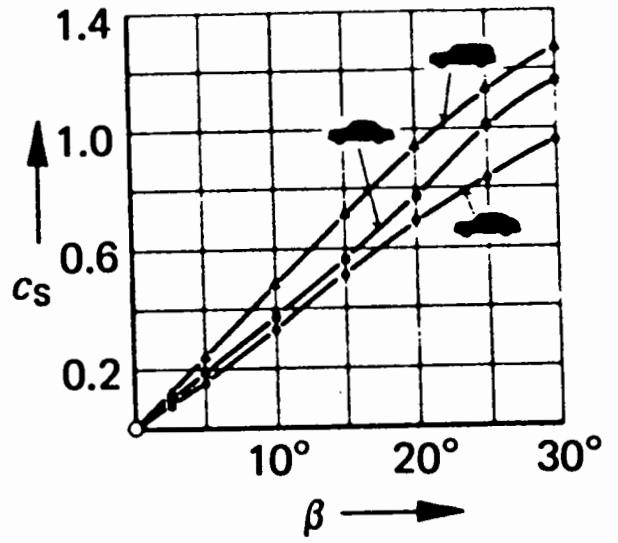
approximation $\frac{U_{\max}}{U_\infty} \approx 1 + \frac{2h}{l}$



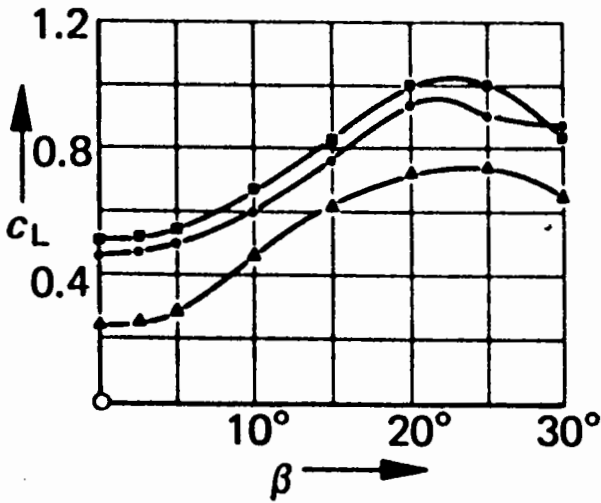
fordító yonath



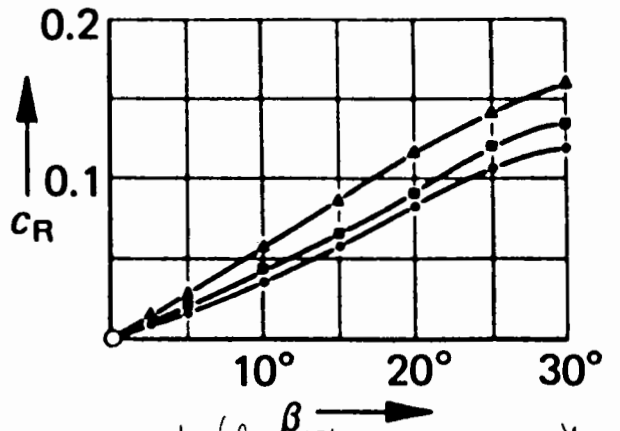
oldaloró



felhagyó oró

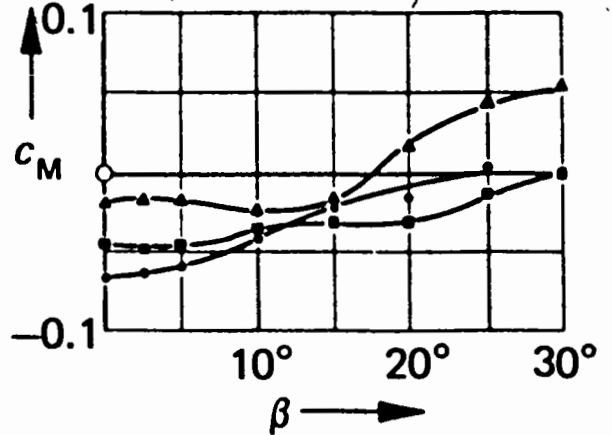


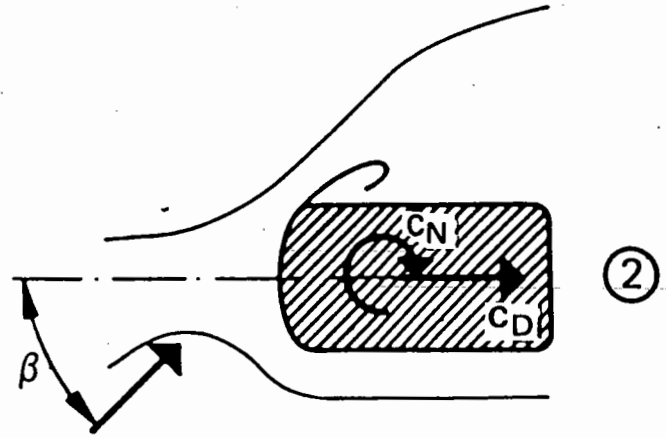
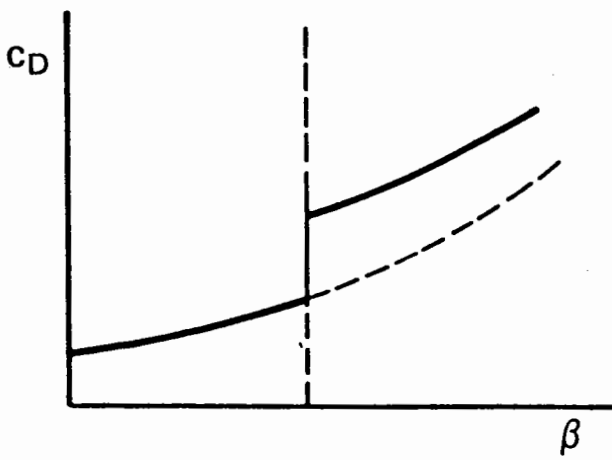
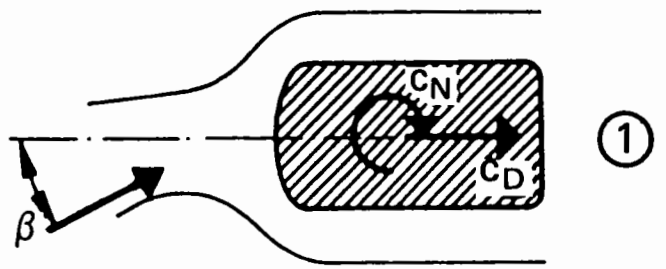
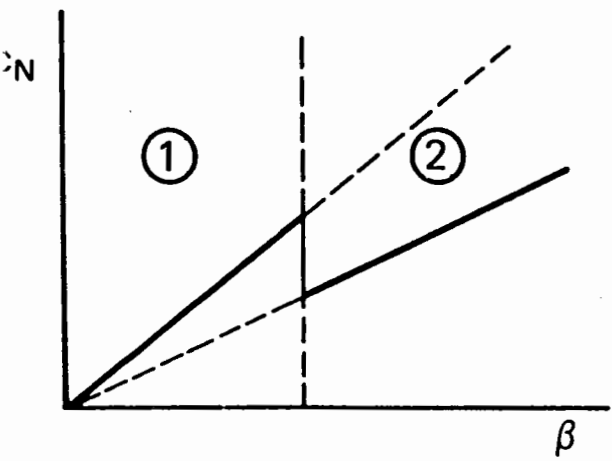
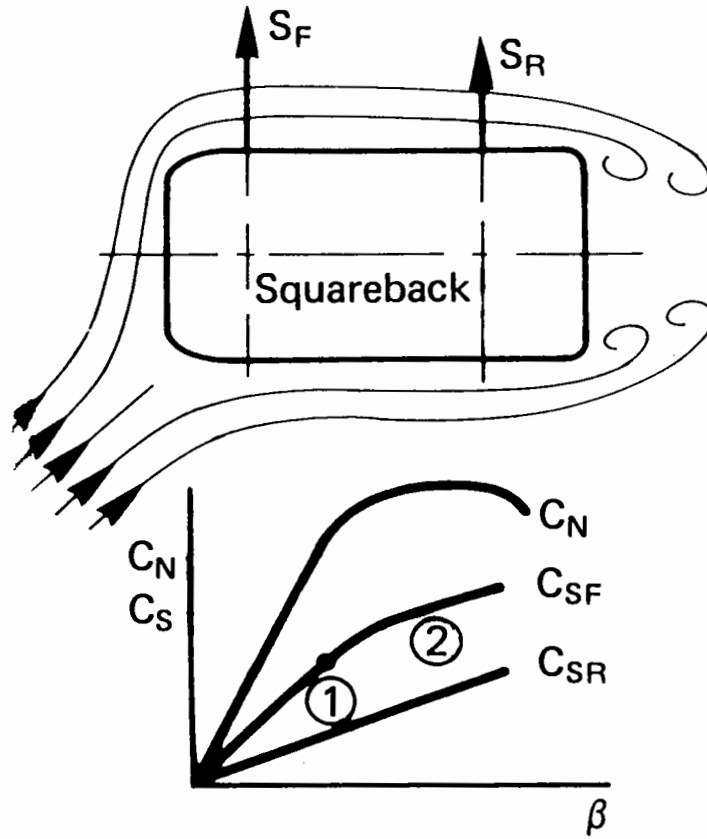
orórá yonath



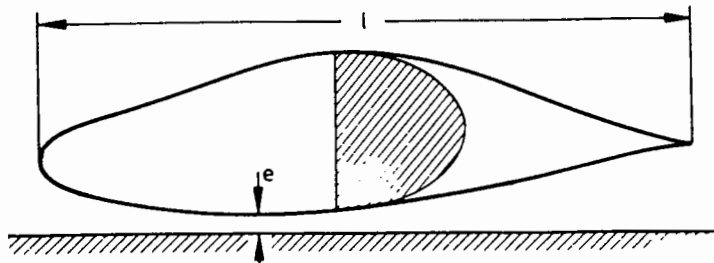
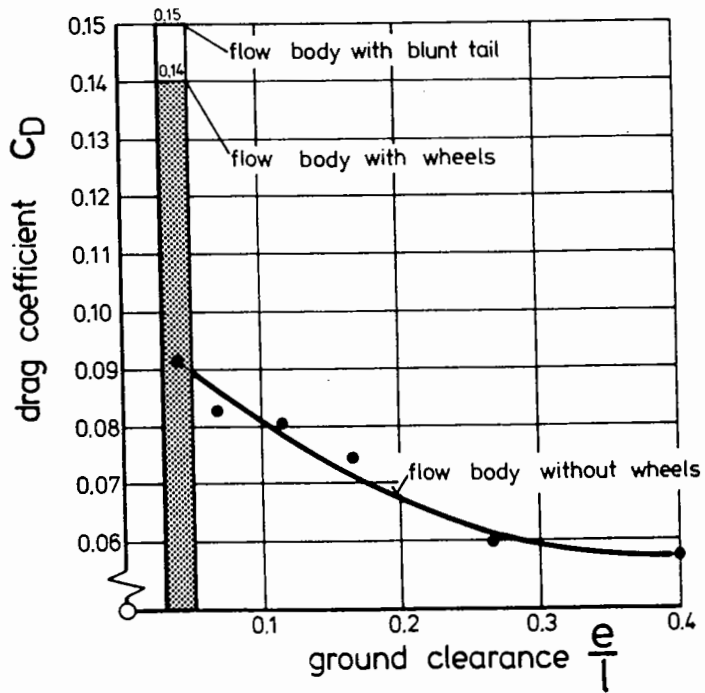
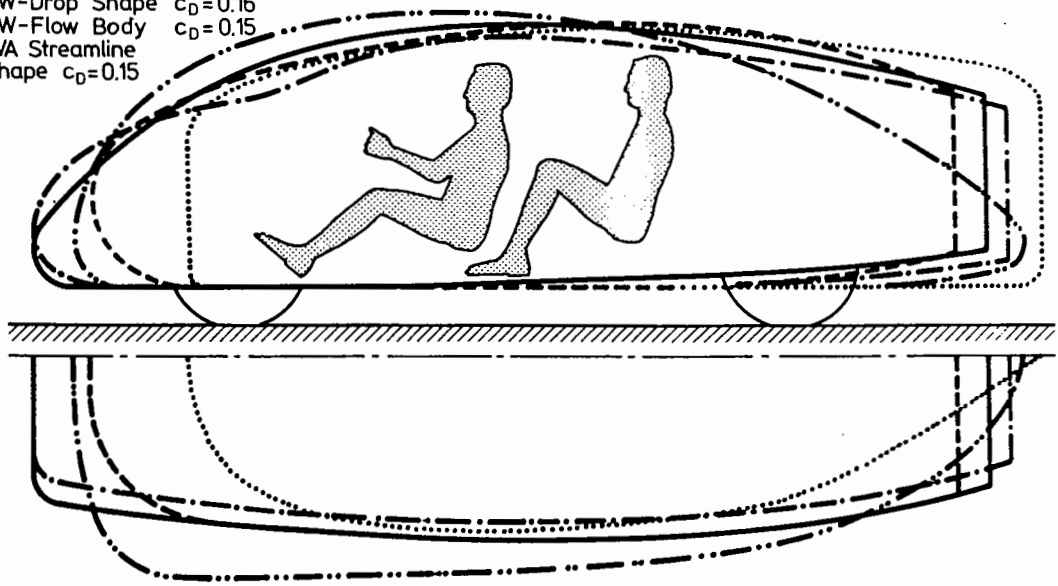
- Type 31 fastback
- Type 31 notchback
- ▲— Type 36 squareback

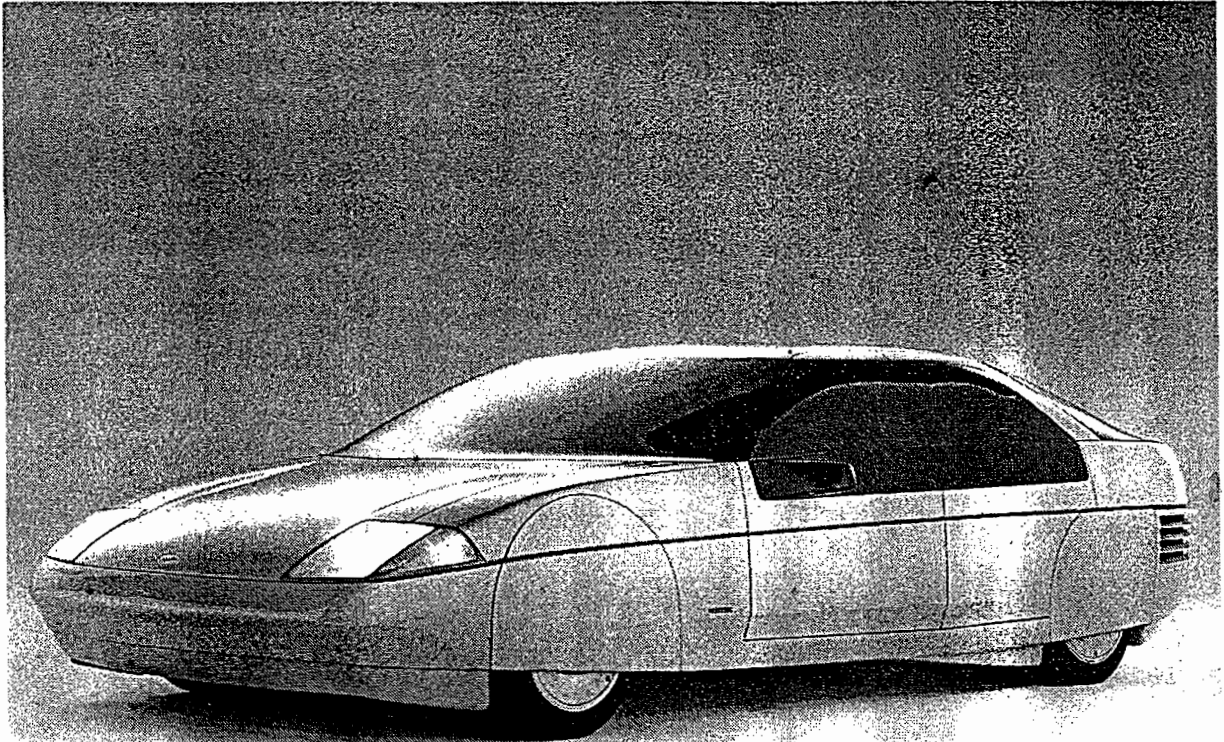
bólító yonath





- VW-Blunt Body $c_D=0.15$
- - - VW-Blunt Body $c_D=0.16$
- ⋯ VW-Drop Shape $c_D=0.16$
- · - VW-Flow Body $c_D=0.15$
- · - AVA Streamline Shape $c_D=0.15$





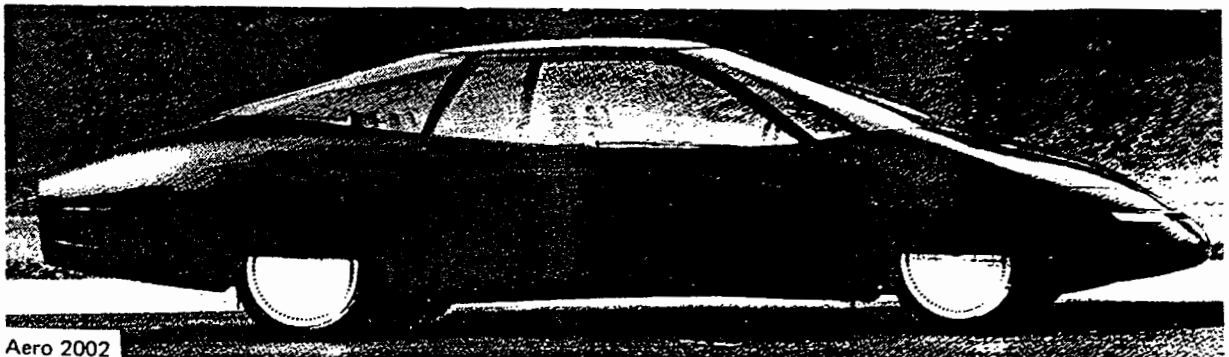
Ford Probe IV
 $C_e = 0.15$

(a)



Aero 2000
 $C_e = 0.23$

(b)



Aero 2002

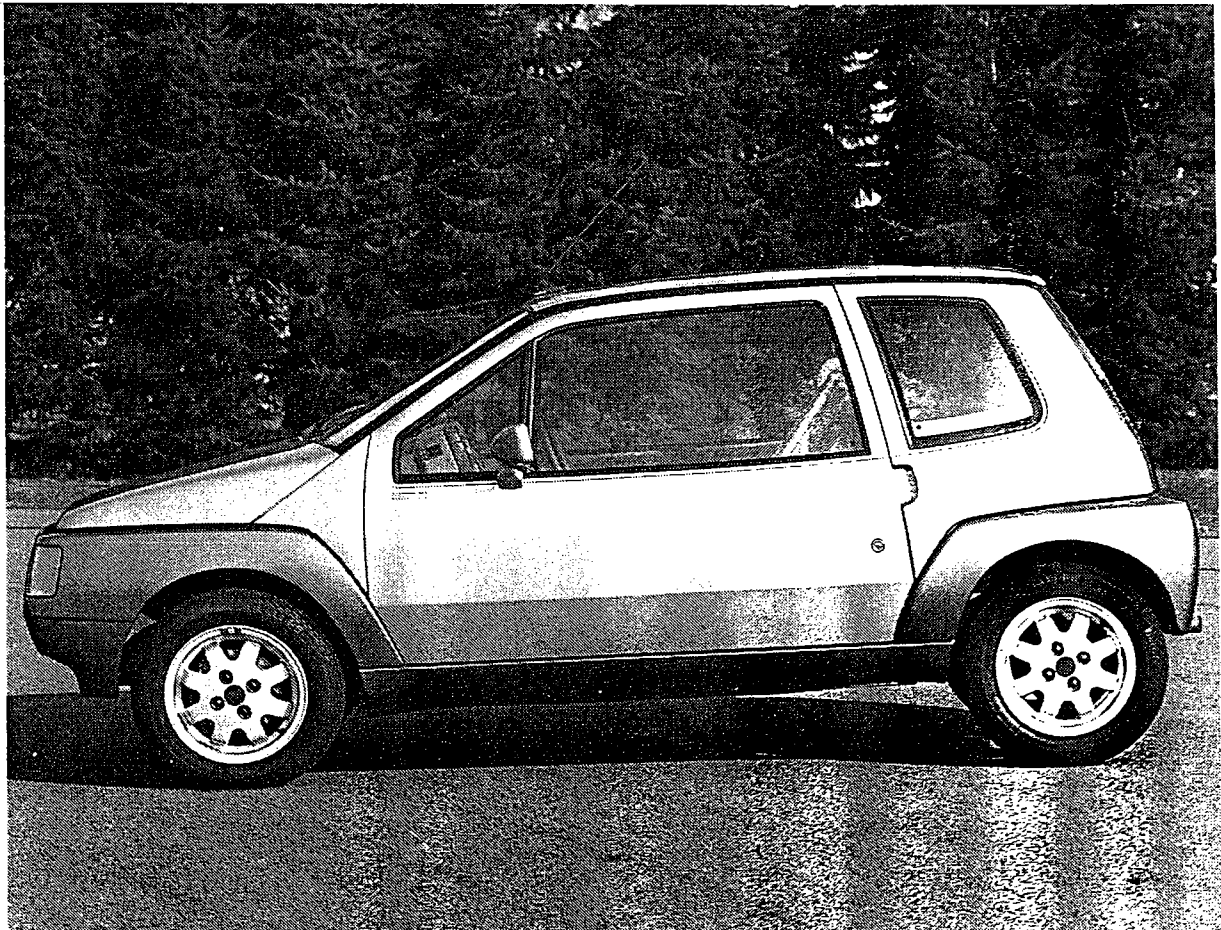
$C_e = 0.14$

(c)



(d)

Opel Junior
 $C_e = 0.31$



(e)

VW student $C_e = 0.3$

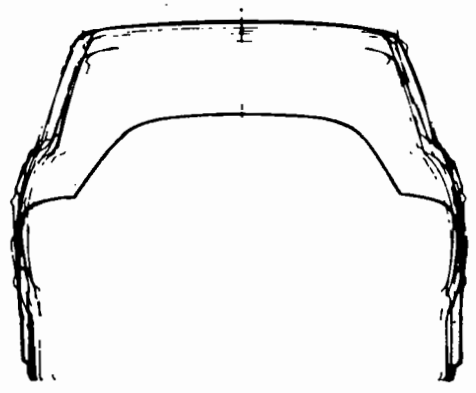
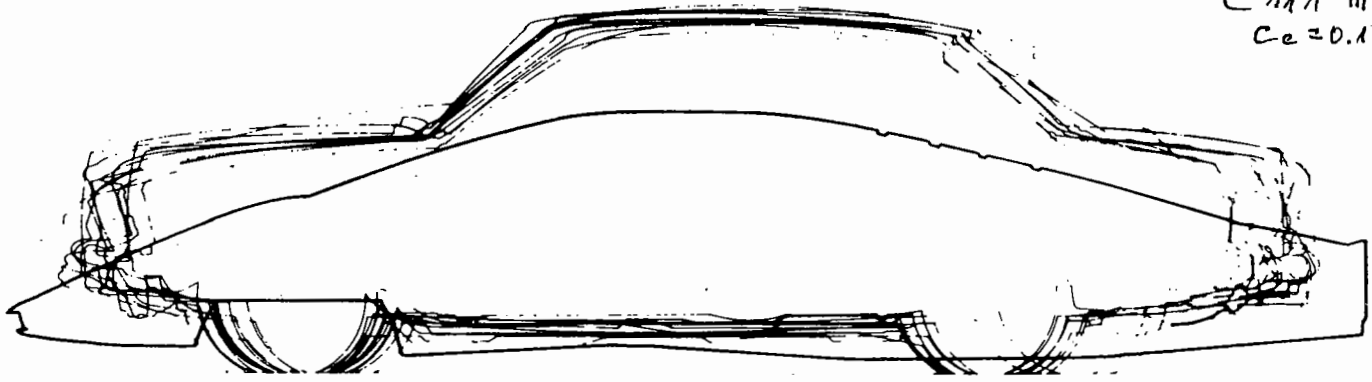
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3.7.4

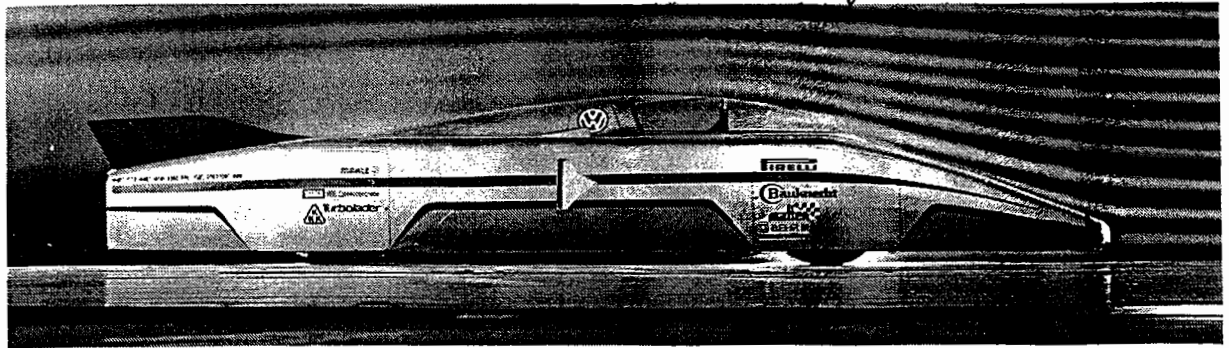
3.6.4



Mercedes Benz
 C 111 III
 $C_e = 0.18$ $A =$



VW Aerodynamic Research Vehicle



$C_e = 0.15$
 $A = 0.75 \text{ m}^2$