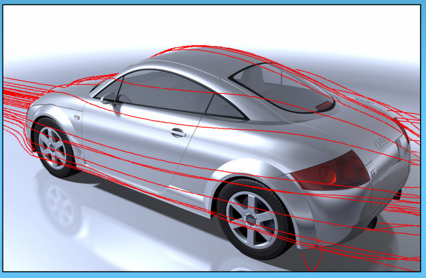
VEHICLE AERODYNAMICS

Introduction



by Rossi 2002 (University of Bologna)

Alessandro Talamelli
KTH-Mekanik
University of Bologna

1

- Course layout
- Importance of vehicle aerodynamics
- Historical review
- Aerodynamics as part of the design process

2

Schedule

I part

Week	Date	Day	Time	Room	Lect.	Notes
11	07-03-14	Wednesday	10-12	V3	AT	1st Lecture
11	07-03-15	Thursday	13-15	V3	AT	2nd Lecture
12	07-03-20	Tuesday	13-15	V3	AT	3rd Lecture
12	07-03-21	Wednesday	10-12	V3	AT	4th Lecture
12	07-03-22	Thursday	13-15	V3	AT	5th Lecture
13	07-03-27	Tuesday	13-15	V3	AT	6th Lecture
13	07-03-28	Wednesday	10-12	V3	AT	7th Lecture
13	07-03-29	Thursday	13-15	V3	AT	8th Lecture + Projects
13	07-03-30	Friday	9-11	-	PE	Elofsson-SCANIA

3

II part

Week	Date	Day	Time	Room	Lect.	Notes
16	07-04-18	Wednesday	10-12	V3	AT	9th Lecture
16	07-04-19	Thursday	13-15	V3	AT	10th Lecture
16	07-04-20	Friday	-	-	-	External Lecture
17	07-04-24	Tuesday	13-15	V3	AT	11th Lecture
17	07-04-25	Wednesday	10-12	E2	AT	12th Lecture
17	07-04-27	Friday	-	-	-	External Lecture
18	07-05-02	Wednesday	13-15	M3	AT	13th Lecture
18	07-05-03	Thursday	10-12	E2	AT	14th Lecture
18	07-05-04	Friday	13-15	V3	AO	Orellano-BOMBARDIER
19	07-05-11	Friday	-	-	LM	Mariella -FERRARI
20	07-05-14	Monday	8-18	MTL	AT	Lab. exercise
20	07-05-15	Tuesday	8-18	MTL	AT	Lab. exercise
20	07-05-16	Wednesday	9-13	-		Project presentation I
20	07-05-16	Wednesday	15-17	-		Project presentation II
21	07-05-21	Monday	-	-	AT	Written Test
21	06-05-22/23				AT	Oral Exams

4

Contents of the course

- Introduction and general overview
- Kinematics of fluids
- Fundamental Equations
- The boundary layer – Aerodynamic and bluff bodies
- Aerodynamic Forces – Lift and Drag
- Bluff body aerodynamics
- The aerodynamics of a passenger car

- Aerodynamics of rail vehicles
- CFD
- Experimental aerodynamics
- High performance vehicles

5

External lecturers I

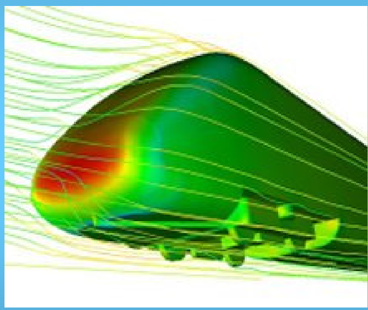
Experimental methods in vehicles aerodynamics
Aerodynamics of commercial vehicles

Per Elofsson
SCANIA CV AB, Fluid Mechanics
Senior Aerodynamicist

6

External lecturers II

Aerodynamics of Rail Vehicles

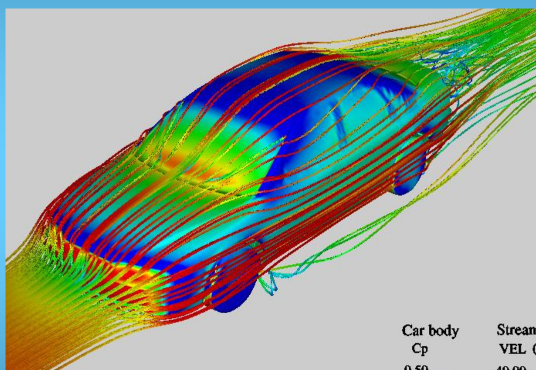


Alexander ORELLANO
Bombardier, Fluid Mechanics
Head of the Aerodynamic group

7

External lecturers III

CFD in Vehicle Aerodynamics

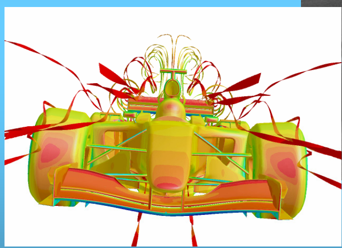


Simone Sebben
CFD Engineer Aerodynamics
Volvo CC.

8

External lecturers IV

The role of CFD in the aerodynamic design of a Ferrari Formula 1 car



Luciano MARIELLA

FERRARI F1 GeS

9

Laboratory exercise (14-15 May)

10

Projects (16 May)

Aerodynamic Devices on Superbikes

Lionel Fiabane - 820805-A311
Romain Mérat - 811029-A518

Royal Institute of Technology, SE-100 44 Stockholm, Sweden

May 18, 2005

Royal Institute of Technology
KTH

5C1211 Vehicle aerodynamics

"Aerodynamics of commercial vehicles"

Mustafa Barri
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An Chen
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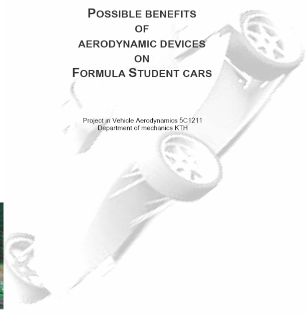
POSSIBLE BENEFITS OF AERODYNAMIC DEVICES ON FORMULA STUDENT CARS

Project in Vehicle Aerodynamics 5C1211
Department of mechanics KTH



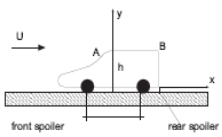
Robert Ny
790614-1515
roppan@kth.se

Final test (21 May)

Name	Family name	Personal Number	e-mail

Stockholm 050901

I) Consider the following 2D car travelling at 100 Km/h:



I- a) Define the local friction coefficient C_f

I- b) Can be the friction coefficient C_f negative ?

☐ yes ☐ no, never ☐ only in compressible flows

I- c) Where ?

☐ on the windshield ☐ in recirculating bubbles ☐ in the center on the roof

I- d) Write on the car a plus where the friction coefficient C_f is high and where you think is close to zero

I- e) How much is the friction coefficient at the separation point ?

☐ maximum ☐ minimum ☐ zero

I- f) What happen to the friction coefficient if the air temperature increases ?

☐ decreases ☐ remains the same ☐ increases

I- g) Why?

Books

R.H. Barnard (2001):"Road Vehicle Aerodynamic Design, 2nd edition". MechAero Publishing, 2001. ISBN 0954073401

Hucho, Wolf-Henrich (1998) "Aerodynamics of road vehicles, 4th edition" SAE International. (can be ordered at http://www.sae.org/products/books/R-177.htm)

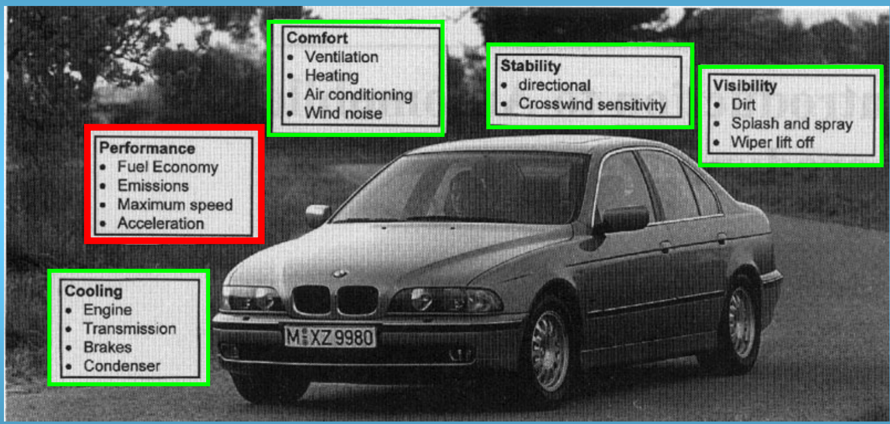
Additional material will be given out during the course.

13

Importance of vehicle aerodynamics

14

Importance of vehicle aerodynamics



Importance of drag

Drag coefficient :

$$c_D = \frac{D}{\frac{1}{2}\rho V^2 A}$$

D = drag force

A = front area

ρ = air density

V = vehicle speed

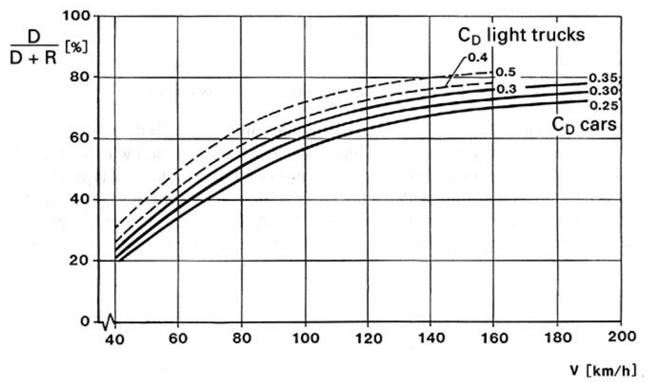


Fig. 3.6 Fraction of aerodynamic drag D in total drag D + R.

Impact of drag on fuel consumption

- Reduced drag more efficient than reduced mass or installed power
- Which parameter is easiest to change?
- Important with relevant driving cycles!

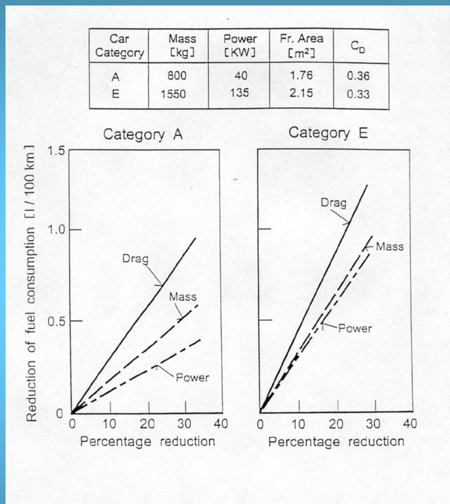
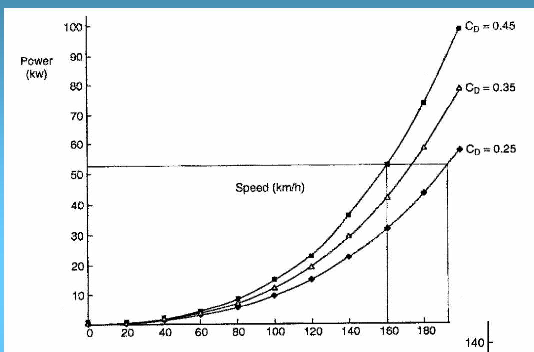


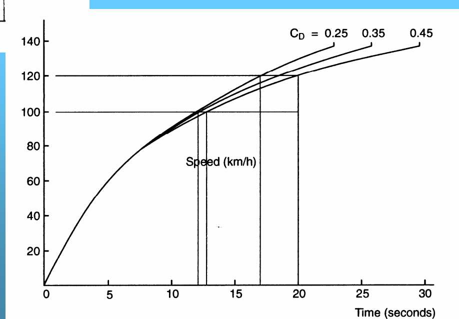
Fig. 2 Impact of Drag, Mass and Power Reduction on Fuel Consumption

From Ahmed (1999)

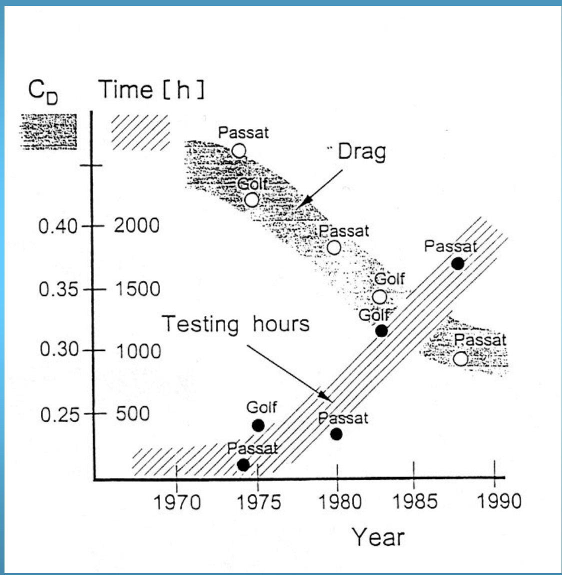
17

Impact of drag on performances





Wind tunnel testing hours at VW



Influenced by fashion

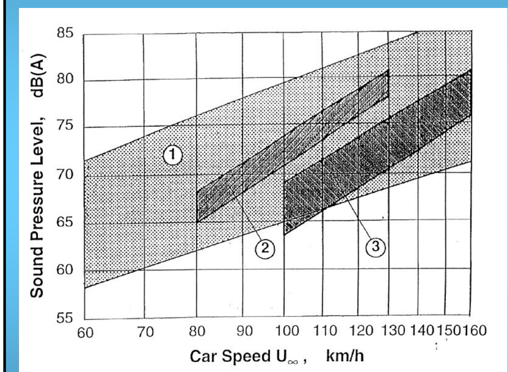
Chrysler PT Cruiser

BMW X5

Aerodynamically induced stability problems

Aerodynamical noise

Exterior noise



1 = tire noise
2 = airflow noise of pick-ups
3 = airflow noise of cars

Sources for fluctuating pressure

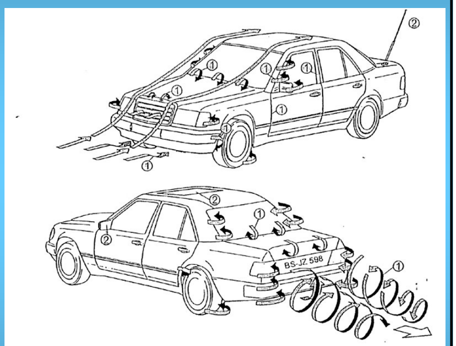


Fig. 18 : Fluctuating pressure locations on a car body

Aerodynamics crucial for race cars

Focus testas tvärställd i vind-tunnel eftersom rallyförarna ändå alltid kör med sladd!

Fords fräckaste Focus
är onekligen den WRC-bil som Colin McRae och Thomas Rådström gör sitt bästa för att ha sönder var tredje helg. Skärmbreddare, sänkt fjädring och stora, feta hjul gör sitt till för utseendet. I detta fall är bilen byggd för Rally Korsika på asfalt och är 136 cm låg, inklusive bakvinge. Topphastigheten för en Focus WRC är 225 km/h, fortare än så går det inte på rallyvägarna. 0-100 km/h tar 4,3 sekunder, motsvarande för en tvåliters "gat-Focus" är 9,2 sekunder.

Teknikens Värld 19/99

23

Aerodynamics of commercial vehicles

Scania press release
14/10-99

"Wind-tunnel tests have shown that the boattail on the trailer alone reduces air drag for the whole combination by more than 10 percent, an improvement that corresponds to fuel savings from perhaps a decade of engine research and development."

24

Aerodynamics of motorbikes

25

Aerodynamical differences

Cars

- Bluff bodies
- Large viscous regions
- Low aspect ratio (3D)
- Strong interaction between body parts
- Ground effects

Airplanes

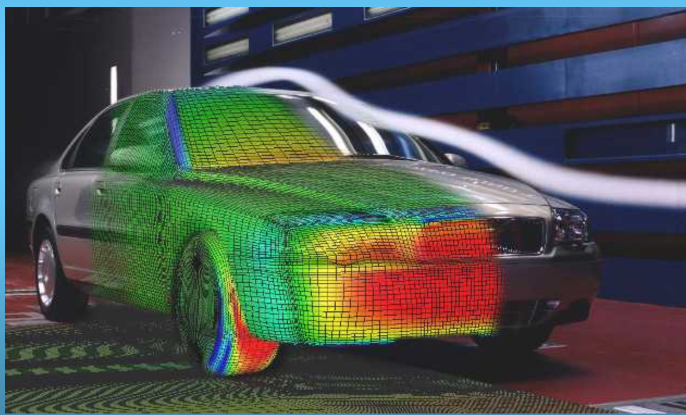
- Streamlined
- Inviscid flow dominates
- High aspect ratio (partly 2D)
- Step-by step optimization

Car aerodynamics still dominated by empiricism!

26

Advanced analysis methods required

- Computational Fluid Dynamics (CFD)
- Wind-tunnel test



27

Historical review: 1900-1925

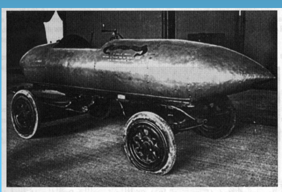


Fig. 1.11 Record-breaking car from CAMILLE JENATZY, 1899. (Photo by Chambre Syndicale des Constructeurs Automobiles Francais)

Jenatzy
1899

Alfa Romeo
1914

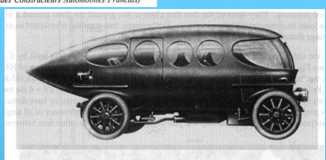


Fig. 1.12 Alfa Romeo of COUNT RICOTTI, 1914. (Photo and exposure Alfa Romeo)

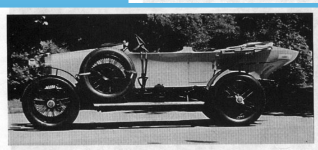


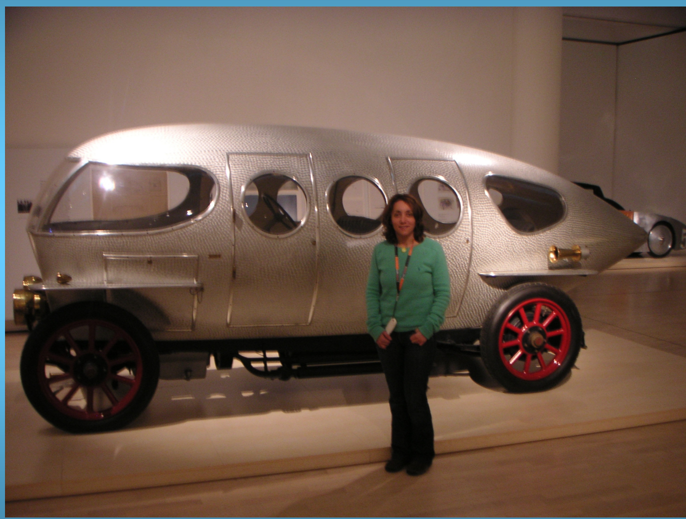
Fig. 1.13 Boat-tailed "Audi Alpensieger," 1913. (Photo and exposure Deutsches Museum, Munich)

Boat-tail
1913

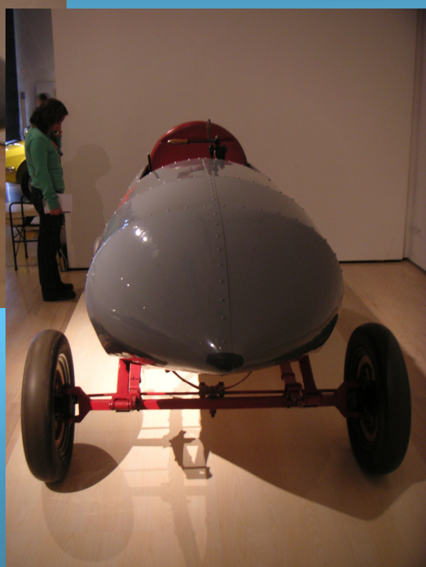
- Borrowed shapes from aeronautics & ships
- Did not consider ground effects
- Free standing wheels gives disturbances

28

Historical review: 1900-1925



29



Streamlined cars 1920-

Rumpler's teardrop car (1922)
c_D=0.28

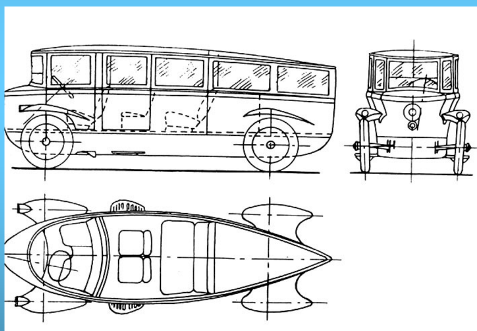


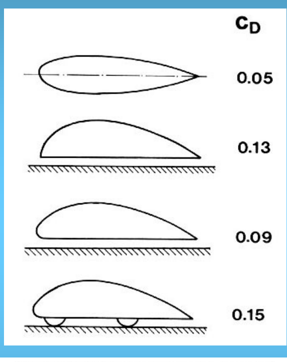
Fig. 1.14 RUMPLER's "teardrop" limousine, 1922.

- Body shaped as 2D wing profile
- Cambered roof and smooth underbody to avoid end-effects
- Low c_D despite open wheels

31

Streamlining based on aeronautical know-how

Klemperer & Jaray (ca 1922)



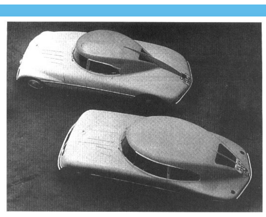


Fig. 1.27 Two typical Jaray cars, made by Huber & Brühwiler, Luzern, 1933-34. Top: 2L Audi; bottom: Daimler-Benz Type 200. (Courtesy R.F.J. KIESELBACH)

Jaray cars
1933-34

- Study ground effect on a body of revolution
- Started to develop cars based on combinations of streamlined bodies
- Revolutionary shapes for that time
- Low c_D (ca 0.30, instead of typically 0.7, without cooling flow)
- Too long tails (Jaray-back) (separation)
- Difficult to find customers!!

32

Lange-car (1937)

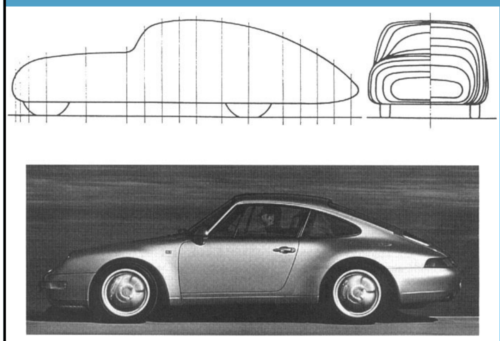


Fig. 1.32 a) Lines of the "Lange-car," $c_D = 0.14$, completely smooth model; b) Porsche 911 Carrera, MY 1995, $c_D = 0.33$, $A = 1.86\ m^2$. (Courtesy Porsche AG)

- Based on two horizontal wing profiles
- c_D=0.16 of smooth model

33

Kamm-back (ca 1939)

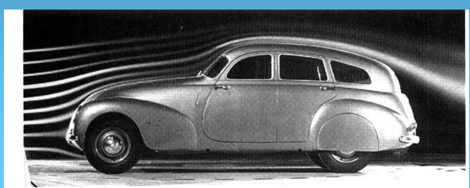


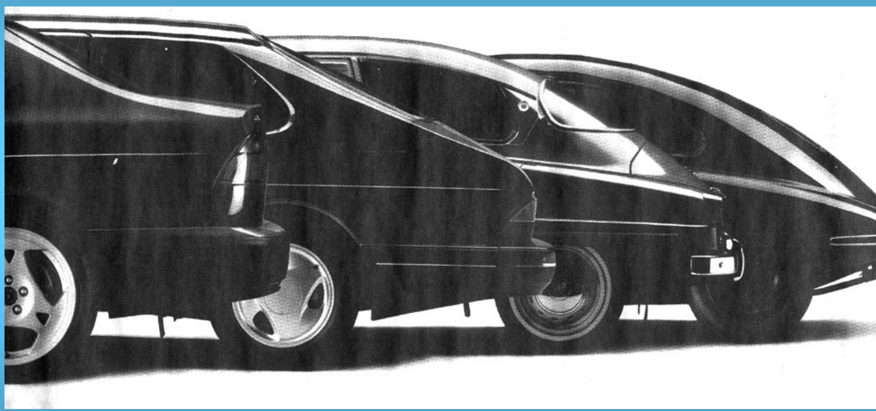
Fig. 1.37 Kamm car K3 from 1938-39 in the large climatic wind tunnel of Volkswagen AG (Photo Volkswagen AG, exposure Langenburg Castle)

- Introduced blunt trailing edge
- Truncated the body just upstream separation point
- Kamm K3: c_D=0.37 (real car)
- More "useful" shapes than Jaray

Fiat Ecobasic c_D=0.28
(TV 1/2000)

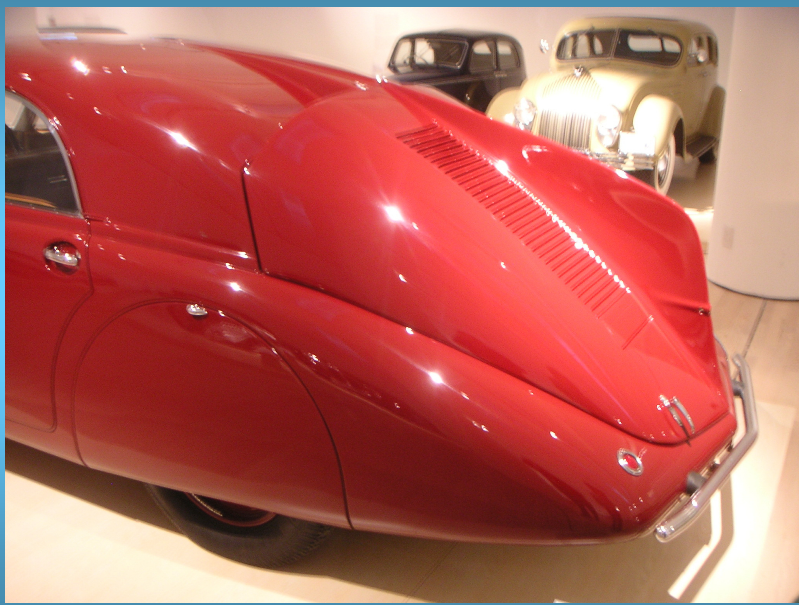
34

Development of rear end shapes



35

36



37

Development of production cars

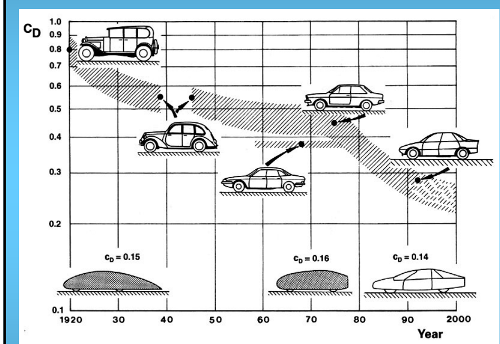
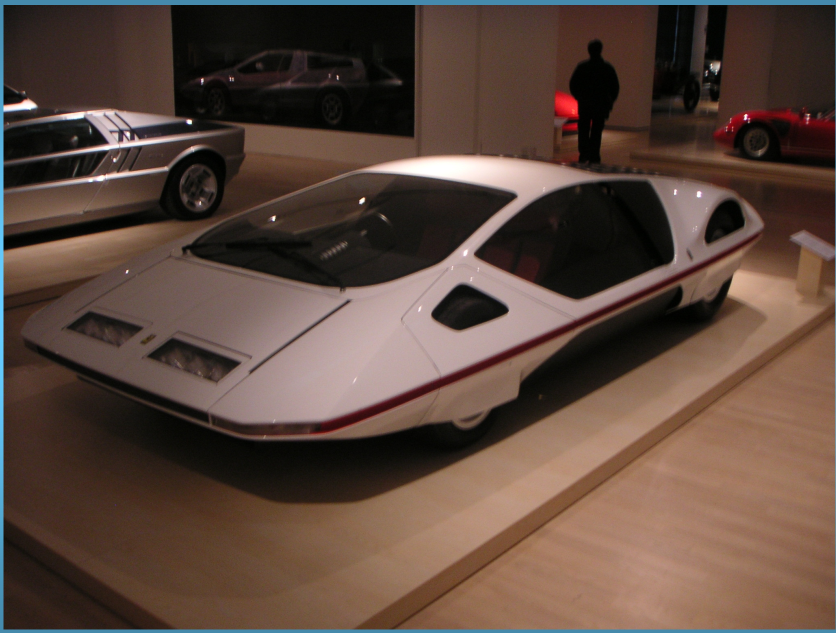


Fig. 1.58 History of drag coefficient c_D of European passenger cars in comparison to low drag configurations and a research car, the Ford Probe V.

- Despite all streamlined bodies cars looked like carriages during 20-30's (c$_D$≈0.7-0.8)
- After WWII: three-volume body (cd≈0.45)
- Oil crisis 1973: Increased focus on aerodynamics(**Detail optimization**)

38



39

Alternative routes to low drag

1) Detail optimization
(basic shape from designers viewpoint)

2) Shape optimization
(start from a streamlined basic shape)

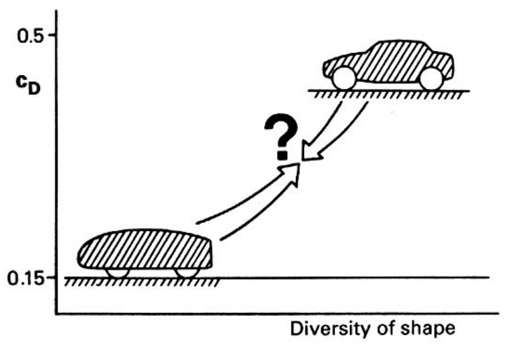


Fig. 1.65 Alternative routes to low-drag shapes.

Limitations how far you can reach with detail optimization (Hucho: difficult to reduce c_D below 0.4)

40

Historical review

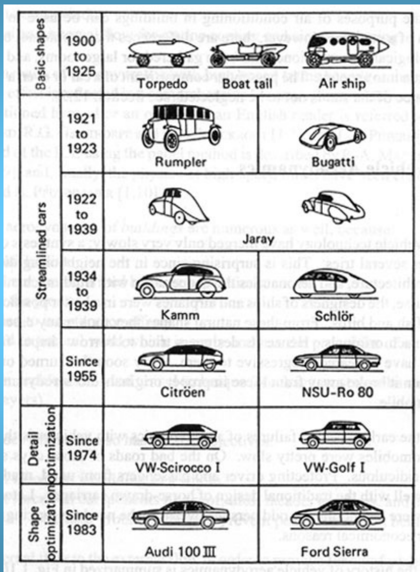
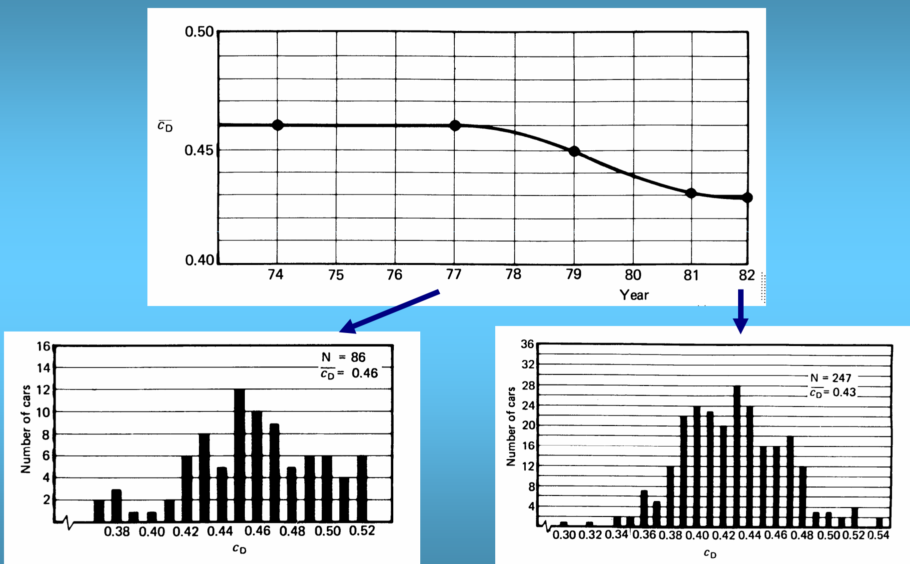


Fig. 1.10 History of vehicle aerodynamics in passenger cars.

- Reached the limit of detail optimization
- Old ideas of Jaray and Kamm re-evaluated today (shape optimization)

Historical review



Present status

Histogram of c_D of production cars (1995)

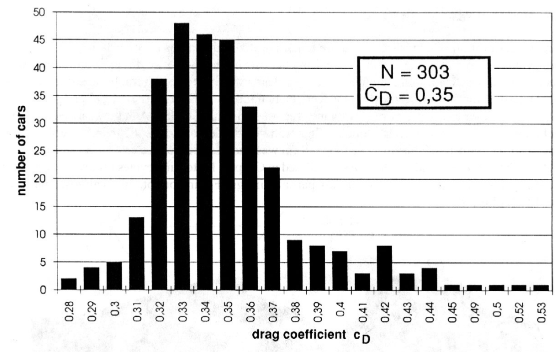


Fig. 1.56 c_D-histogram of cars for sale in Europe 1995. (Courtesy B. Leie, Volkswagen AG)

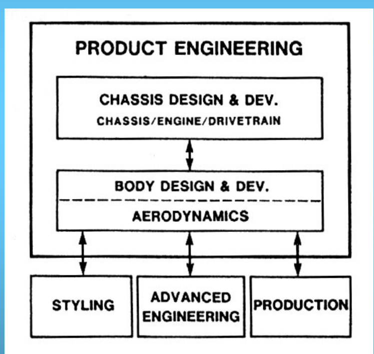
Today: average c_D close to 0.30 (?)

43

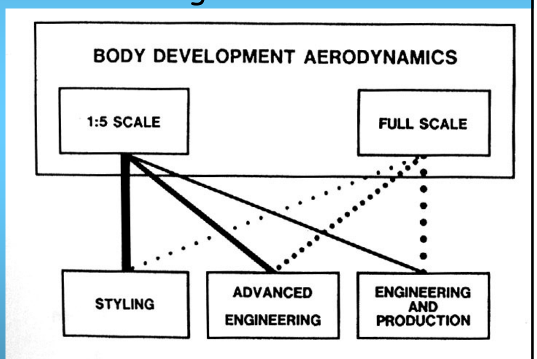
Aerodynamics as part of the design process

The development of Opel Calibra

Organisation



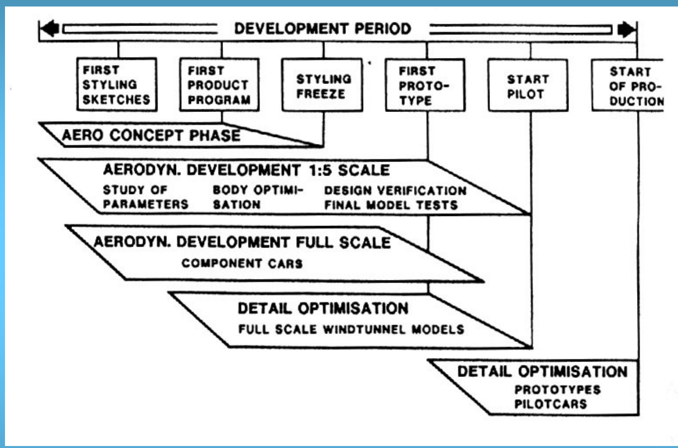
Interaction within the organisation



From Emmelman, Berneburg & Schulze (1990)

44

Aerodynamic timing (Opel Calibra)



C_D = 0.26

From Emmelman, Berneburg & Schulze (1990)

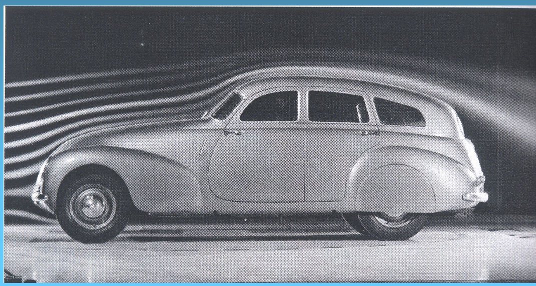
45

The lesson was learned

One of the present cars with lowest C_D

C_D = 0.25

46



47

Several present production cars have $C_D \leq 0.3$

48