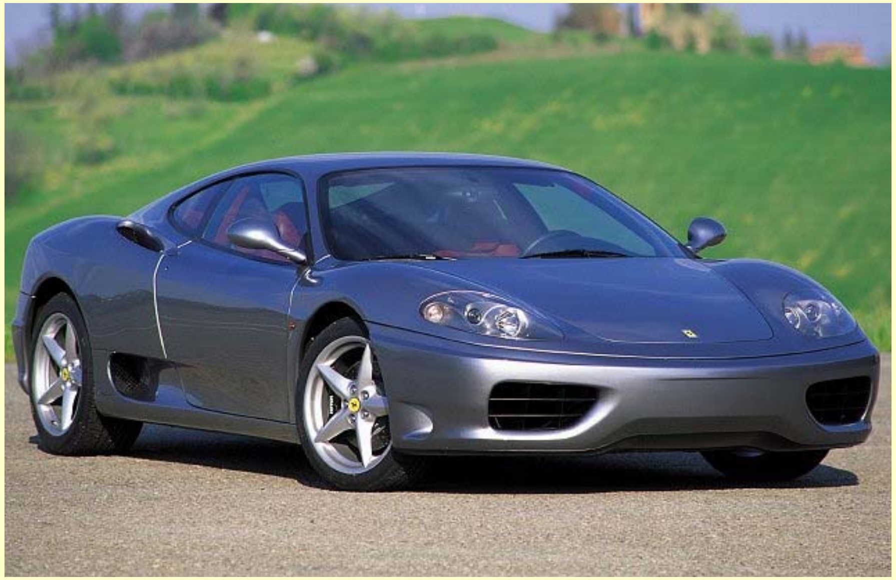
The Influence of Aerodynamics on the Design of High-Performance Road Vehicles



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CONTENTS

AERODYNAMIC FORCES

THE AERODYNAMIC FORCES ACTING ON A BODY IN MOTION IN A FLUID DEPEND ON:

- GEOMETRY OF THE BODY → SHAPE, DIMENSIONS
- MOTION OF THE BODY → DIRECTION, VELOCITY
- CHARACTERISTICS OF THE FLUID
- INTERFERENCE WITH OTHER BODIES

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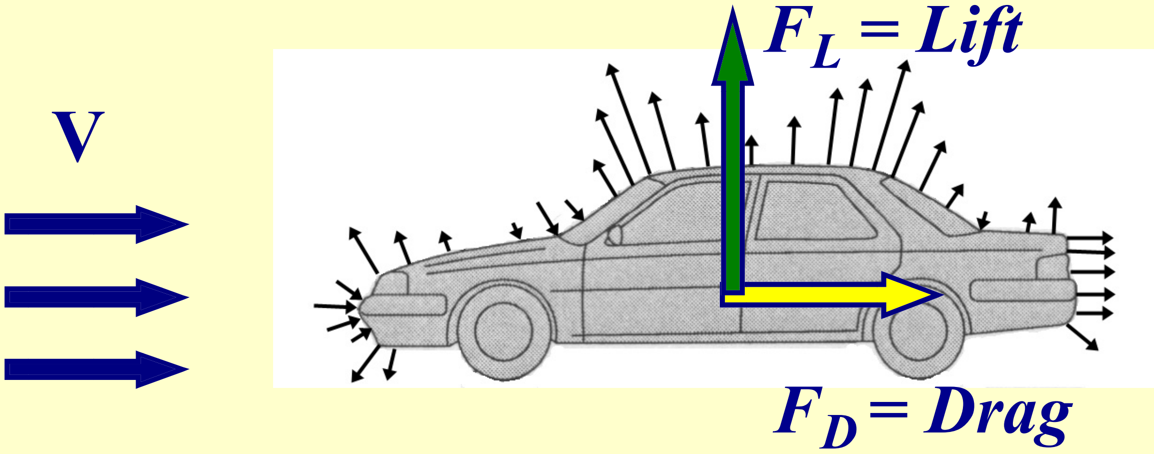
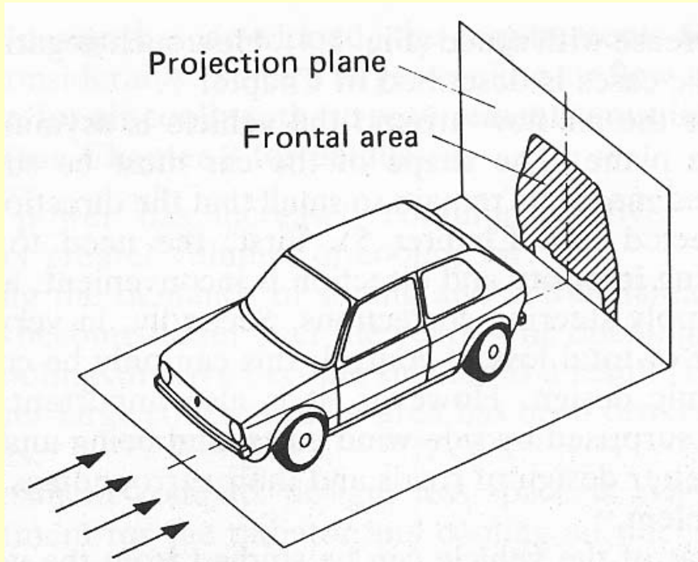
Origin of the forces:

- **Friction over the body surface**
- **Pressures on the body surface**





$$F_D = \frac{1}{2}\rho V^2 \cdot S \cdot C_D \qquad F_L = \frac{1}{2}\rho V^2 \cdot S \cdot C_L$$

Drag Coefficient

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 \cdot S}$$

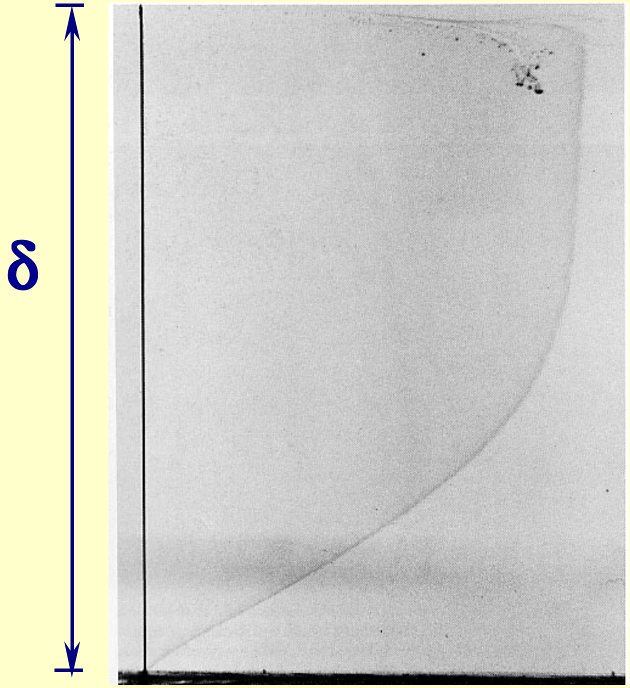
Lift Coefficient

$$C_L = \frac{F_L}{\frac{1}{2}\rho V^2 \cdot S}$$

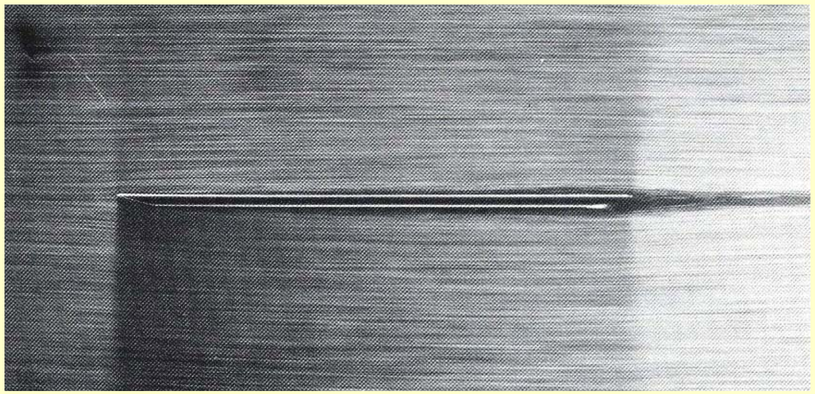
Boundary layers

At the wall the relative velocity between fluid and body is zero and a boundary layer develops

But if the Reynolds number *Re* is high the thickness of the boundary layer may be very small

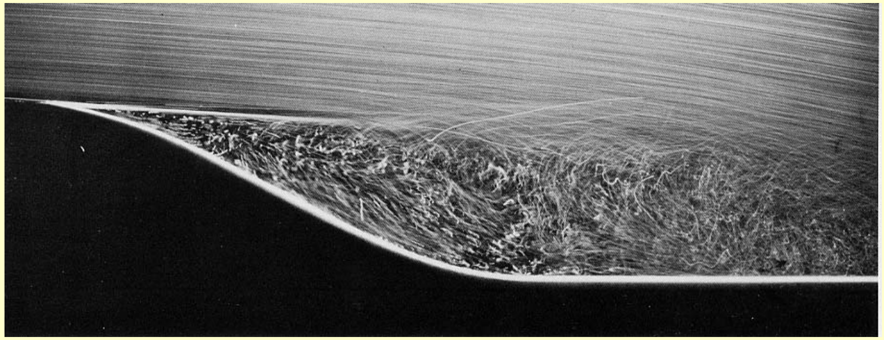


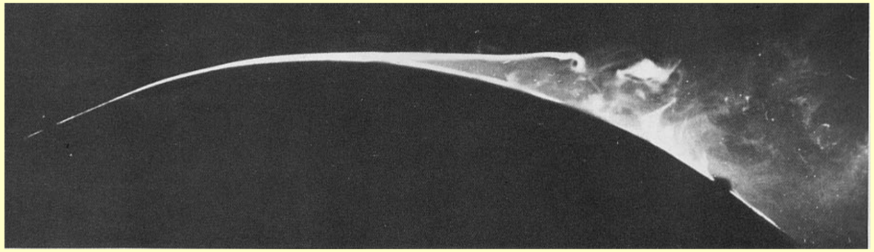
$$Re = \frac{\rho V L}{\mu}$$

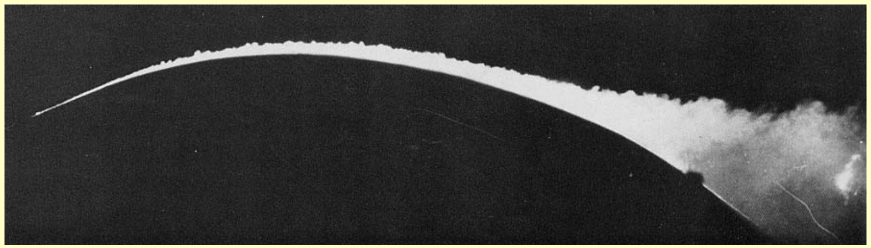


Boundary layer separation

If the curvature of the wall is excessive separation may occur







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Aerodynamic classification of bodies

Aerodynamic bodies:

Boundary layer attached over all their surface
Thin and generally steady wakes

Bluff bodies:

Boundary layer separates from their surface
Wide and generally unsteady wakes

Examples of Aerodynamic bodies

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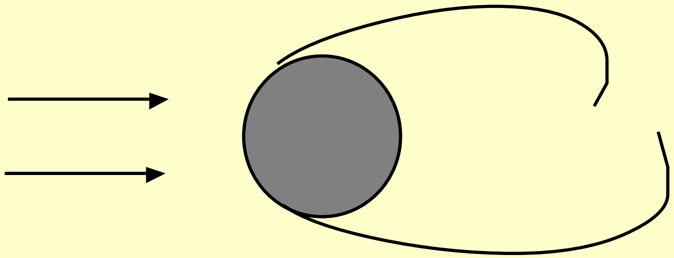
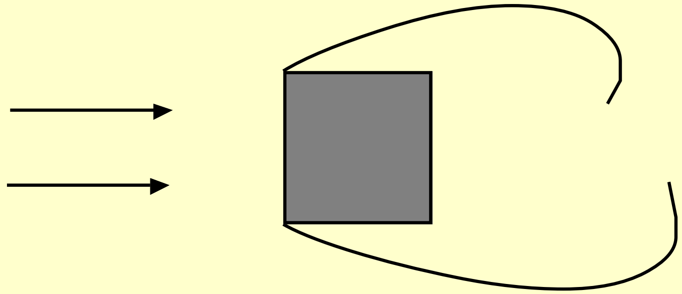
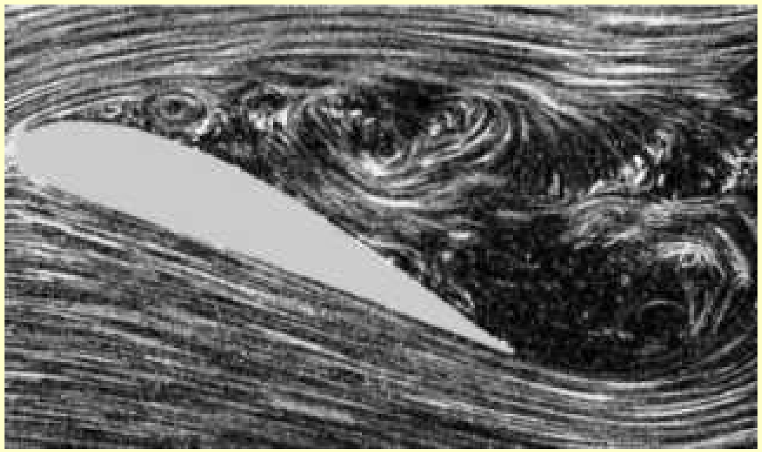
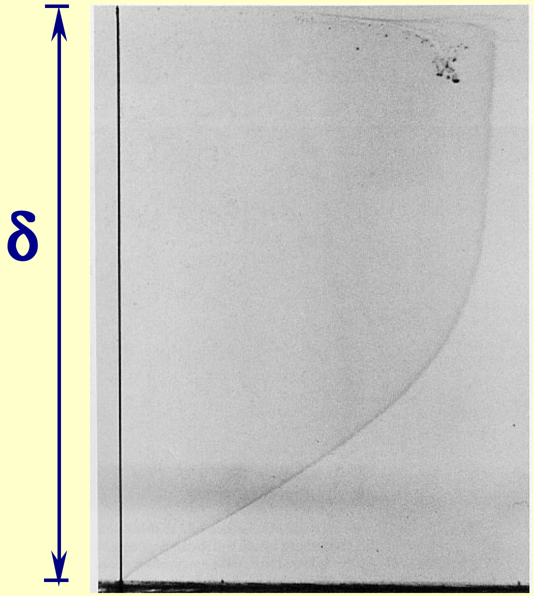
Examples of Bluff bodies







The complete equations of motion (Navier-Stokes equations) are non-linear and very complex



However, Prandtl showed that

$$p(x,\delta) \cong p(x,0)$$

and that outside the boundary layer a simple equation of motion applies ("potential flow" equation)

$$\nabla^2\phi = 0 \quad \text{with} \quad \vec{V} = \nabla\phi$$

Inside the boundary layer the equations of motion may be simplified, even if they remain non-linear

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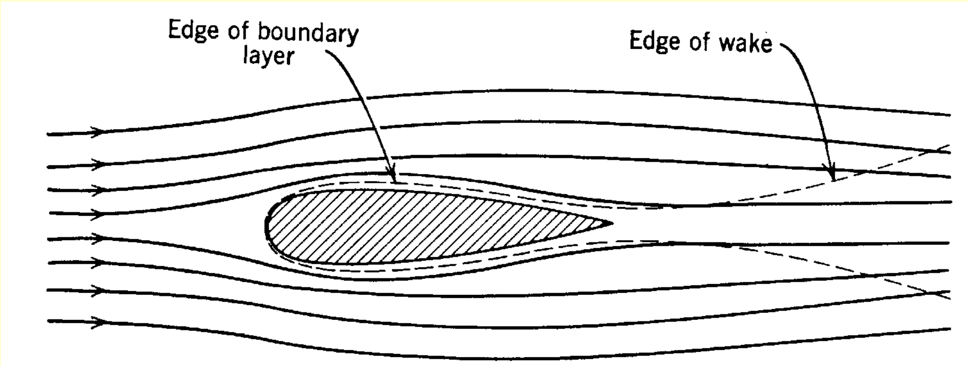
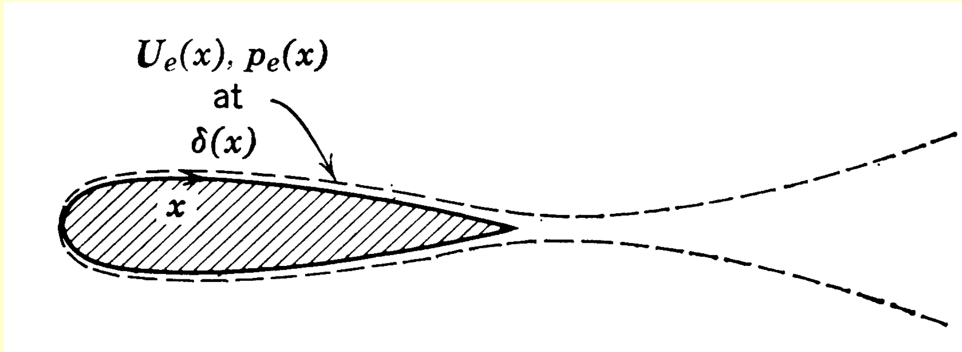
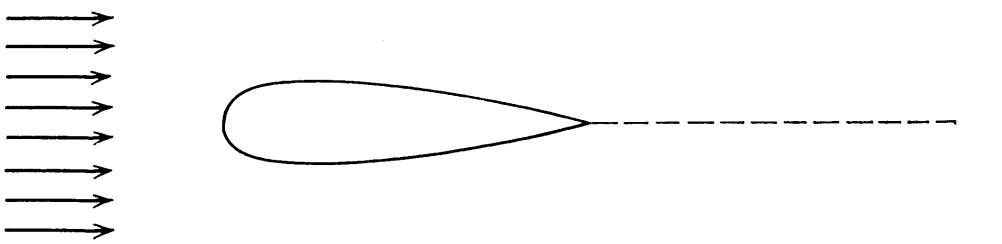
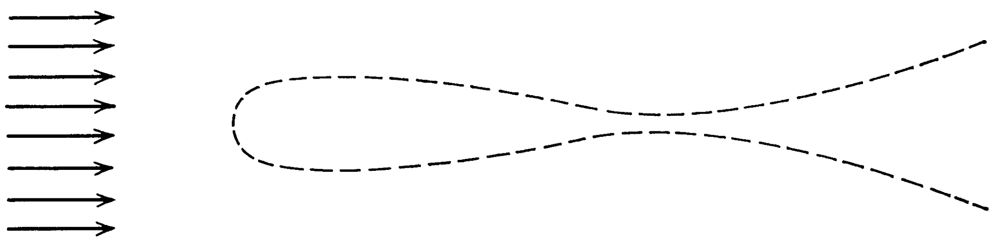
For aerodynamic bodies a simplified procedure may then be devised for the evaluation of the aerodynamic loads









<u>This is not possible for bluff bodies!</u>

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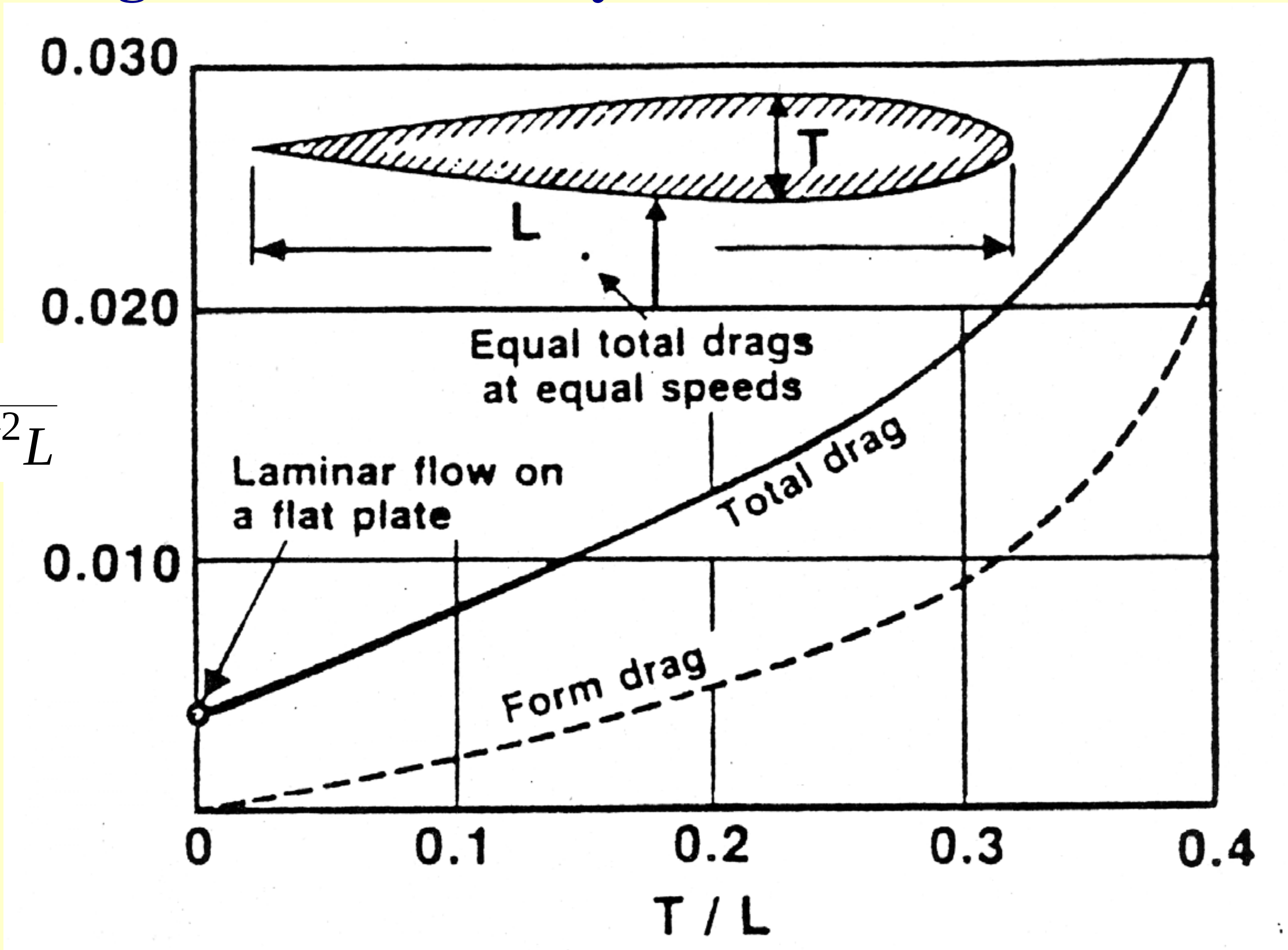
Solution of Navier-Stokes equations or experimental data

Drag forces on aerodynamic and bluff bodies

$$\frac{F_D}{1/2\rho V^2 L}$$



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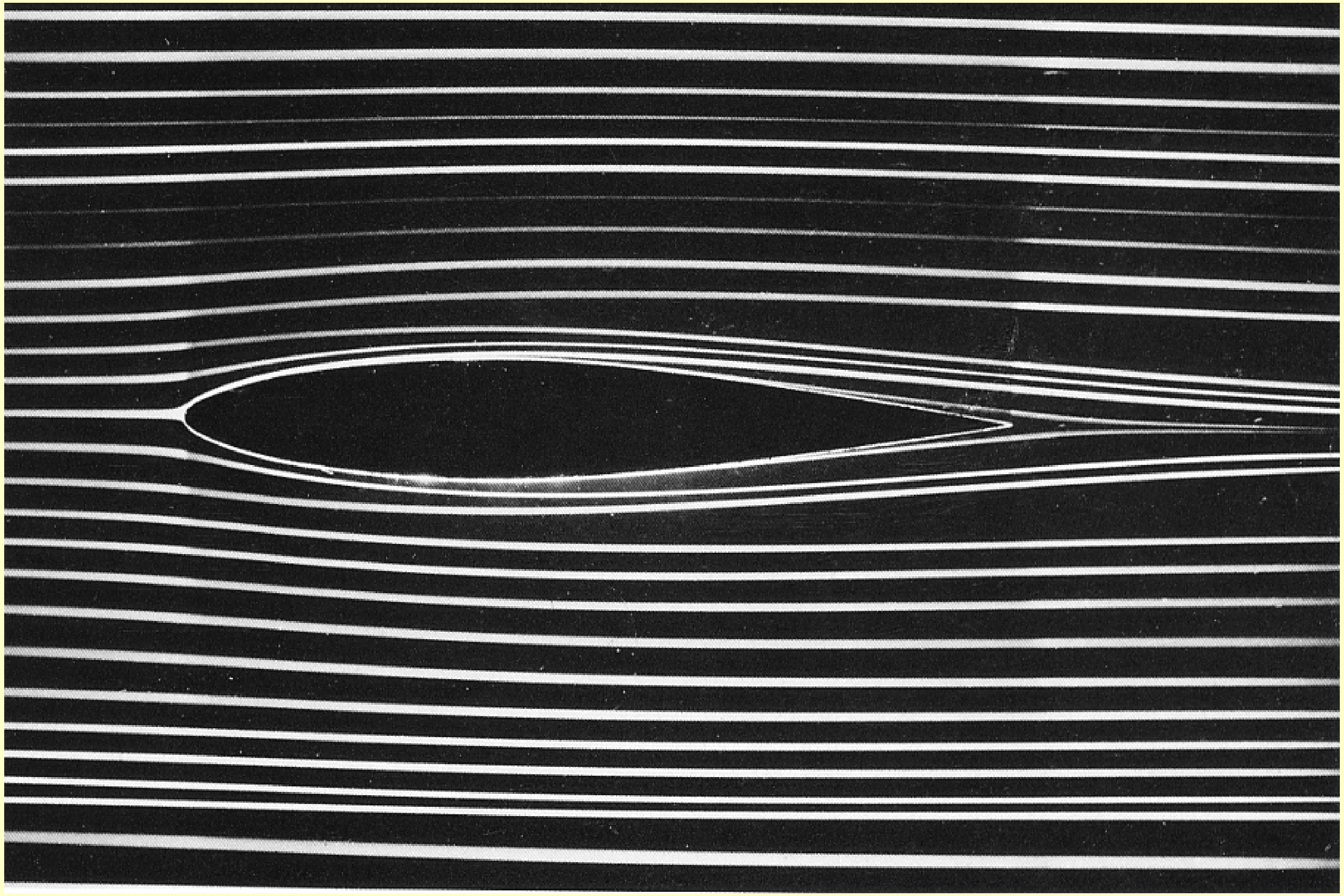
Flow around an aerodynamic body



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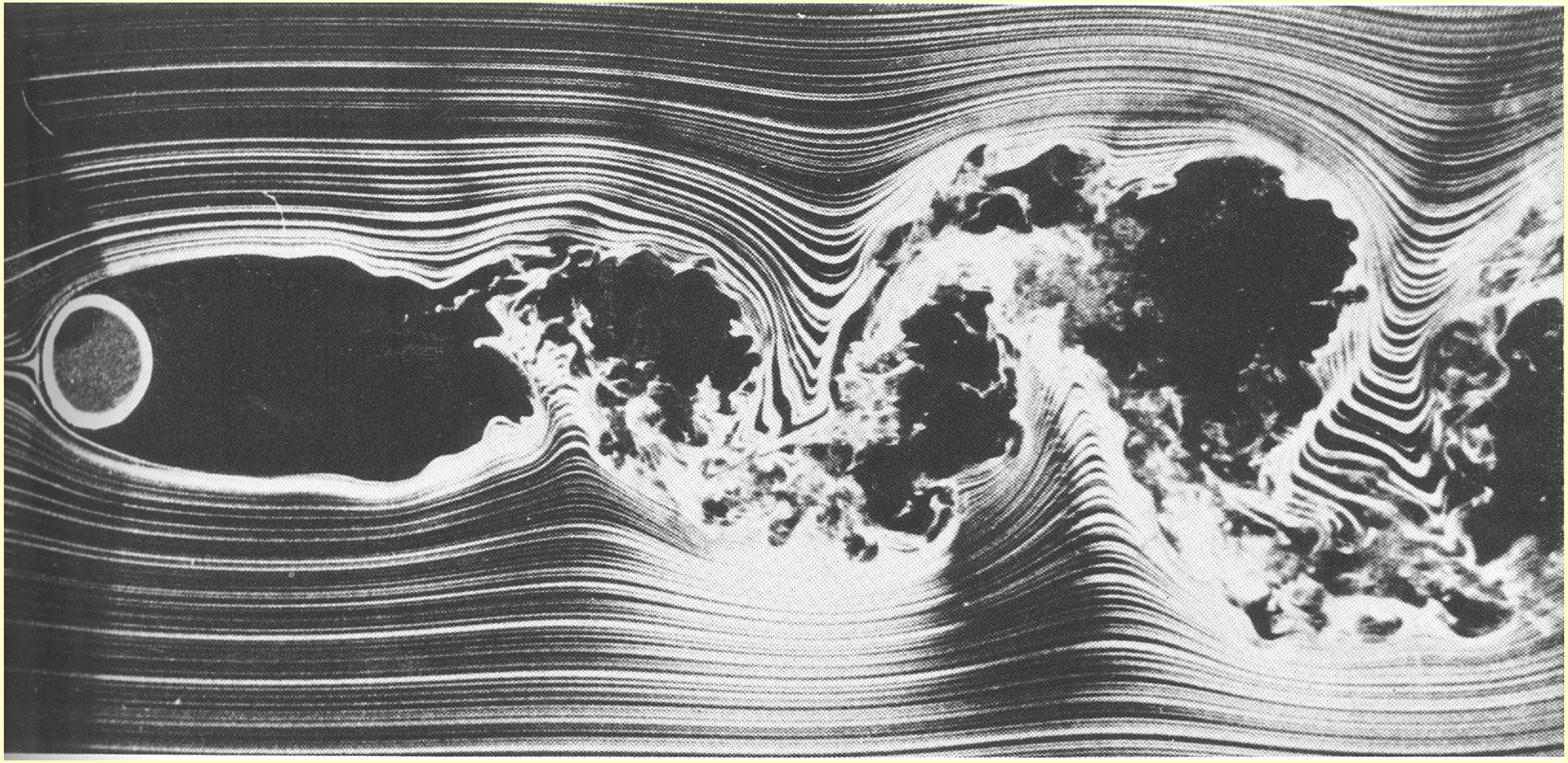
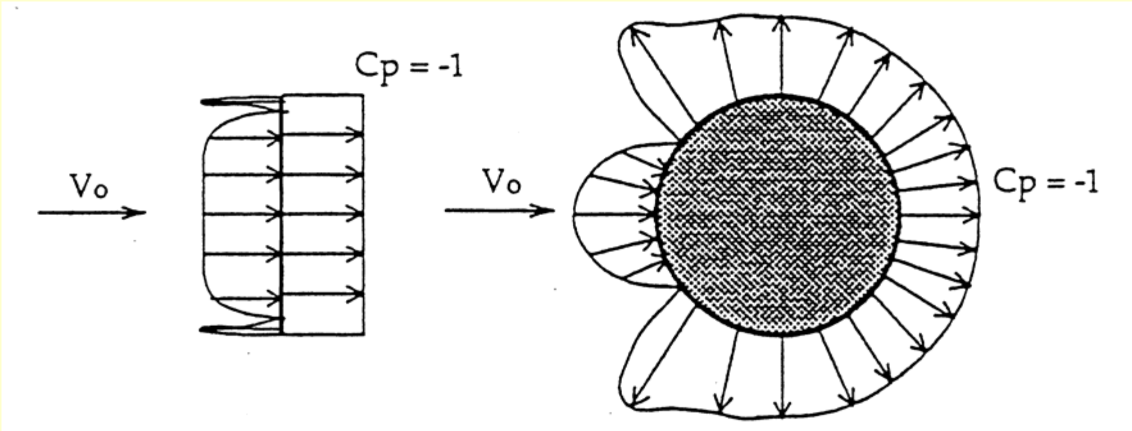
Flow around a bluff body



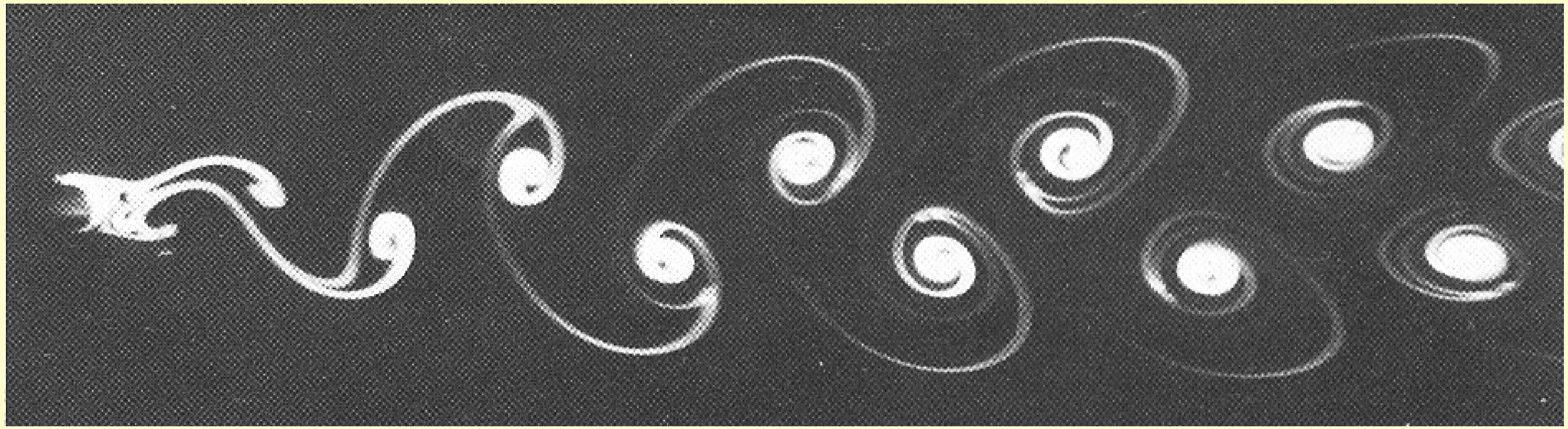
Pressures on bluff bodies

$C_D = 2$



$C_D = 1.2$

Wake flow of two-dimensional bluff body



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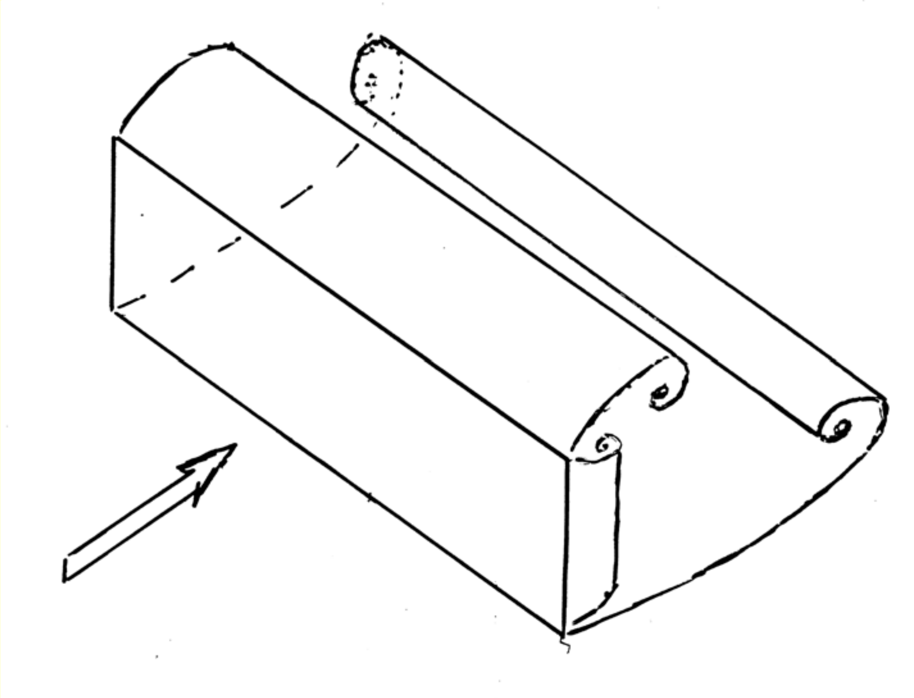
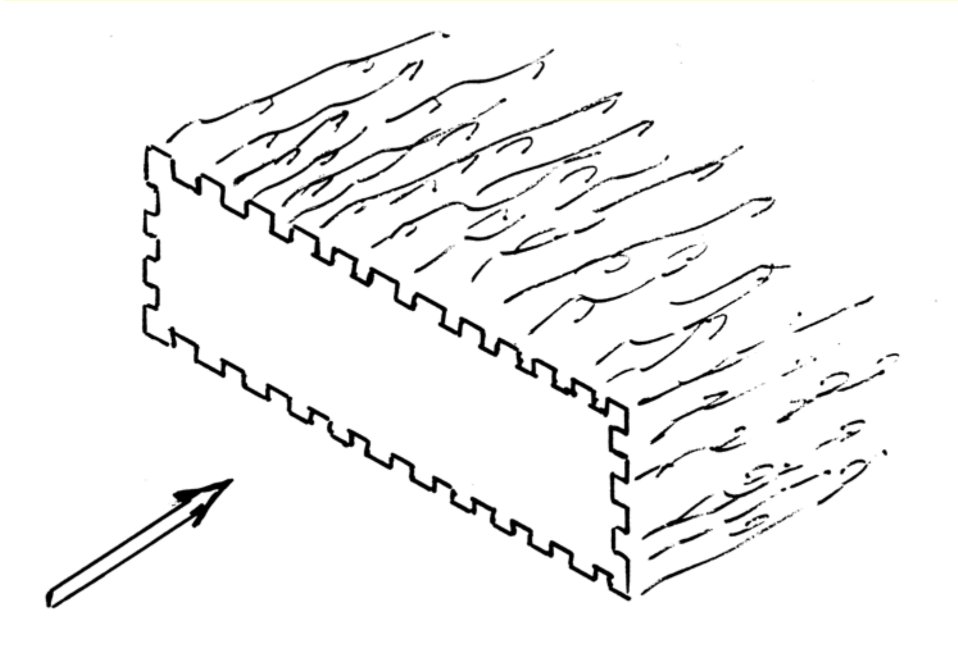
The aerodynamics of bluff bodies is often not obvious…



$C_D = 1.8$



$C_D = 0.9$

It is important to understand physics in order to control it!

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All cars are bluff bodies…but not all with the same bluffness!

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For all road vehicles:

The spent power is linked to the aerodynamic drag and depends on the cube of velocity

$$P = F_D \cdot V = \frac{1}{2}\rho V^3 \cdot S \cdot C_D$$

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To decrease the aerodynamic drag implies

⇓

Decreasing the frontal area

Decreasing the drag coefficient

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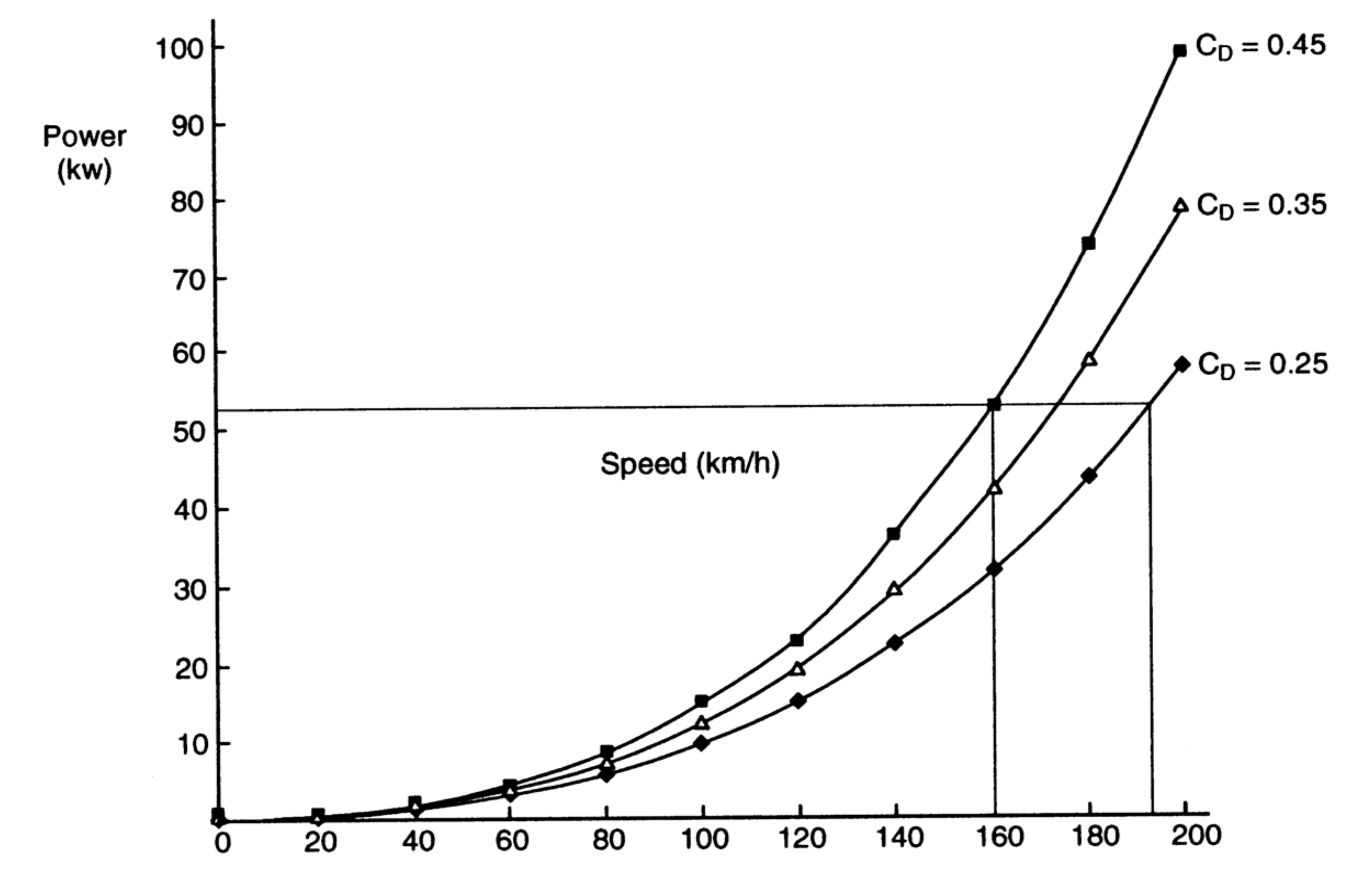
Influence of Drag Coefficient on velocity



Aerodynamic Drag Force
and necessary power with increasing velocity

$S = 2.1\ \text{m}^2$ $C_D = 0.35$

V (km/h)	F_D (Kg)	P (HP)
50	8.9	1.6
100	35.5	12.9
130	59.9	28.3
200	141.8	102.9
300	319.0	347.4
350	434.2	551.6

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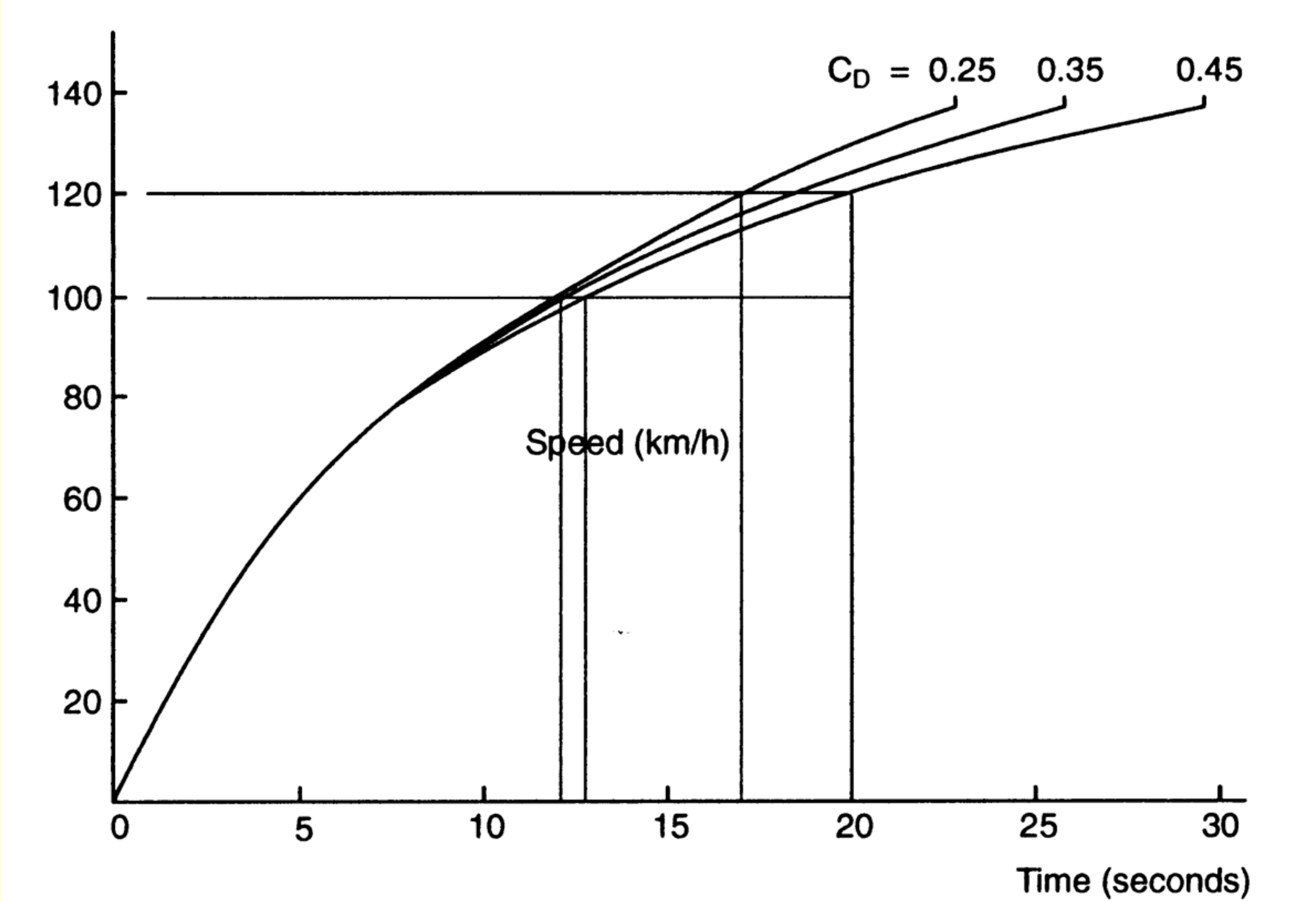
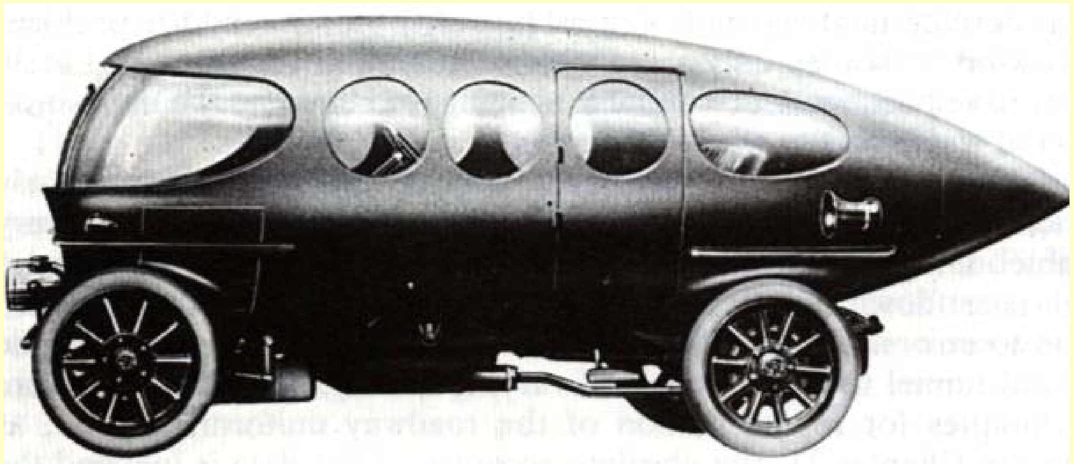
Influence of Drag Coefficient on acceleration



Brief historical overview…

Jamais Contente of
Camille Jenatzy (1899)



Alfa Romeo of
Count Ricotti (1913)

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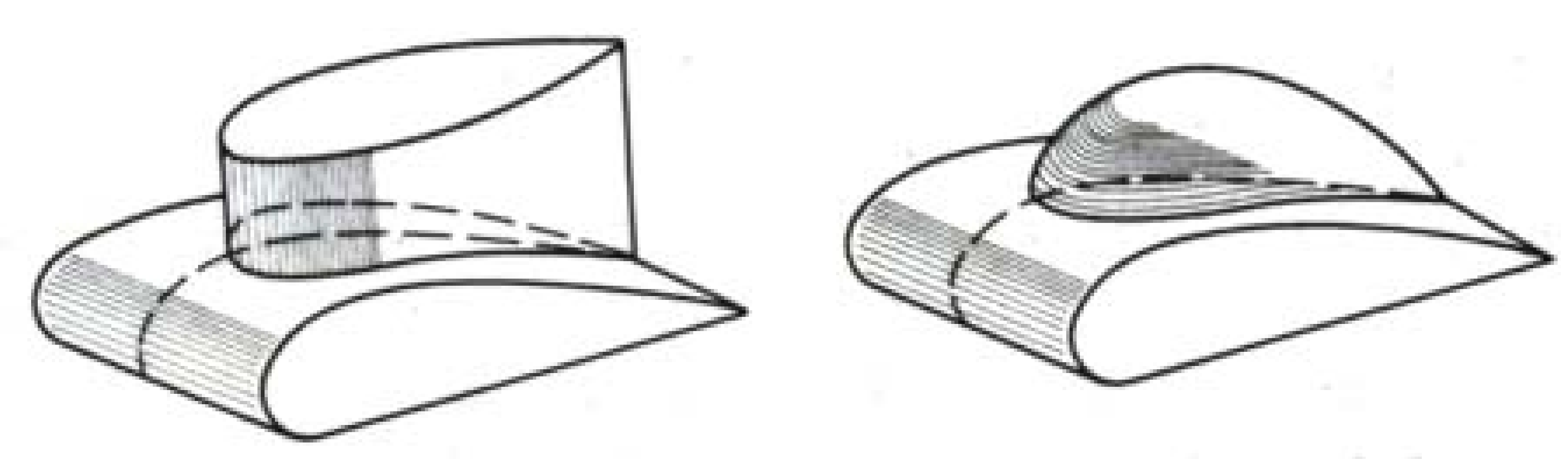
Brief historical overview…



The combined aerodynamic shapes of Paul Jaray (1921)

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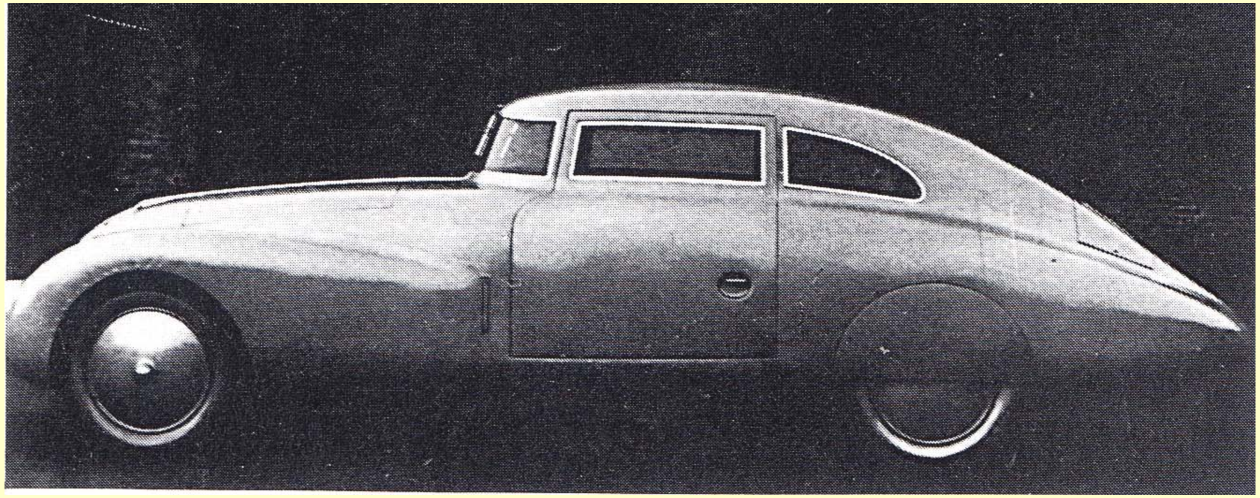
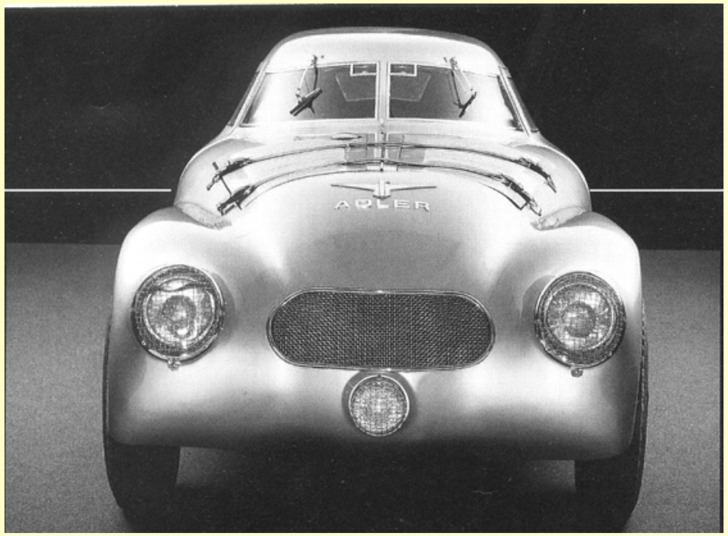
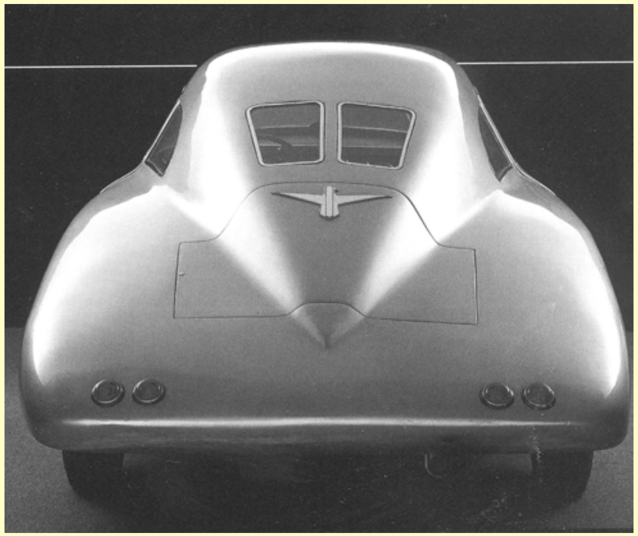
Brief historical overview…

Adler-Trumpf
1.5 liter (1934)







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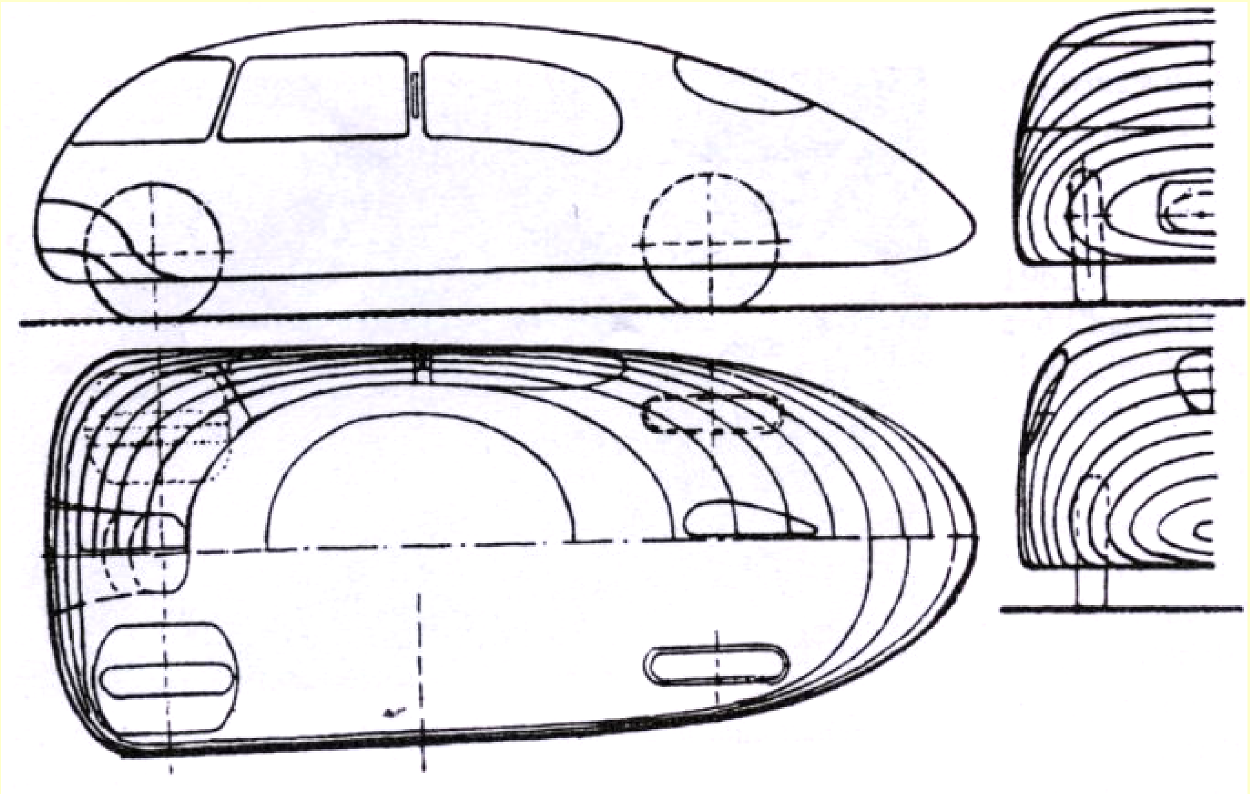
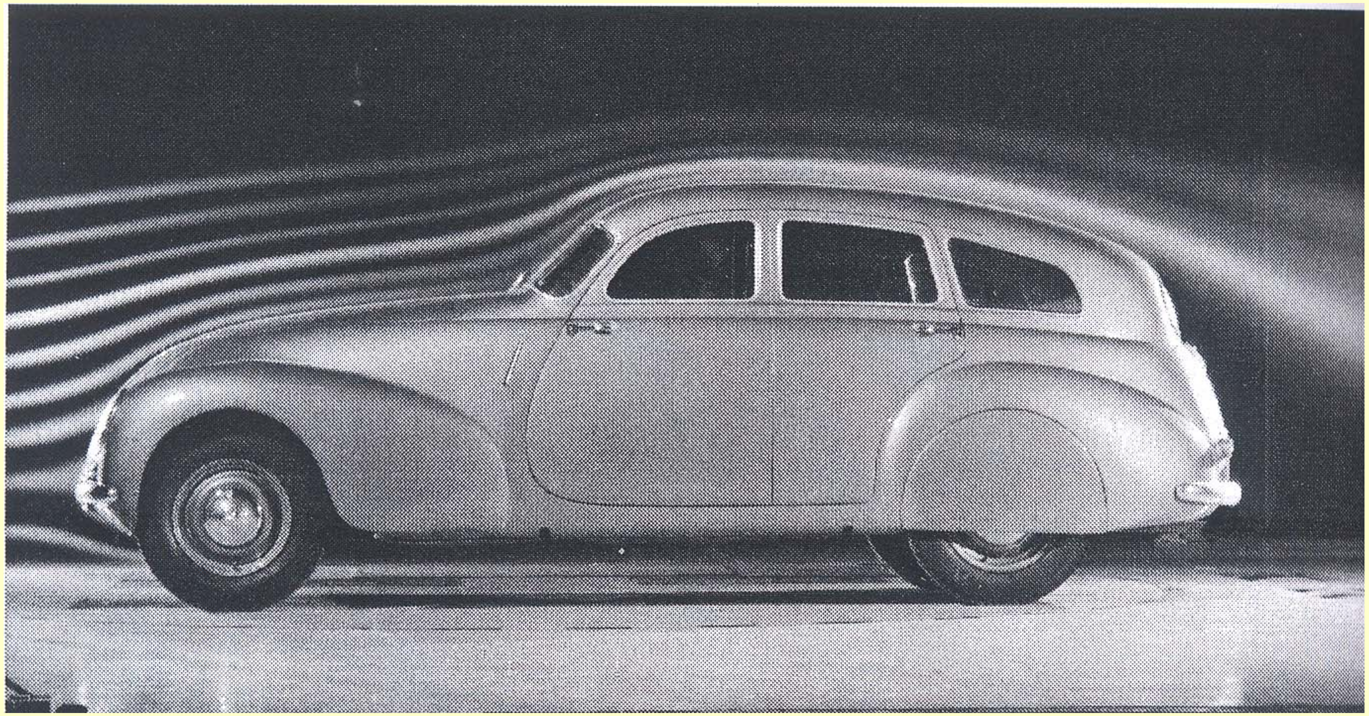
Brief historical overview…



The ideal automobile shape of Schlör (1938)

Brief historical overview…



***K5* of Kamm (1938)**

$C_D = \underline{0.37}$

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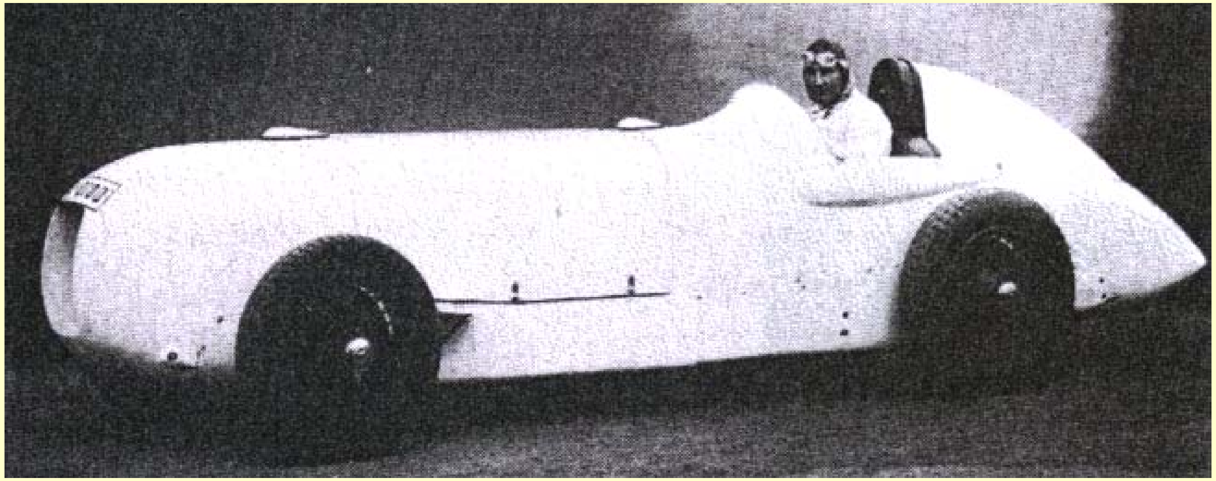
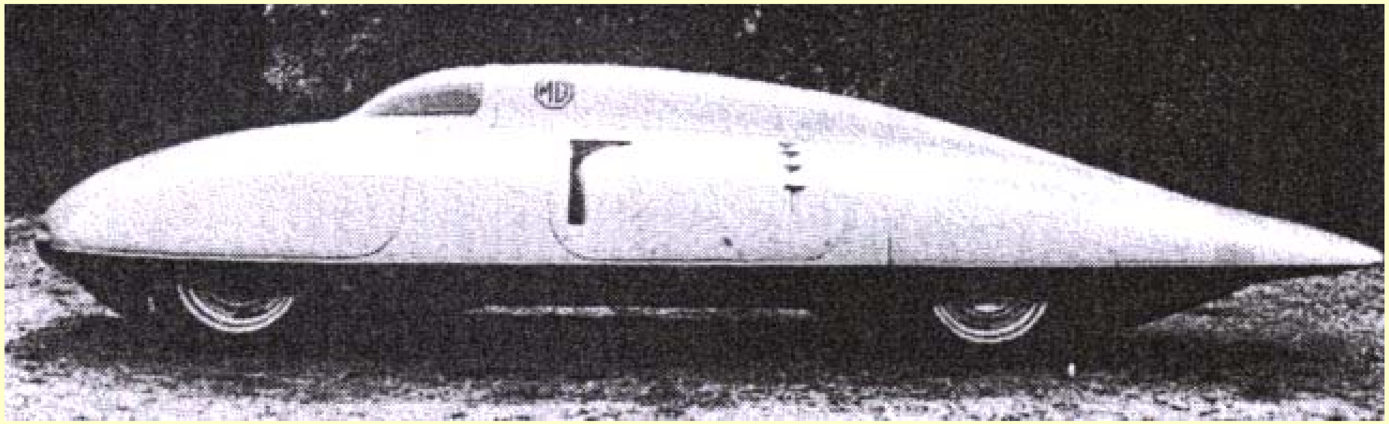
Brief historical overview…



Mercedes-Benz SSK
of Baron
König-Fachsenfeld (1932)



The record car
***MG/EX181* (1957)**

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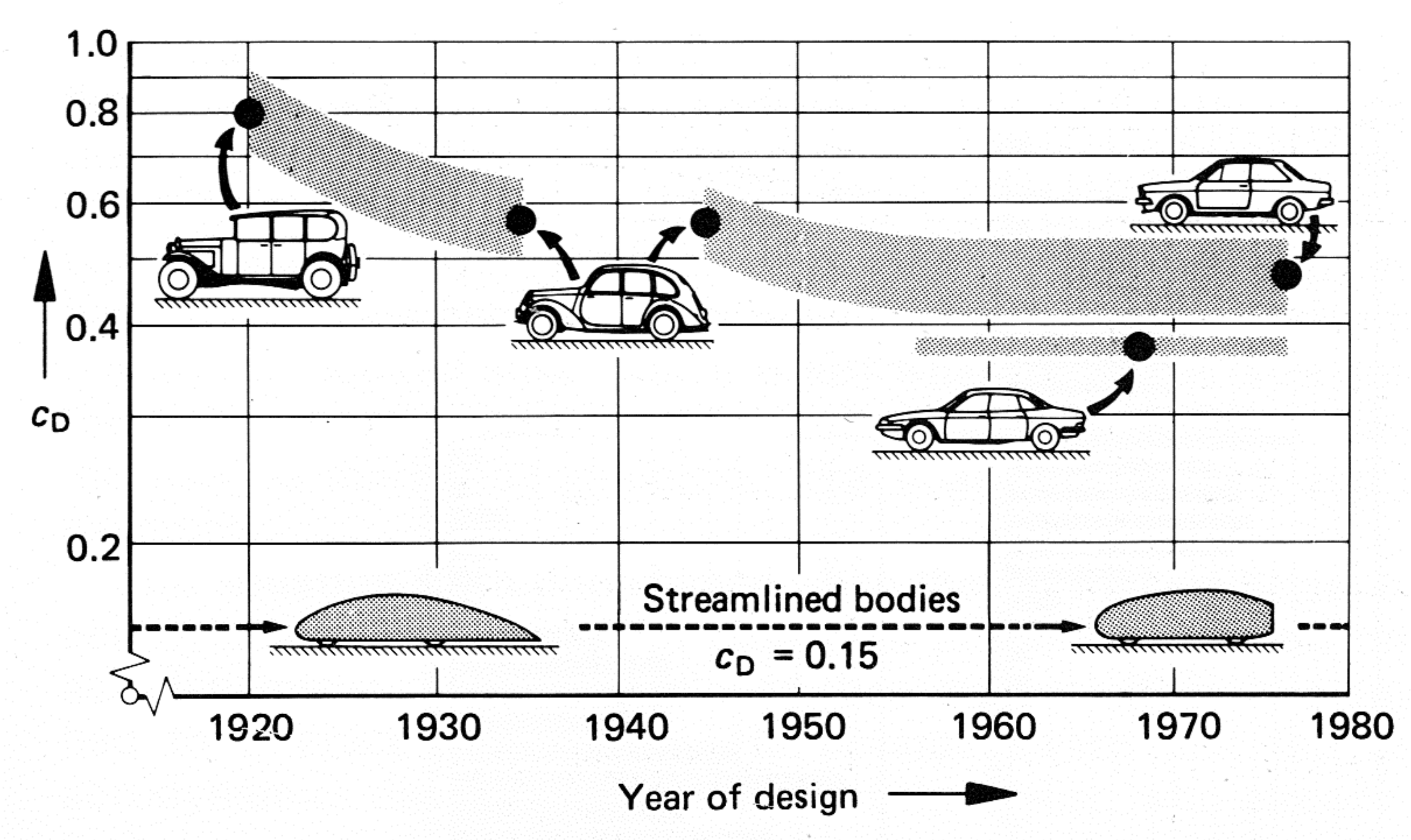
Evolution of C_D of cars



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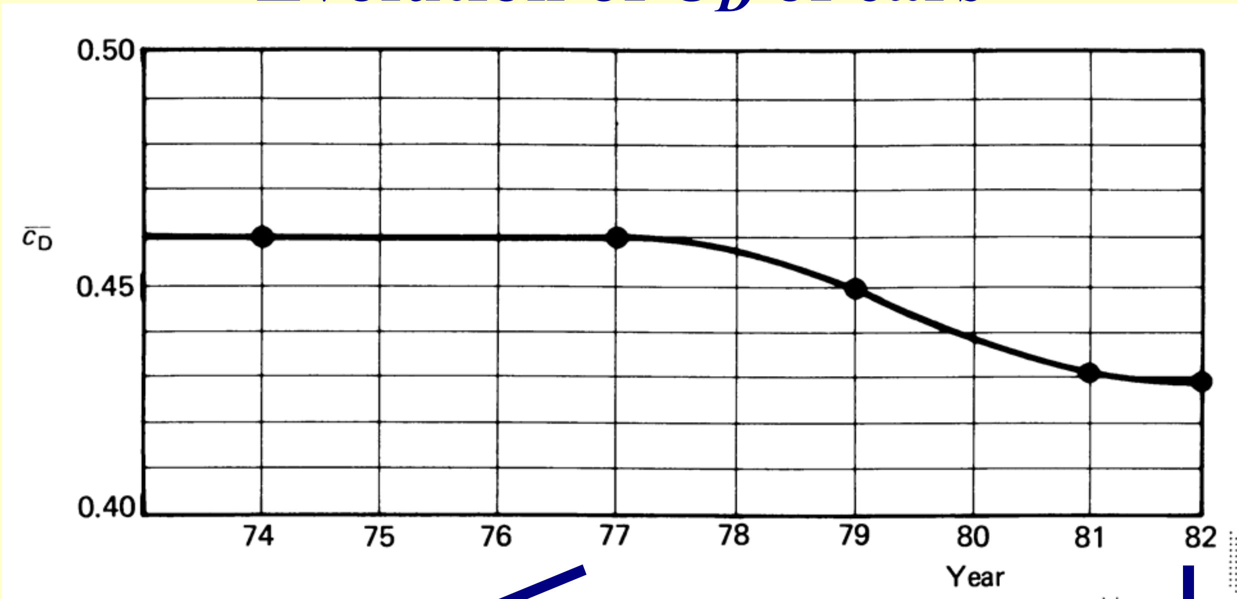
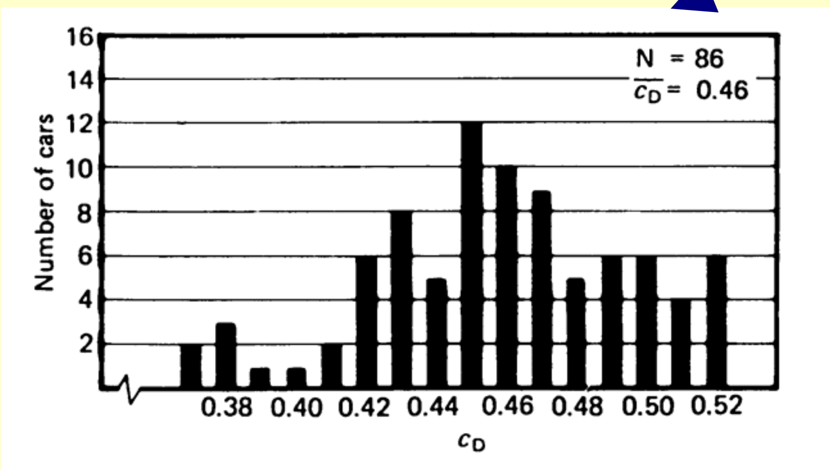
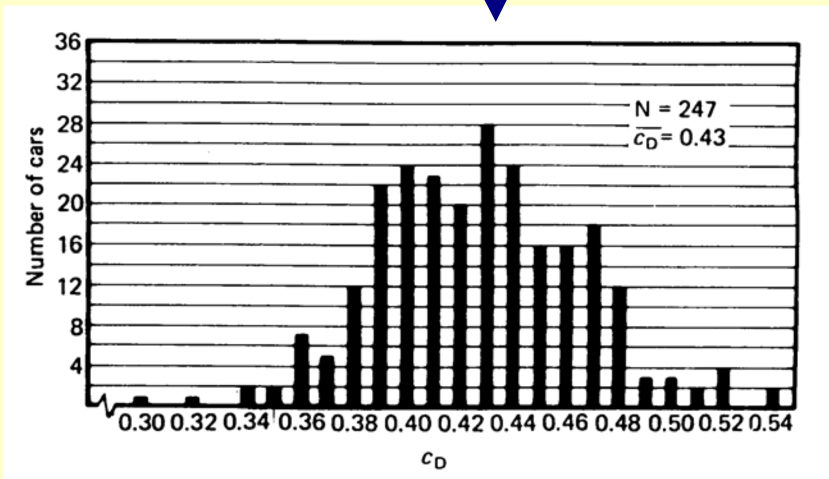
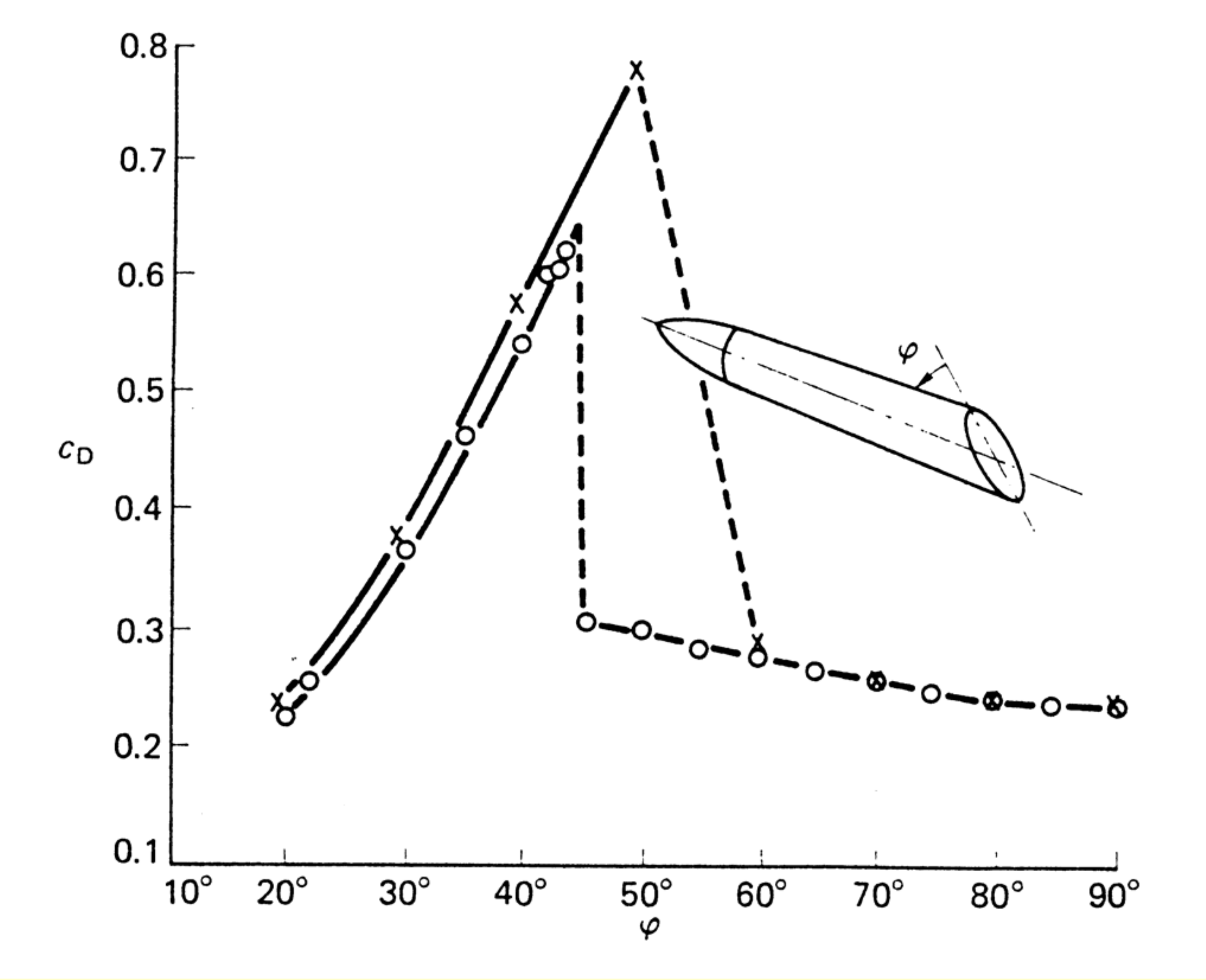
Evolution of C_D of cars



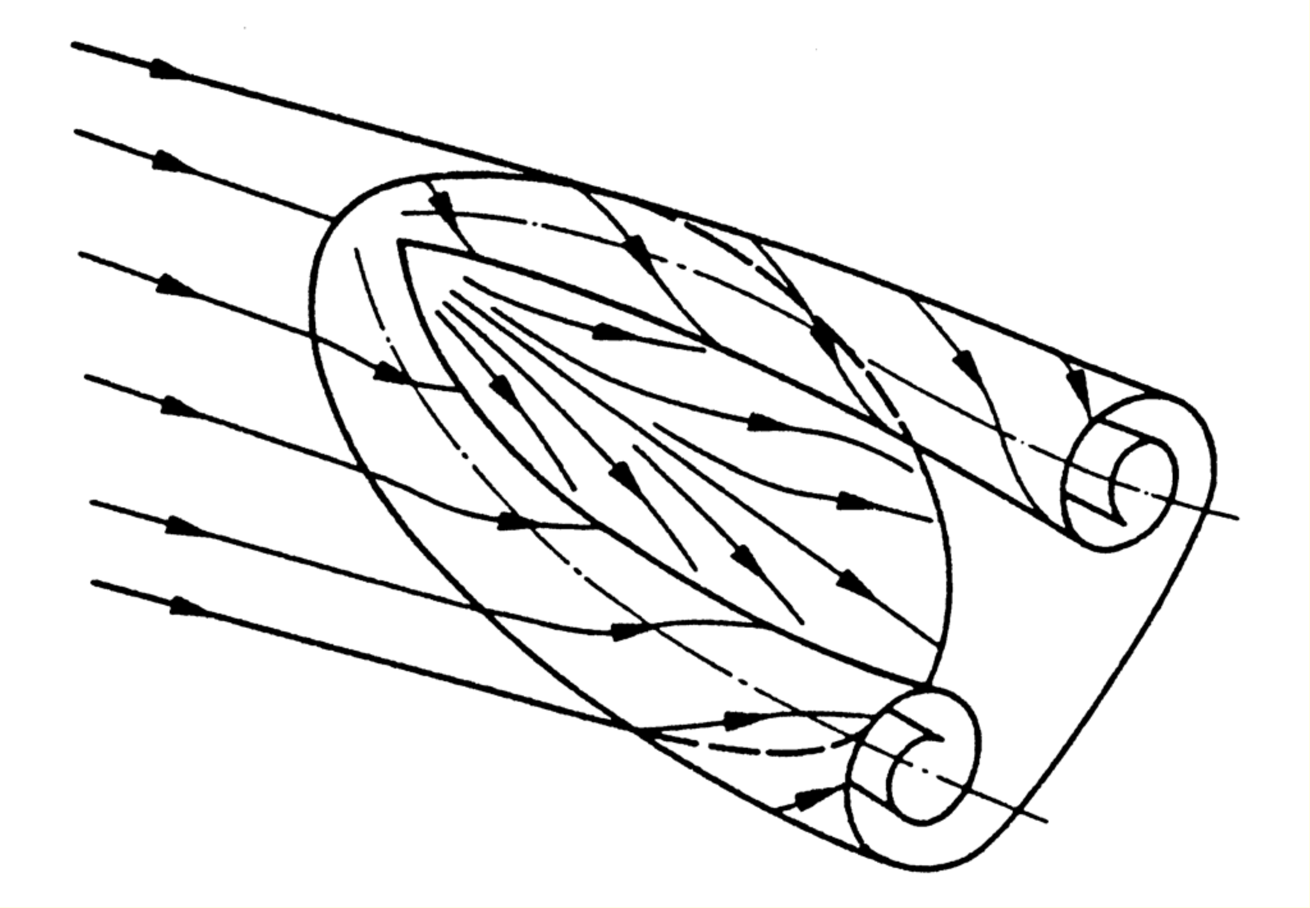




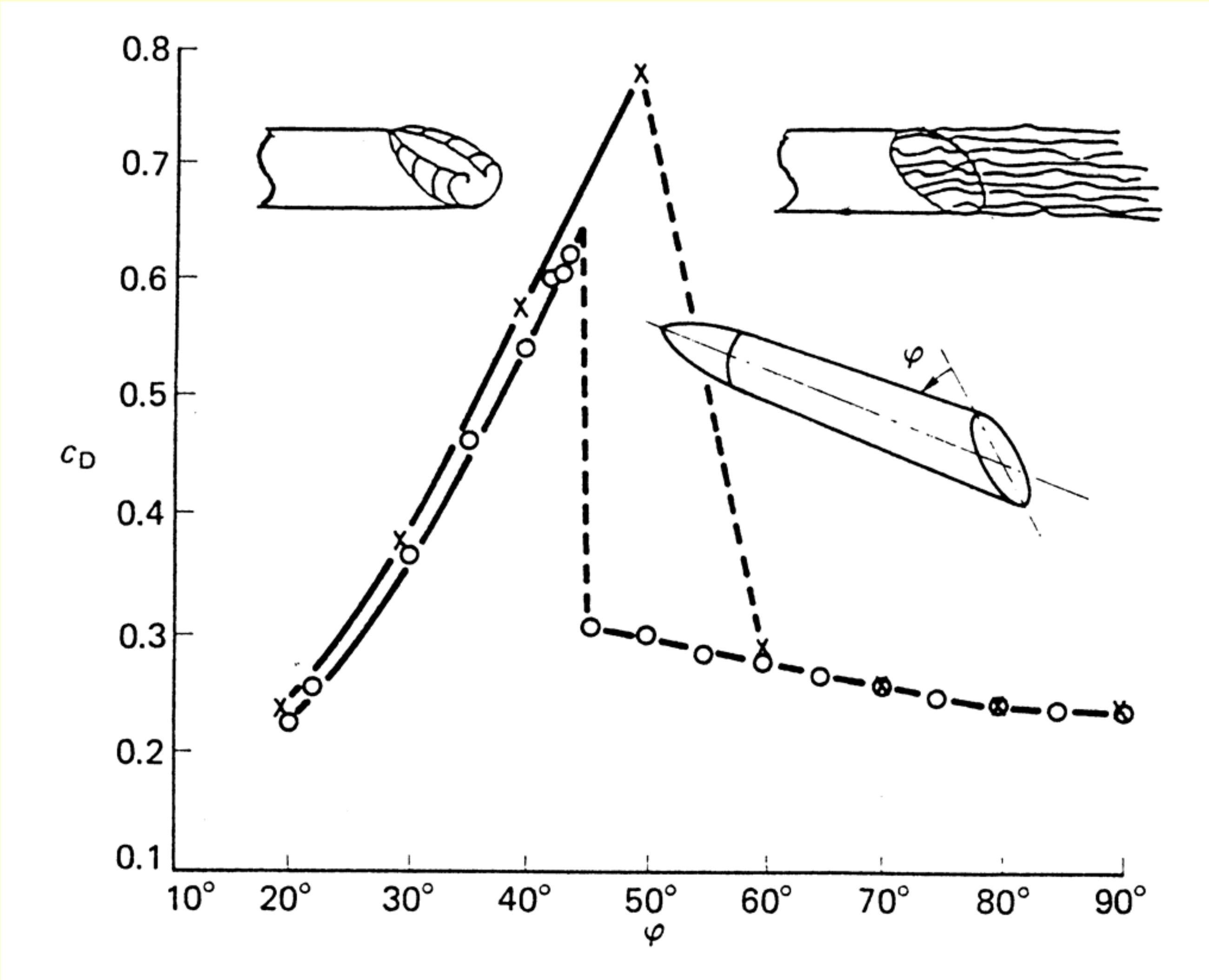
The Morel bodies

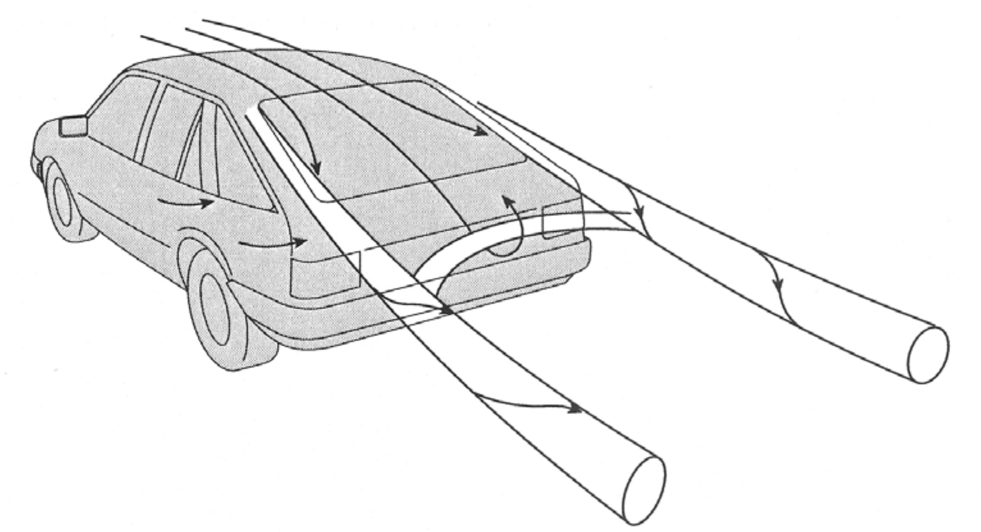


Base flow with concentrated vortices

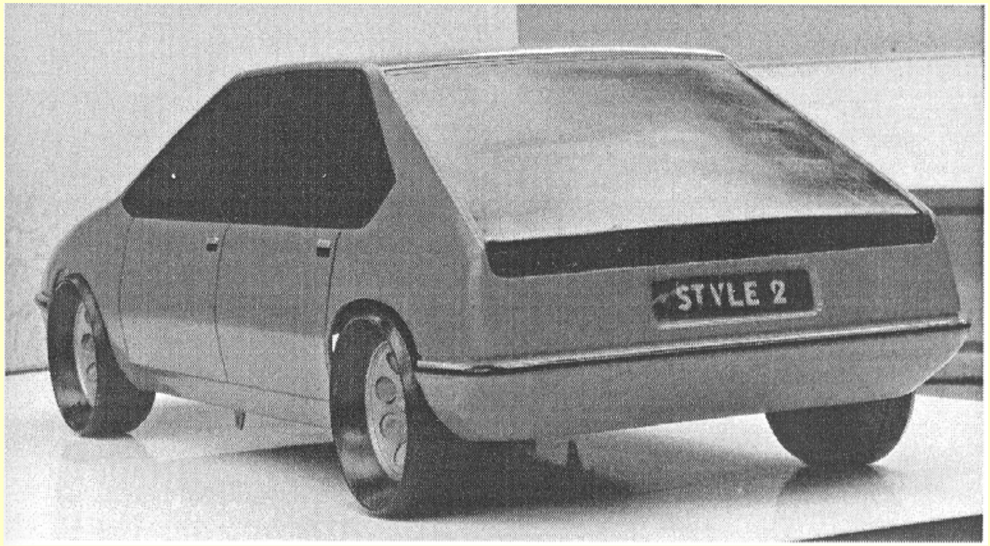


The Morel bodies





The same phenomenon may occur also for cars



$C_D = 0.55!$

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In the '70s several cars were Morel bodies…

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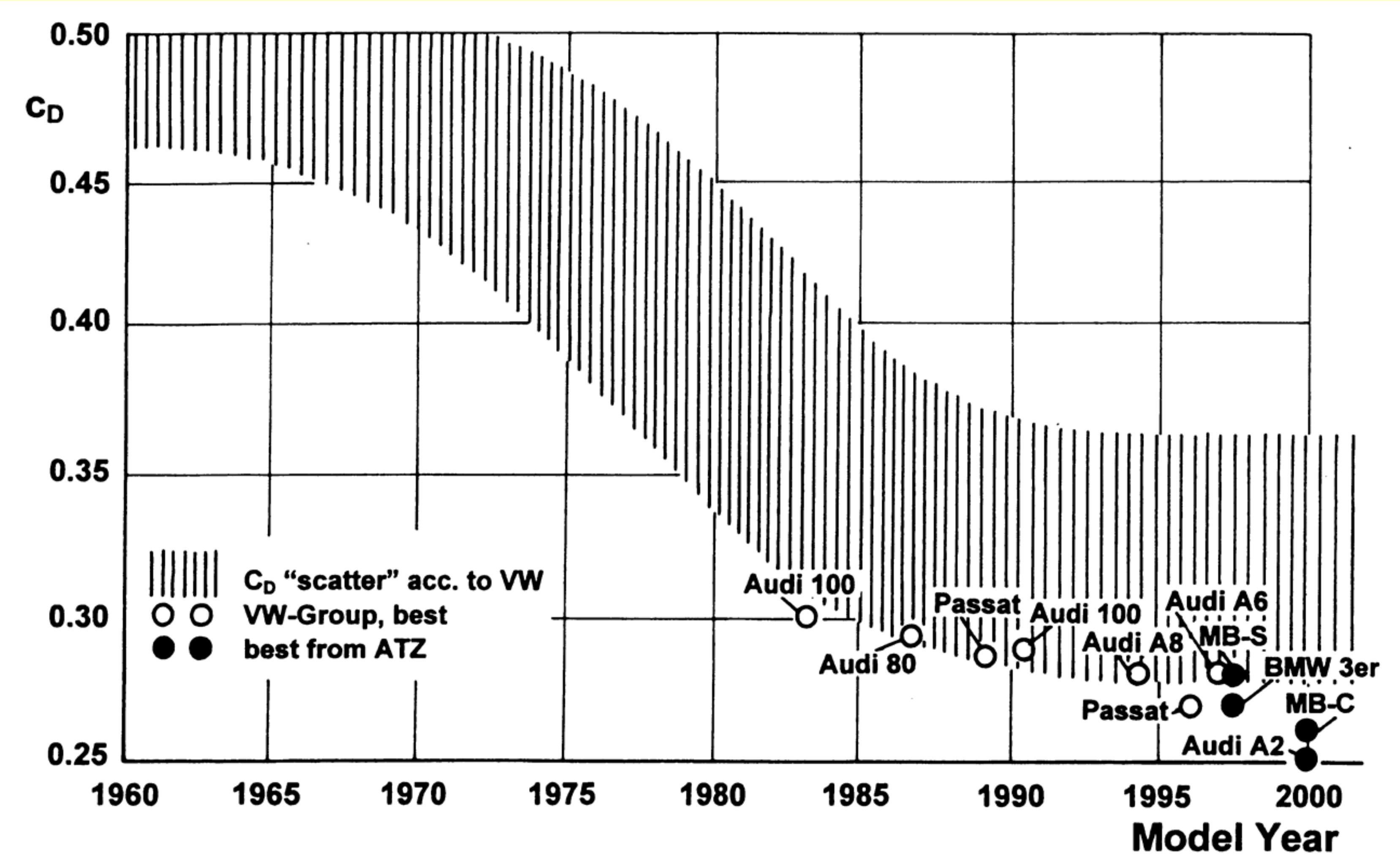
But then the lesson was learned…

Evolution of C_D of cars



Anyway…

Certain cars were found to have a higher C_D than expected

⇓

Investigation to understand the reason

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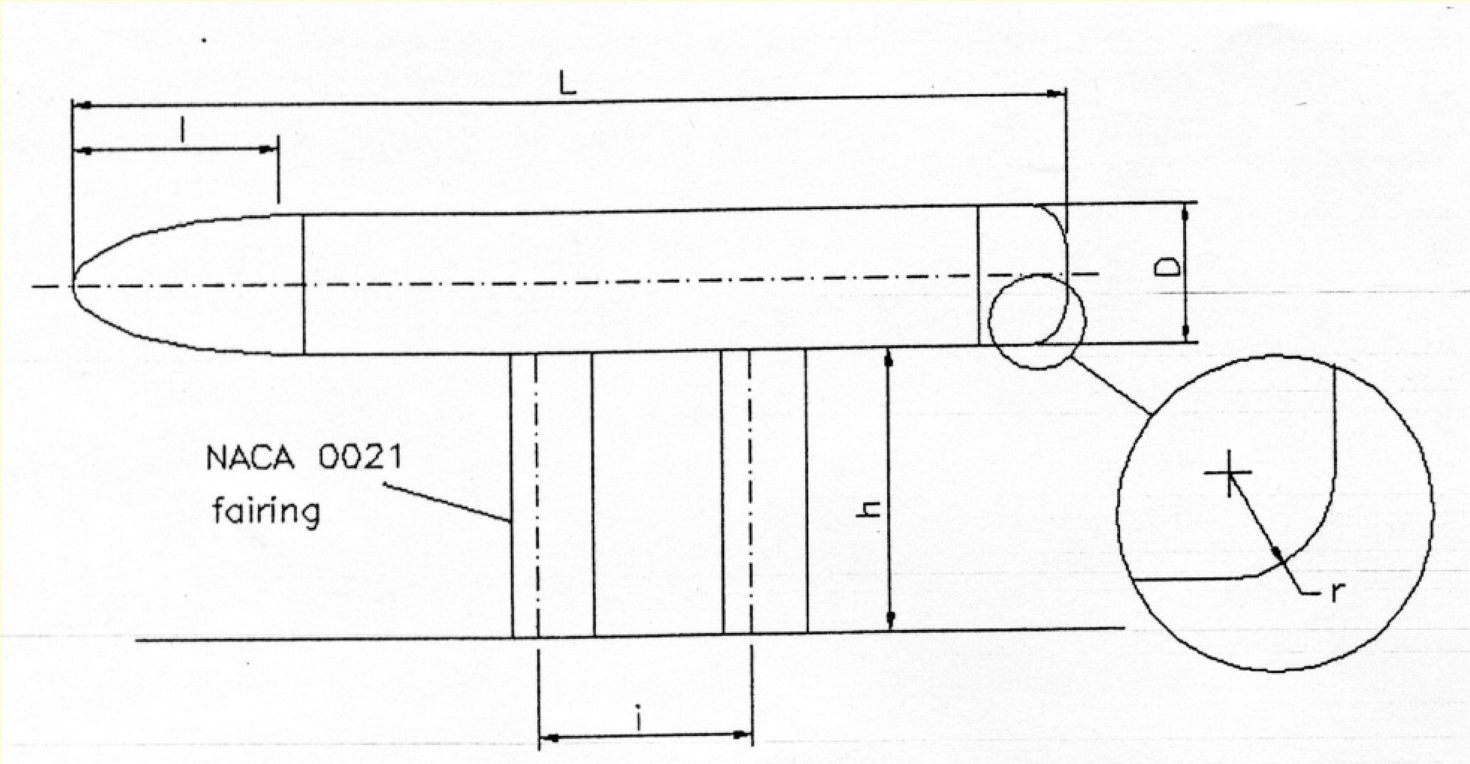
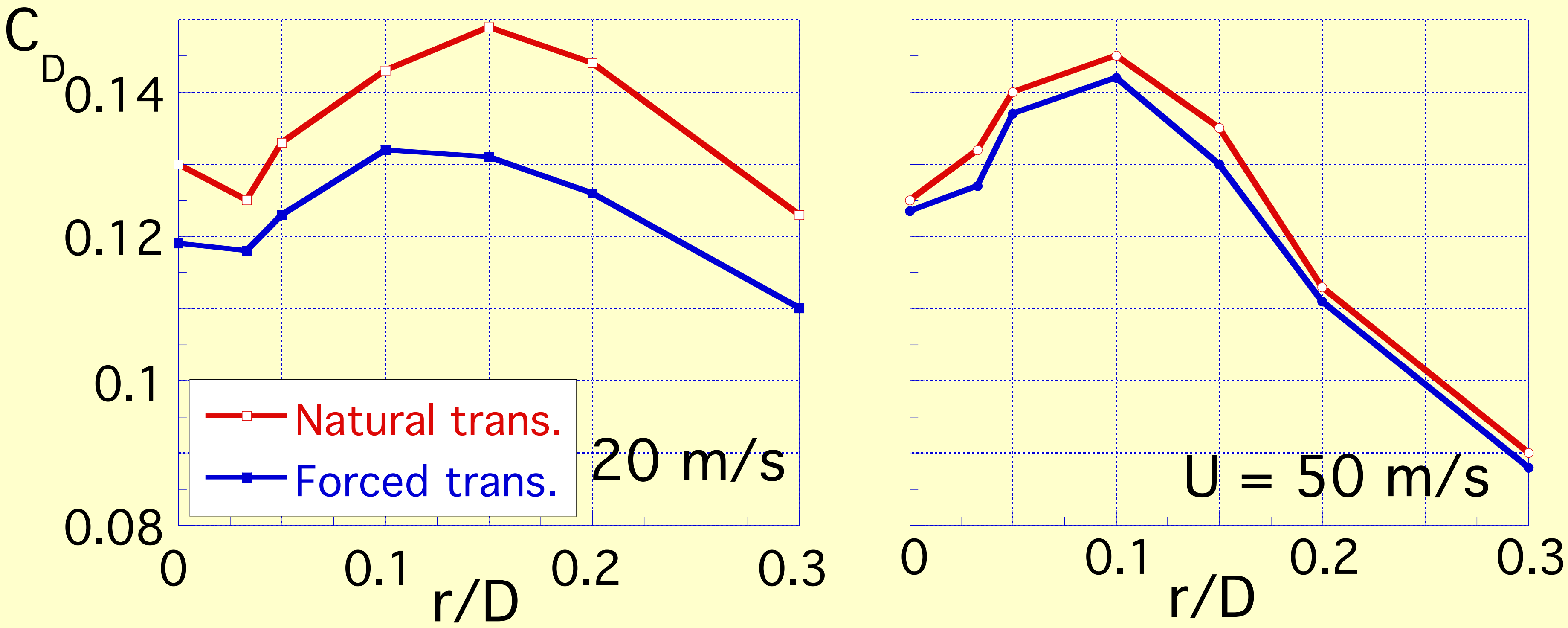
Analysed problem: Axisymmetrical body ending with different radius of curvature, *r/D*



- Measurement of forces and pressures

Effect of afterbody rounding



A maximum of drag exists for a certain value of r/D

The phenomenon depends on geometrical and flow parameters

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Also in this case the lesson has been learned…

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One of the present cars with lower C_D

$C_D = 0.25$

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Prototypes of cars with $C_D < 0.2$

C.N.R.
Prototype

Fioravanti Flair
Prototype

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Several present production cars have $C_D \leq 0.3$




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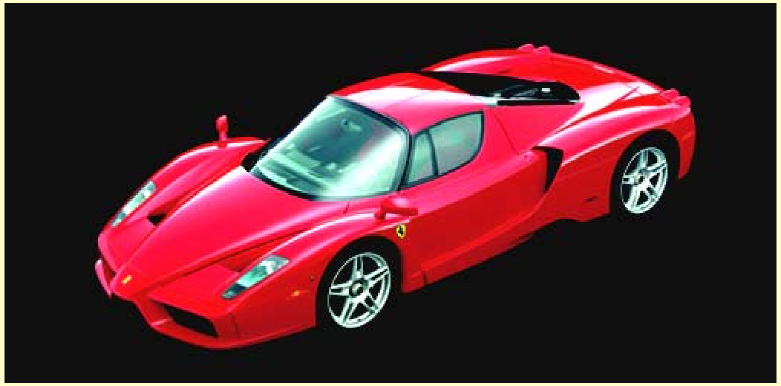

High engine power

↓

V_{max} > 300 km/h

Necessity of assuring high and safe global performance

↓

For high-performance cars it is essential that the vertical aerodynamic force be not directed upwards

Indeed:

The grip of the tyres is proportional to the downward force acting on them (weight ± aerodynamic force)

If the grip <u>decreases</u>:

- The breaking space increases

- The maximum admissible turning velocity decreases

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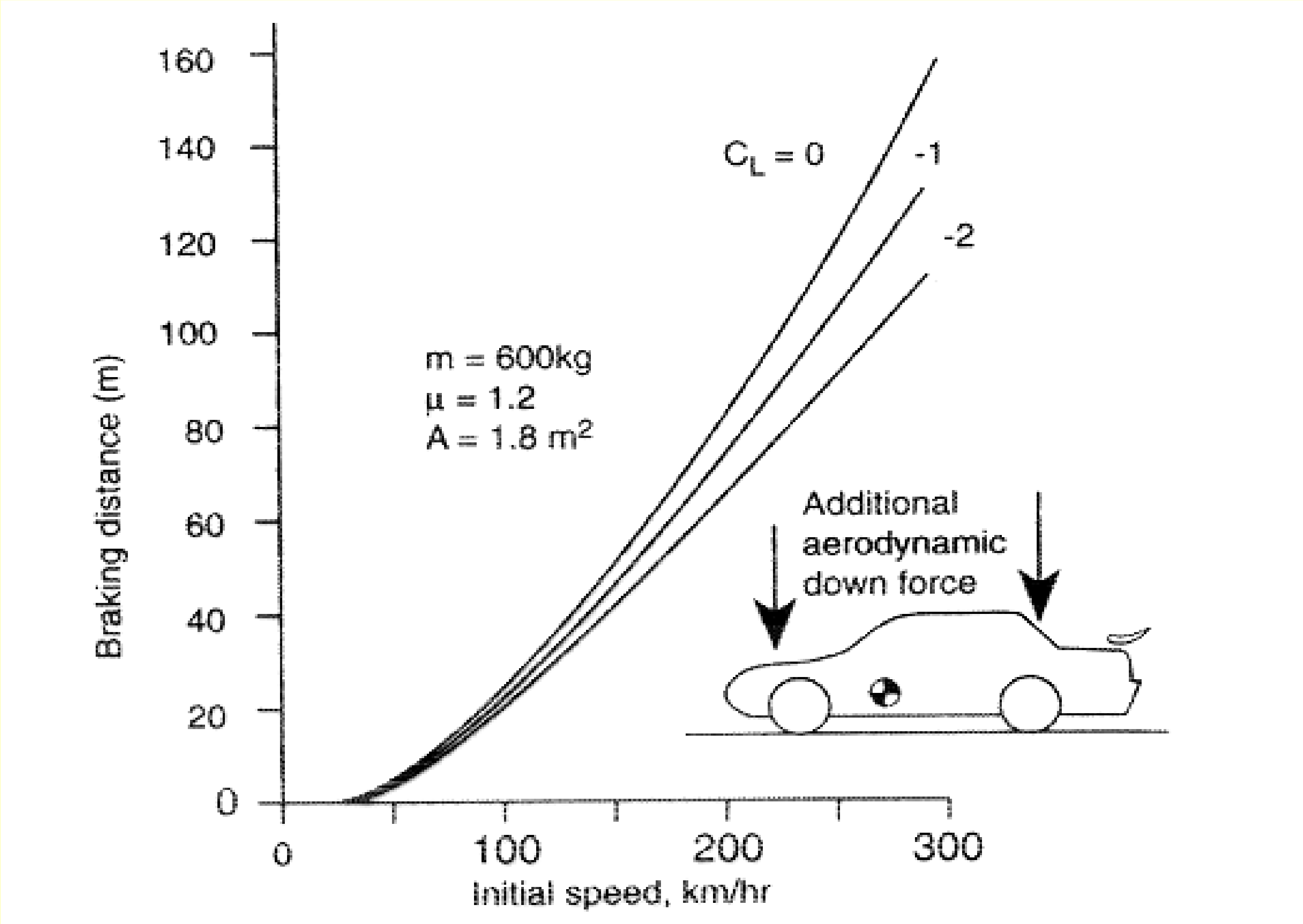
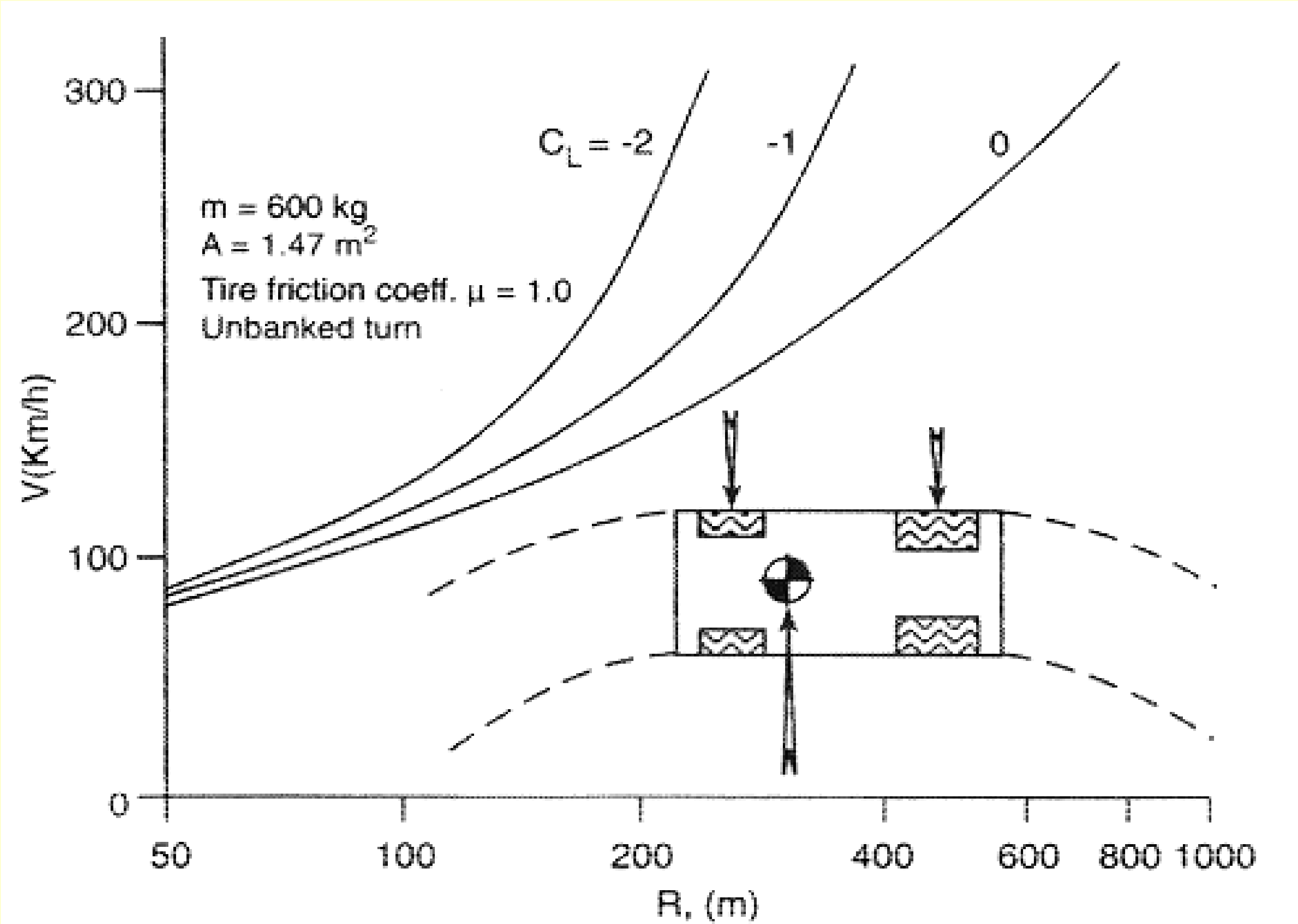
Effect on breaking space



Effect on maximum admissible turning velocity



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In general cars tend to be *lifting bodies*
(upward vertical aerodynamic force)

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This may cause even beautiful cars to become potentially dangerous

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Aerodynamic Design Goals:

High downward aerodynamic forces (negative lift)

High efficiency (low drag)

⇩

Negative C_z
Balance between front and rear wheels
C_x as small as possible

The increase of the vertical download generally causes an increase in drag

Generation of Aerodynamic Download

Added devices: wings, spoilers, etc.

High and concentrated load

Interference with the style and increased drag

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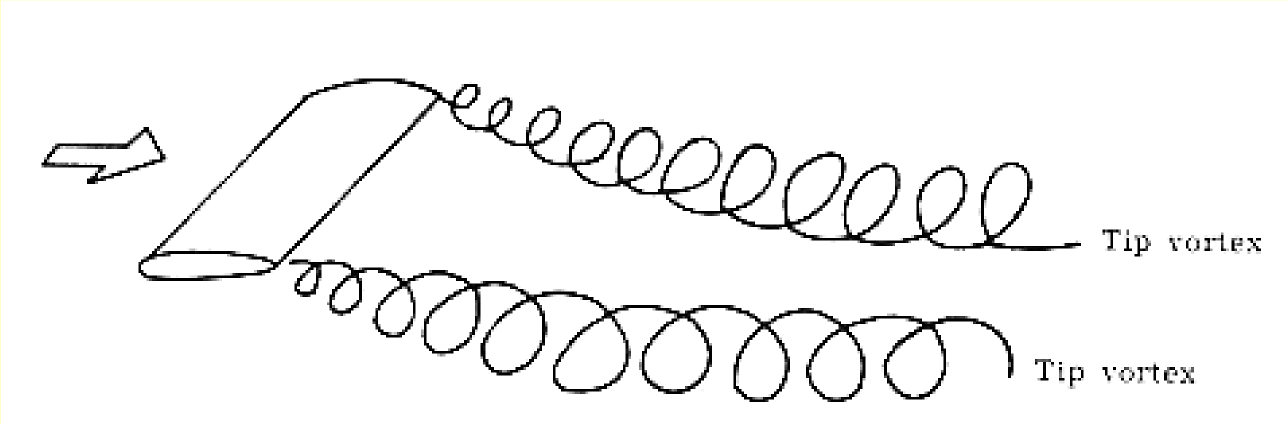
Wing wake drag



Generation of Aerodynamic Download

The whole car may be used to generate the download

Body

The design of the upper part of the car may be used to generate the required download producing the minimum amount of drag

Underbody

An appropriate design of the underbody allows high aerodynamic performance to be obtained without interfering with the style

- A "rough" uncovered underbody slows the airflow and does not allow the lower part of the car to be used to generate a download.
- A smooth faired underbody improves the airflow, increases the download and reduces the drag.
- A smooth faired underbody "modelled" with a diffuser accelerates the airflow below the vehicle and further improves the aerodynamic performance.

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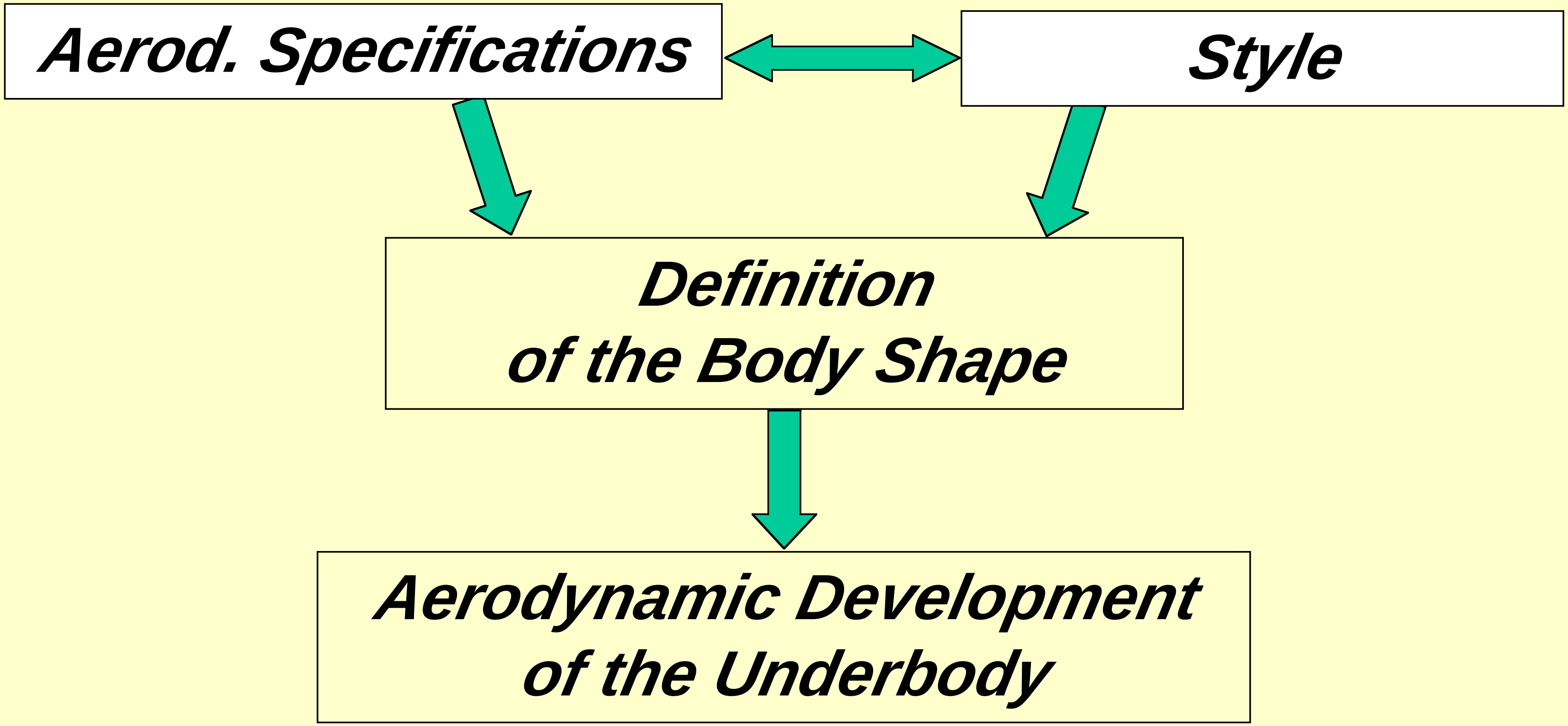
SCHEME OF AERODYNAMIC DESIGN



HAVE A PAUSE!
SEE YOU SOON!