

aerodynamika osobního automobilu II

Poznámky k přednášce

Tekutiny

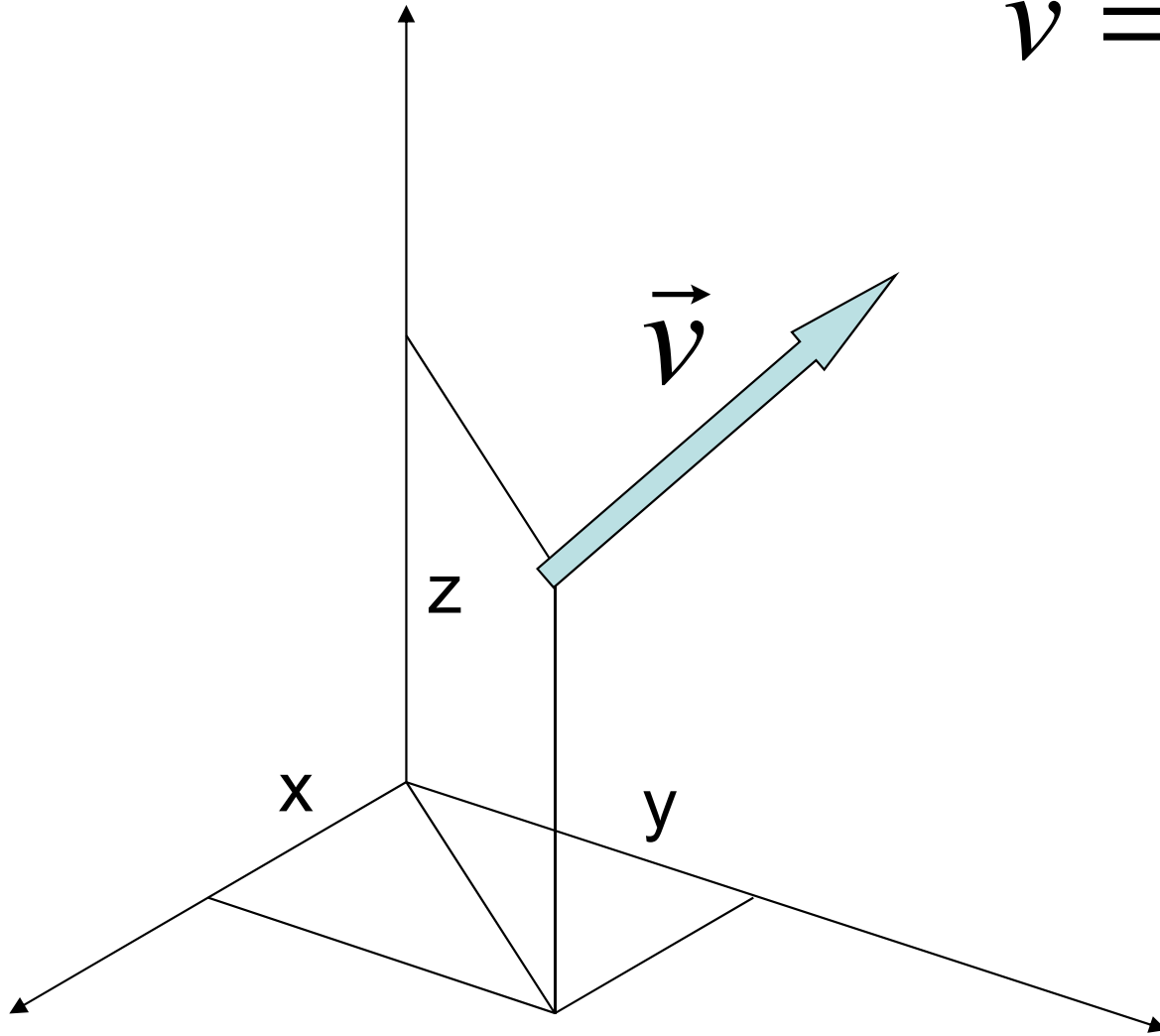
- tekutina: plyny, kapaliny
- ideální tekutina, tekutina bez vnitřního tření, (nestlačitelná)
- klasická reálná tekutina má vždy vnitřní tření

Pohyb tekutiny

- popis pomocí pole: každému bodu uvažovaného prostoru je přiřazen určitá veličina.
- vektor rychlosti $\vec{v} = \vec{v}(x, y, z)$
- vektor zrychlení
- (příklad vektorových polí)
- hustoty $\rho = \rho(x, y, z)$
- entropie, teploty...
- (příklad skalárních polí)

Pole rychlostí

$$\vec{v} = \vec{v}(x, y, z)$$



viskosita

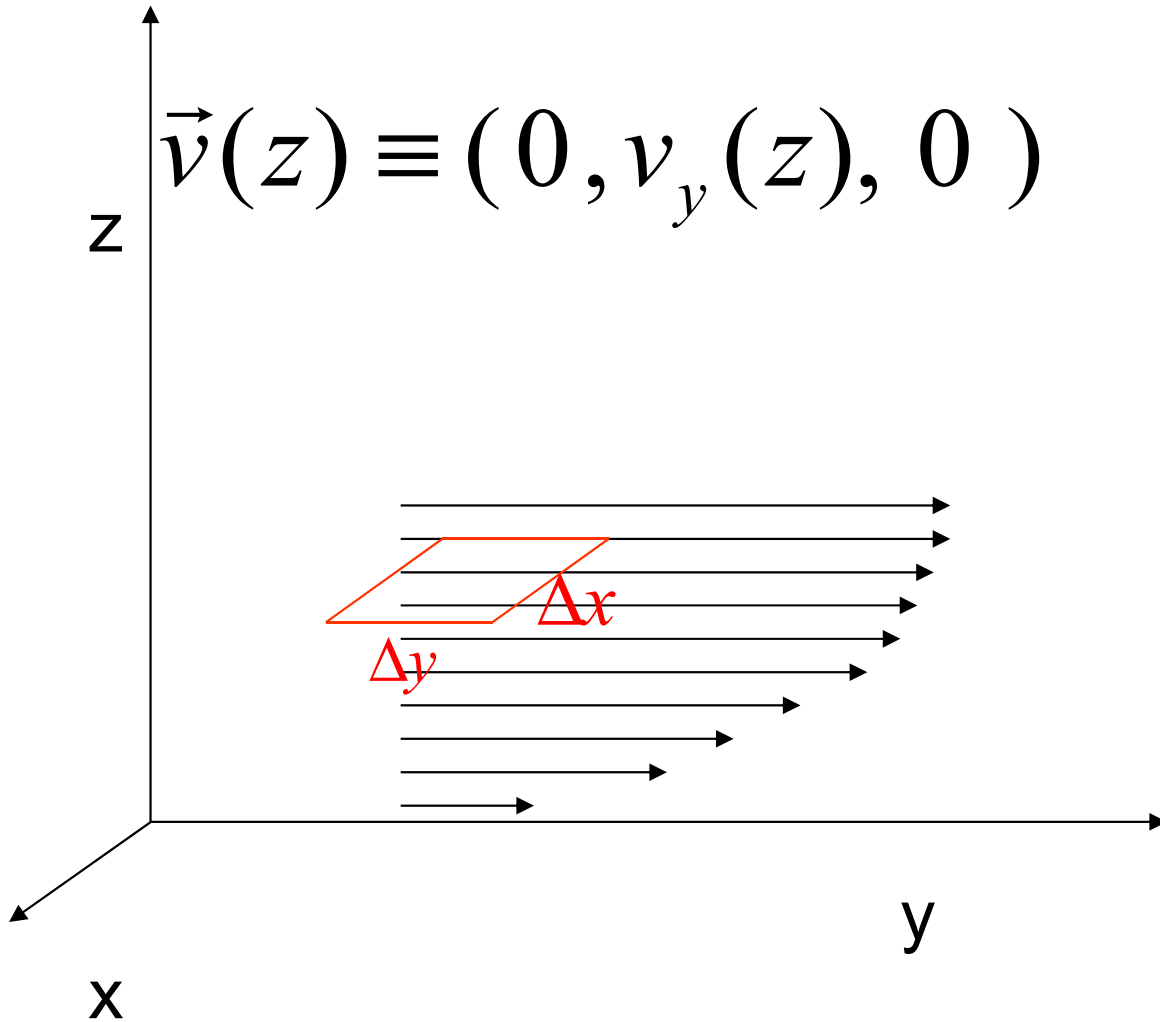
pole rychlosti

$$\vec{F}_{\Delta x \Delta y} \equiv (0, \Delta F_{\Delta x \Delta y}, 0)$$

$$\vec{v}(z) \equiv (0, v_y(z), 0)$$

$$F_{\Delta x \Delta y} = \Delta x \Delta y \tau$$

$$\tau = \eta \frac{\partial v_y(z)}{\partial z}$$



pohybová rovnice vazké tekutiny

- II Newtonův pohyb. zák. součin zrychlení a hmotnosti částice je dán součtem všech sil, které na částici působí

$$m\vec{a} = \vec{F}_{tlak} + \vec{F}_{tíhová} + \vec{F}_{viskosita} + \dots$$

Objemový element tekutiny $\Delta V = \Delta x \Delta y \Delta z$

Hmotnost objemového elementu $\Delta m = \rho \Delta V$

pohybová rovnice vazké tekutiny

$$\vec{F}_{tlak} = \Delta V \vec{f}_{tlak} = -\Delta V \operatorname{grad} p(x, y, z)$$

$$\vec{F}_{tíhová} = \Delta V \vec{f}_{tíhová} = \Delta V \rho \vec{g}$$

$$\vec{F}_{visc.} = \Delta V \vec{f}_{visc.} = \Delta V \eta \Delta \vec{v}$$

$$\Delta V = \Delta x \Delta y \Delta z$$

pohybová rovnice vazké tekutiny

$$m\vec{a} = \vec{F}_{tlak} + \vec{F}_{tíhová} + \vec{F}_{viskosita}$$

$$\Delta V \rho \vec{a} = -\Delta V \text{grad } p + \Delta V \rho \vec{g} + \Delta V \eta \Delta \vec{v}$$

$$\rho \vec{a} = -\text{grad } p + \rho \vec{g} + \eta \Delta \vec{v}$$

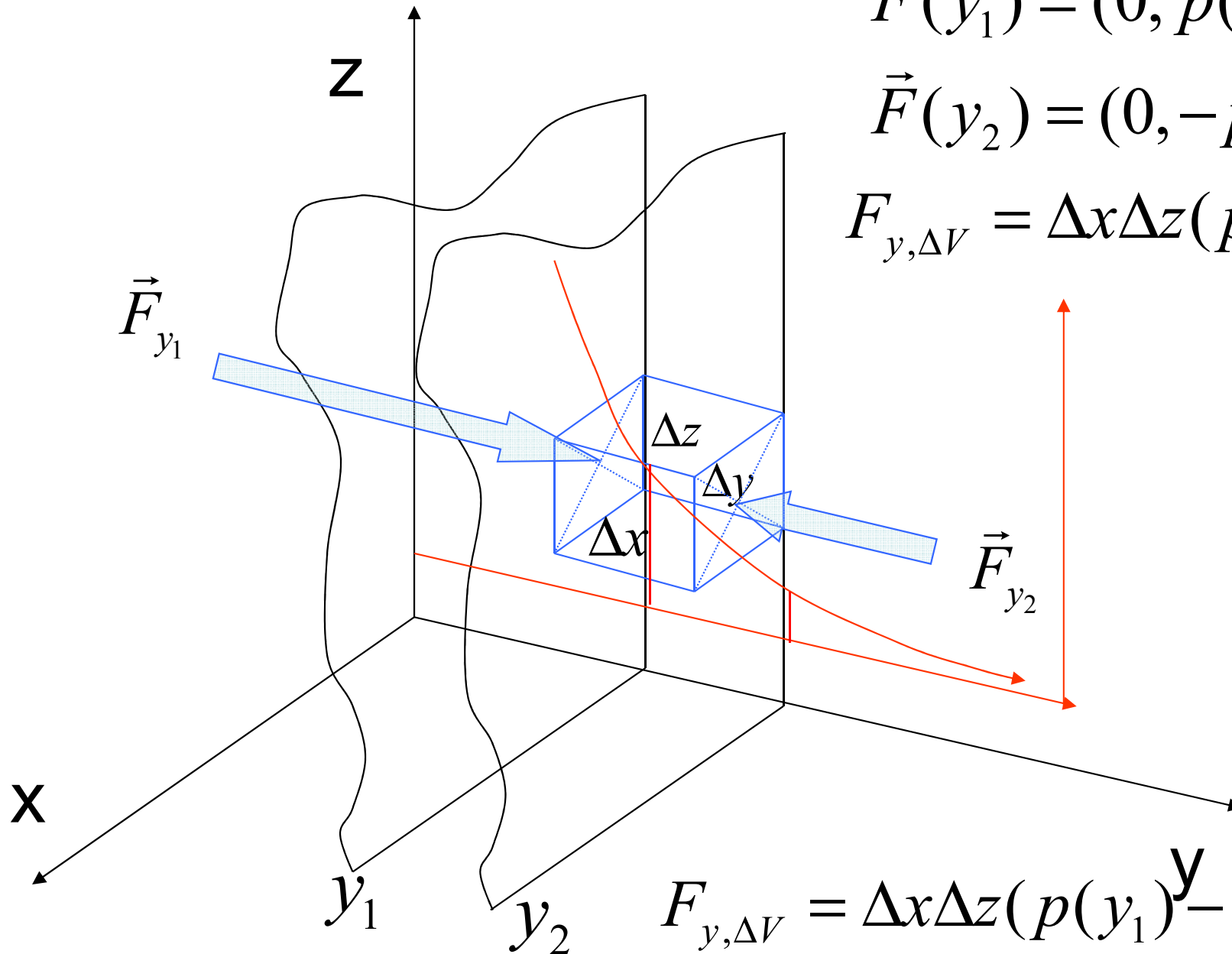
tlaková síla v tekutině

$$\vec{F}_{\Delta V} = \vec{F}_{y_1} + \vec{F}_{y_2}$$

$$\vec{F}(y_1) = (0, p(y_1)\Delta x\Delta z, 0)$$

$$\vec{F}(y_2) = (0, -p(y_2)\Delta x\Delta z, 0)$$

$$F_{y,\Delta V} = \Delta x\Delta z(p(y_1) - p(y_2))$$



$$F_{y,\Delta V} = \Delta x\Delta z(p(y_1) - p(y_2))$$

tlaková síla v tekutině

$$F_{y,\Delta V} = \Delta x \Delta z (p(y_1) - p(y_2))$$

$$F_{y,\Delta V} = -\Delta x \Delta z (p(y_2) - p(y_1))$$

$$F_{y,\Delta V} = -\Delta x \Delta z \Delta y \frac{(p(y_2) - p(y_1))}{\Delta y}$$

$$F_{y,\Delta V} = -\Delta V \frac{(p(y_1 + \Delta y) - p(y_1))}{\Delta y}$$

tlaková síl v tekutině

$$F_{y,\Delta V} = -\Delta V \frac{(p(y_1 + \Delta y) - p(y_1))}{\Delta y}$$

$$f_y = \lim_{\Delta x, \Delta y, \Delta z \rightarrow 0} \frac{F_{y,\Delta V}}{\Delta V} = - \lim_{\Delta y \rightarrow 0} \frac{(p(y_1 + \Delta y) - p(y_1))}{\Delta y}$$

$$f_y = - \lim_{\Delta y \rightarrow 0} \frac{(p(y_1 + \Delta y) - p(y_1))}{\Delta y} = - \frac{\partial p}{\partial y}$$

$$\vec{f} = -grad p(x, y, z) = \frac{\partial p}{\partial x} \vec{e}_x + \frac{\partial p}{\partial y} \vec{e}_y + \frac{\partial p}{\partial z} \vec{e}_z$$

Navier Stokesova rovnice pohyb vazké tekutiny

$$\rho \frac{D\vec{v}}{Dt} = -grad p + \rho \vec{g} + \vec{f}_{visc.}$$

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \vec{v}\vec{\Delta}$$

$$\vec{f}_{visc.} = \eta \Delta \vec{v}$$

$$\frac{\partial \vec{v}}{\partial t} - \vec{v} \times rot \vec{v} = -\frac{1}{\rho} grad p + \frac{1}{2} grad v^2 + \vec{g} + \eta \Delta \vec{v}$$

Bernoulliova rovnice pro nestlačitelnou ideální tekutinu

$$\frac{1}{2} \rho v^2 + p + h \rho g = konst$$

- součet kinetické energie + potenciální energie objemové jednotky a tlaku je podél proudnice pro stacionární proudění nestlačitelné ideální tekutiny konstantní
- stacionární proudění
- nestlačitelná tekutina
- proudění beze ztrát (zisku) mechanické energie

Bernoulliova rovnice pro stlačitelnou ideální tekutinu

$$\frac{1}{2}v^2 + w + hg = konst \quad w = \varepsilon + p \frac{1}{\rho}$$

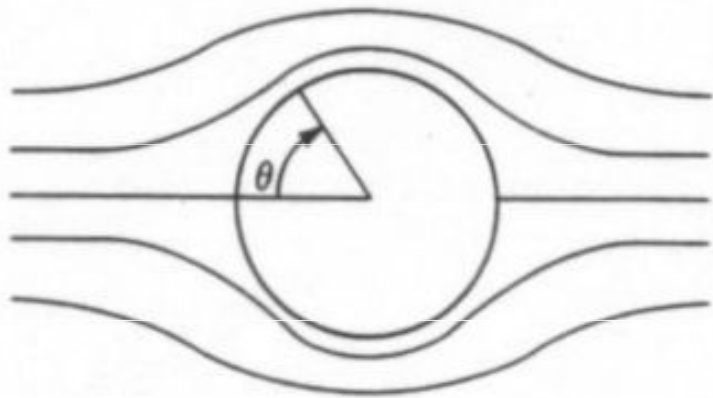
- platí podél proudnice
- w je entalpie vztažená na jednotku hmotnosti
- izentropické stacionární proudění
- bez ztrát (zisku) mechanické energie

Je možné napsat něco podobného
i pro nestacionární proudění?

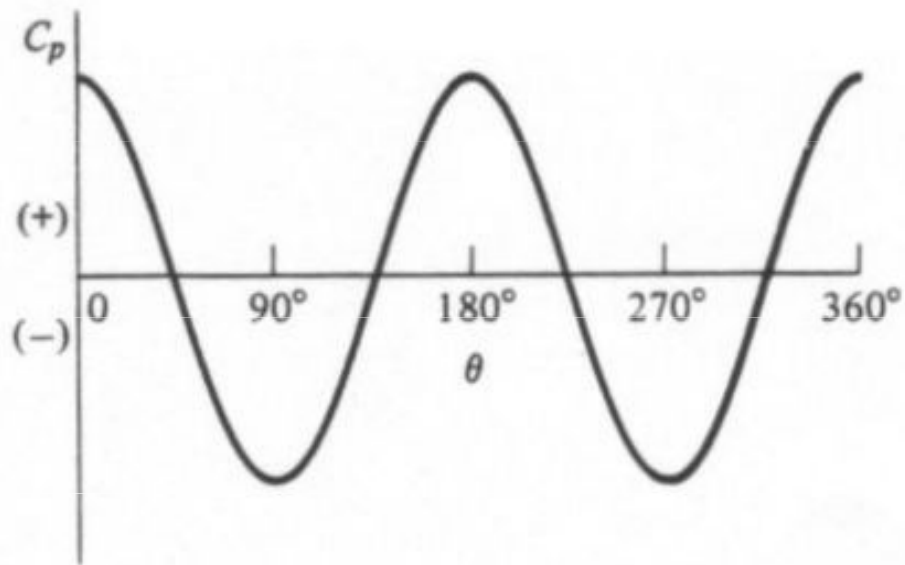
- Pro nestacionární případ je možné vyjádřit první integrál Eulerovy rovnice (pohybová rovnice pro tekutinu) za předpoladu, že je rychlostní pole je gradient nějaké funkce.
- takové proudění se nazývá potenciální.
- potenciální proudění je proudění nevírové

$$\vec{v} = \text{grad} \phi \quad \text{rot} \vec{v} = \text{rot} \text{grad} \phi \equiv 0$$

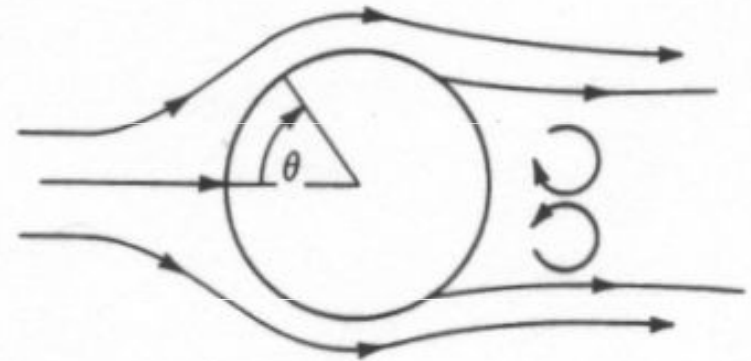
- pŕívod odporu **Odpor**



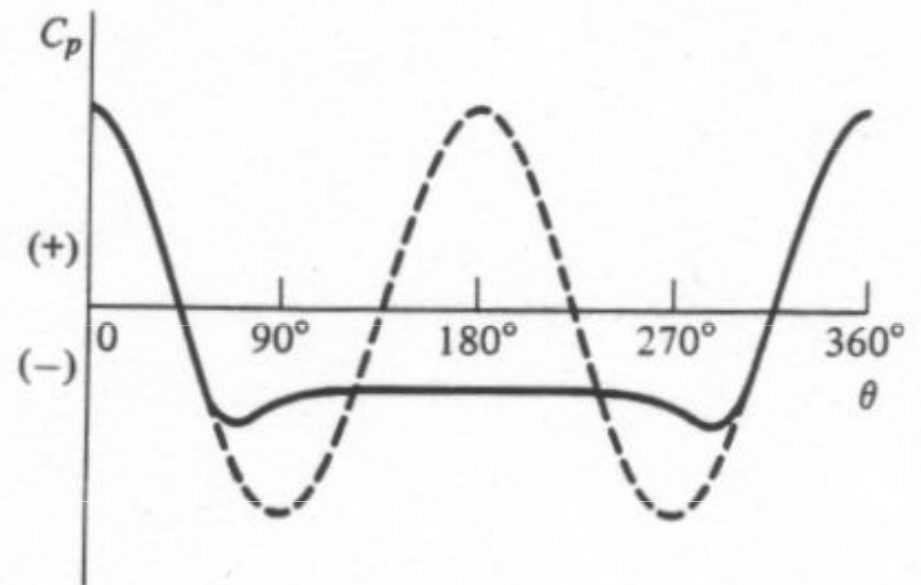
(a)



(b)



(a)



(b)

Reynolds number

$$\text{Re} = \frac{\rho V L}{\mu} = \frac{V L}{\nu} = \frac{Q L}{\nu A}$$

V is the mean fluid velocity ([SI units](#): m/s)

L is a characteristic linear dimension, (traveled length of fluid, or [hydraulic diameter](#) when dealing with river systems) (m)

μ is the [dynamic viscosity](#) of the [fluid](#) (Pa·s or N·s/m² or kg/(m·s))

ν is the [kinematic viscosity](#) ($\nu = \mu / \rho$) (m²/s)

ρ is the [density](#) of the fluid (kg/m³)

And in pipes:

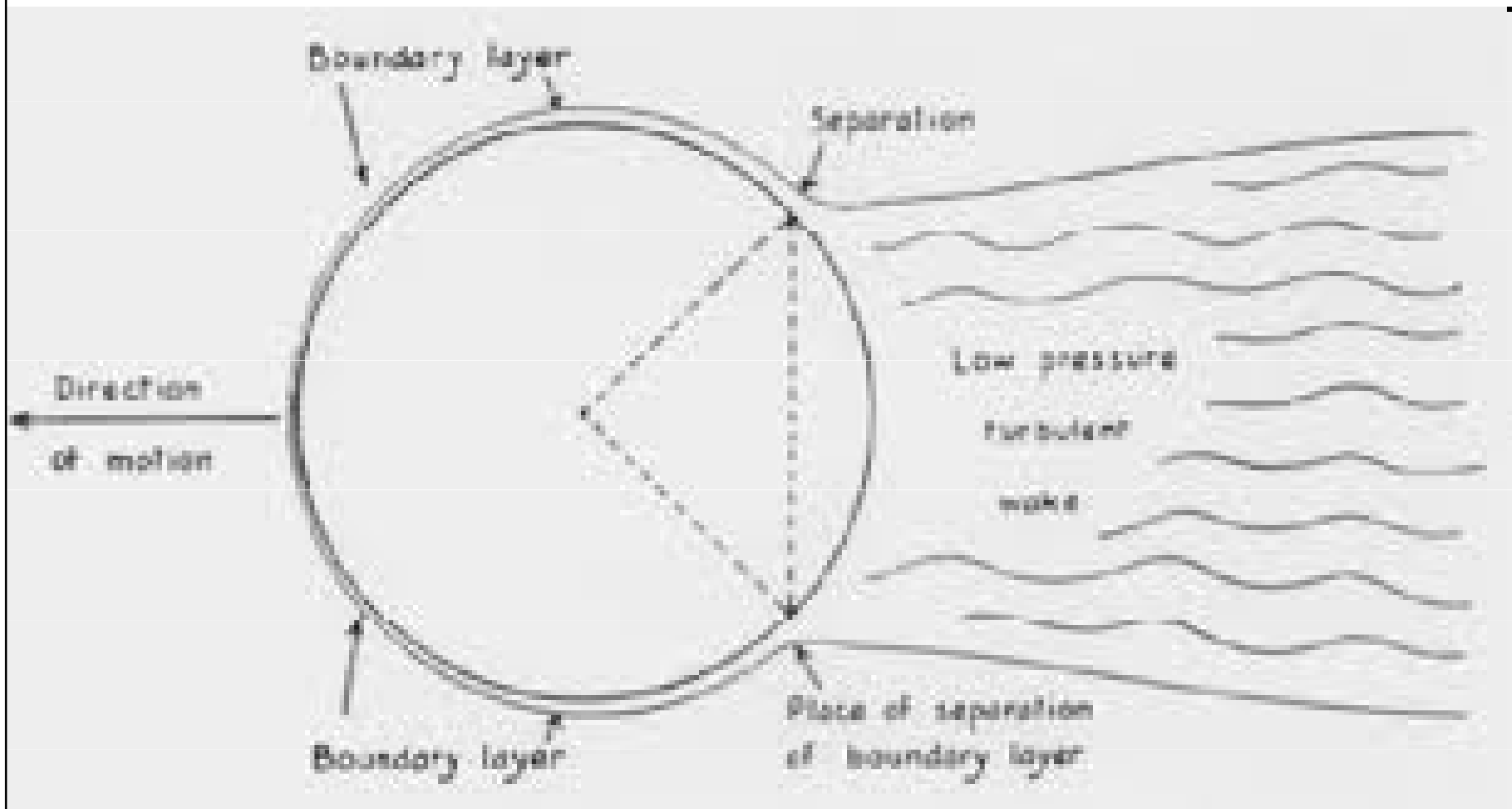
Q is the volumetric [flow rate](#) (m³/s)

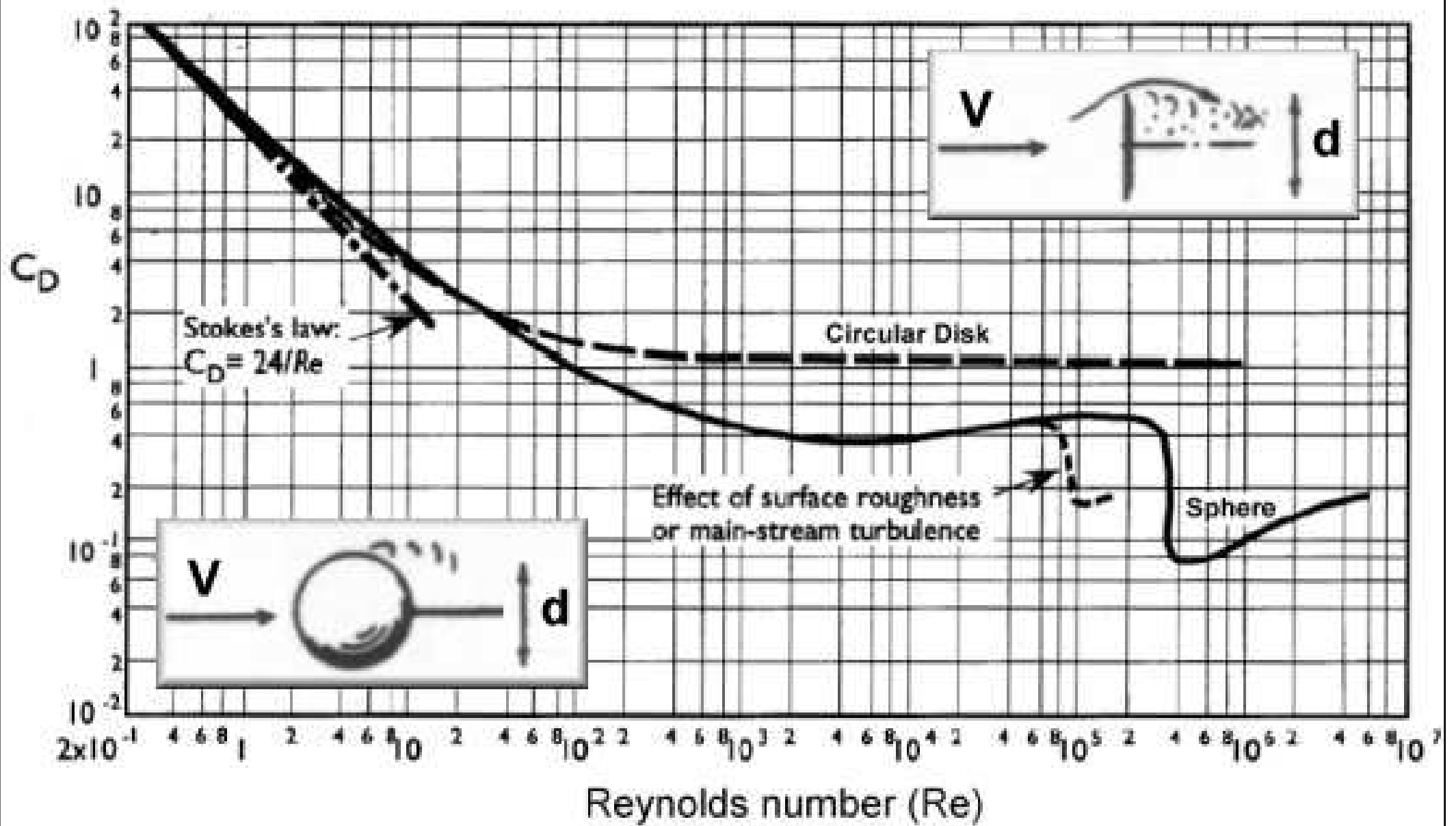
A is the pipe *cross-sectional* area (m²).

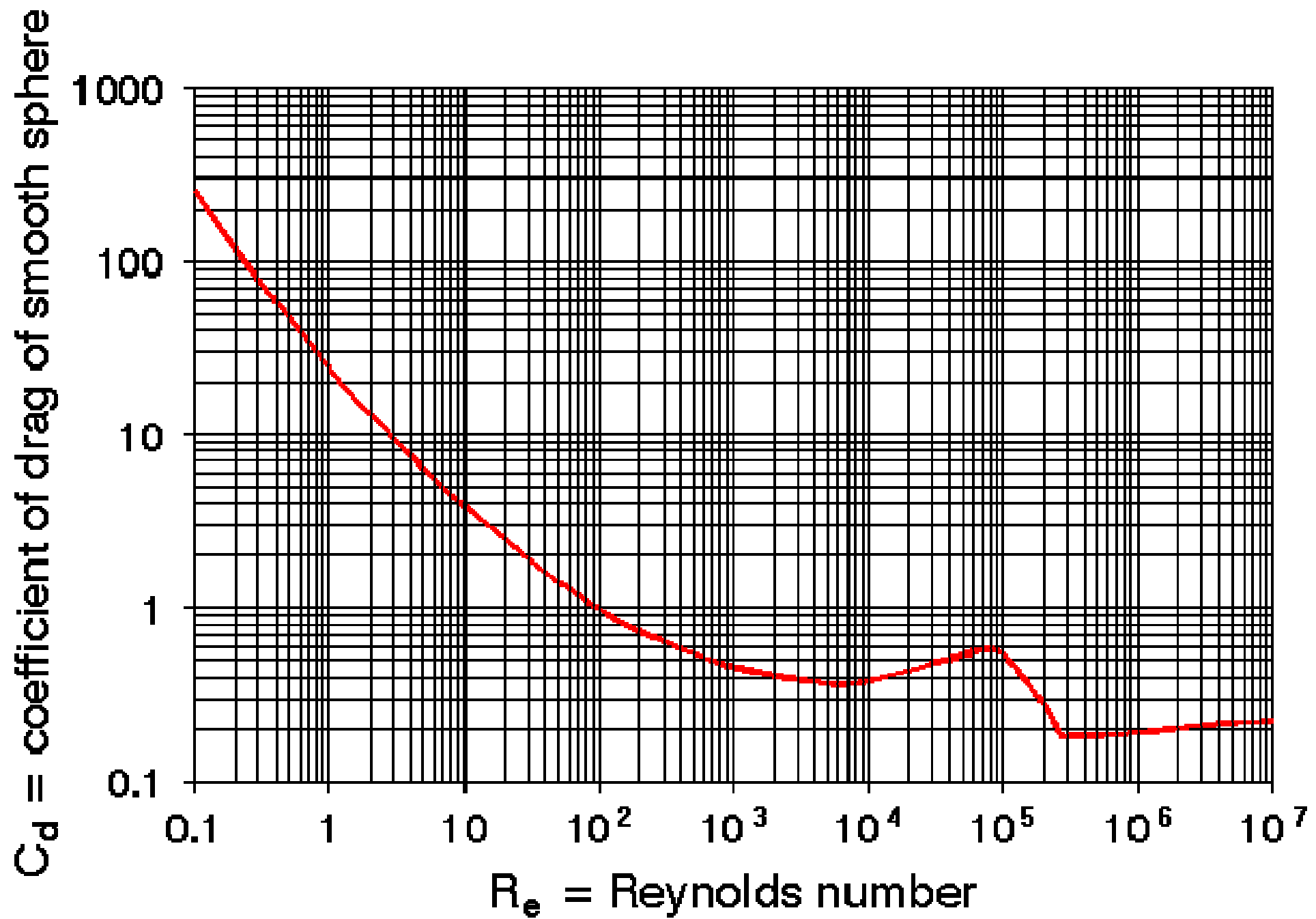
$$\sigma = 1,23 \text{ kg/cm}$$

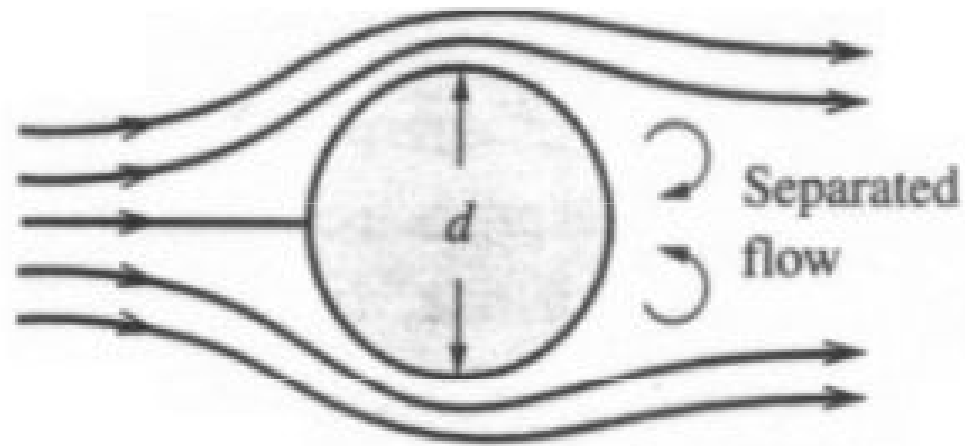
$$\mu = 1,79 \cdot 10^{-5} \text{ Ns/m}^2$$

$$\nu = 1,46 \cdot 10^{-5} \text{ m}^2/\text{s}$$



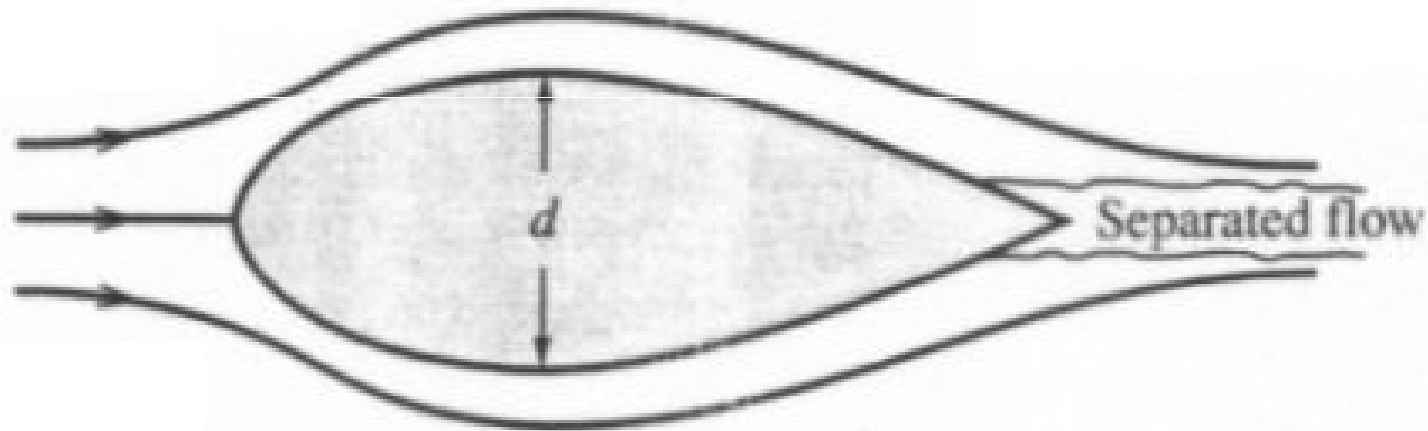
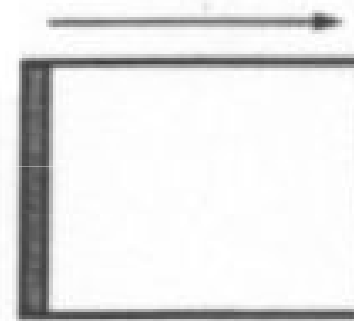




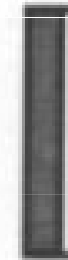


(a) Blunt body

Relative drag force



(b) Streamlined body



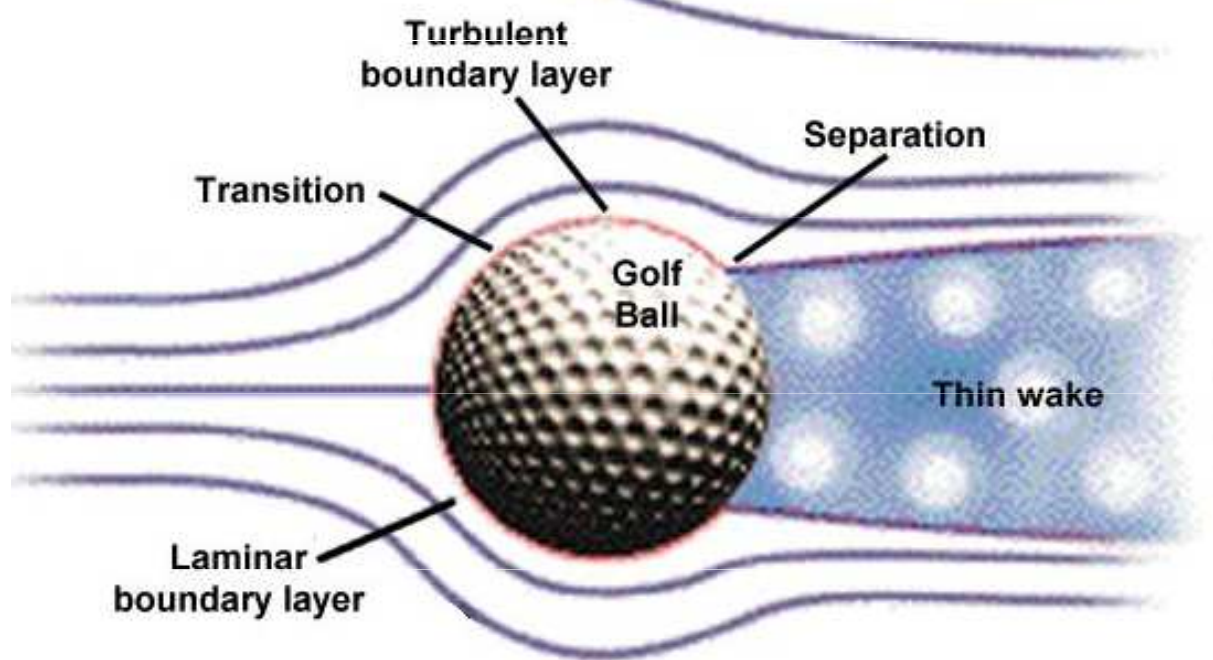
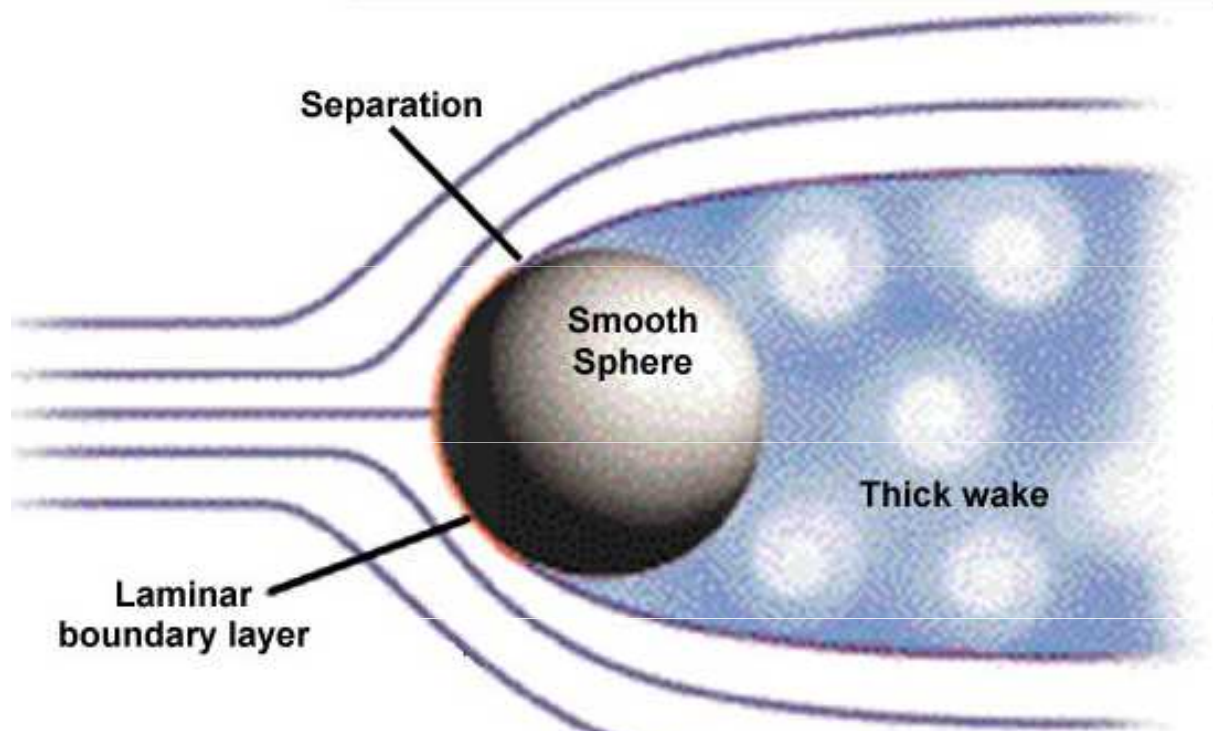
Code

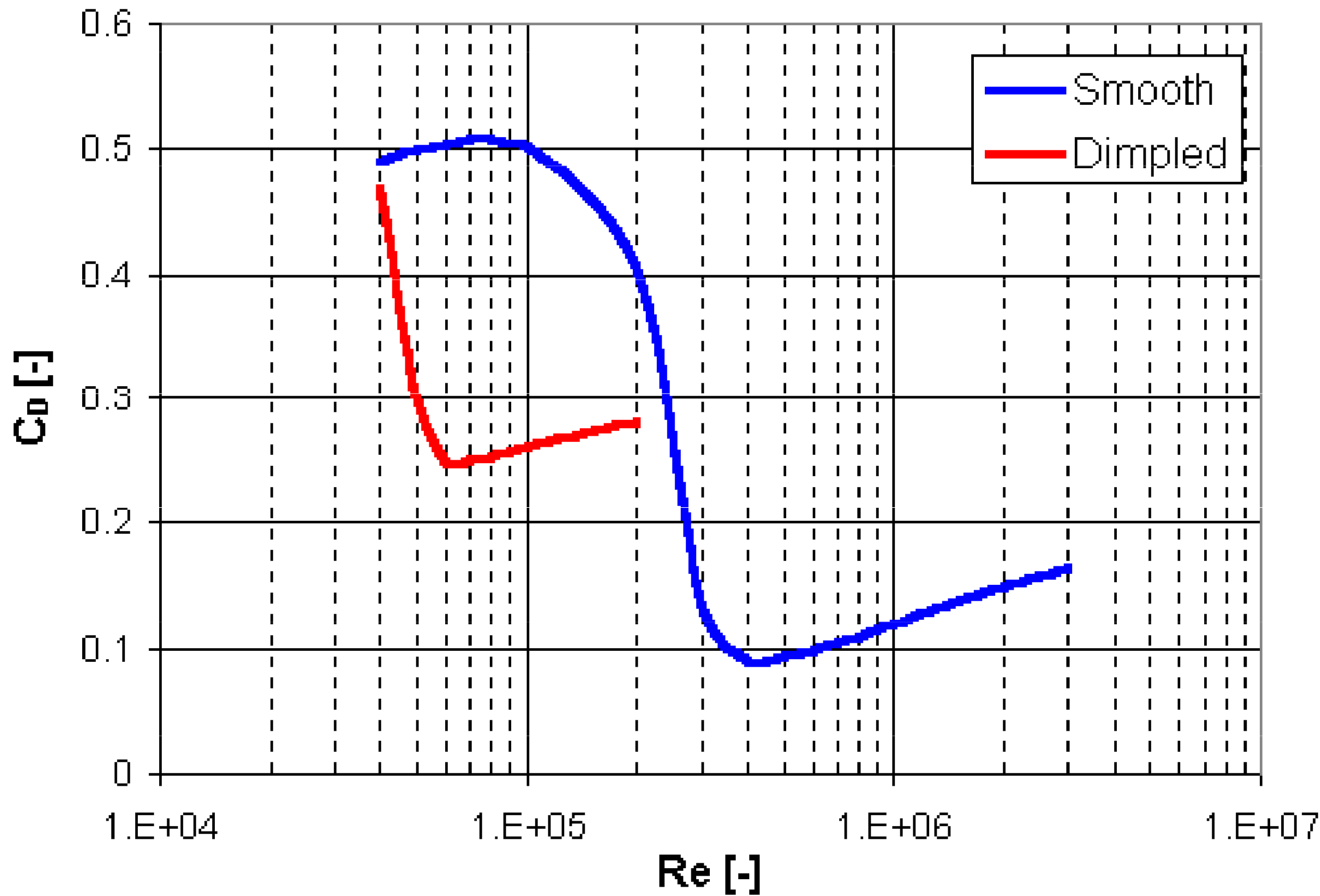


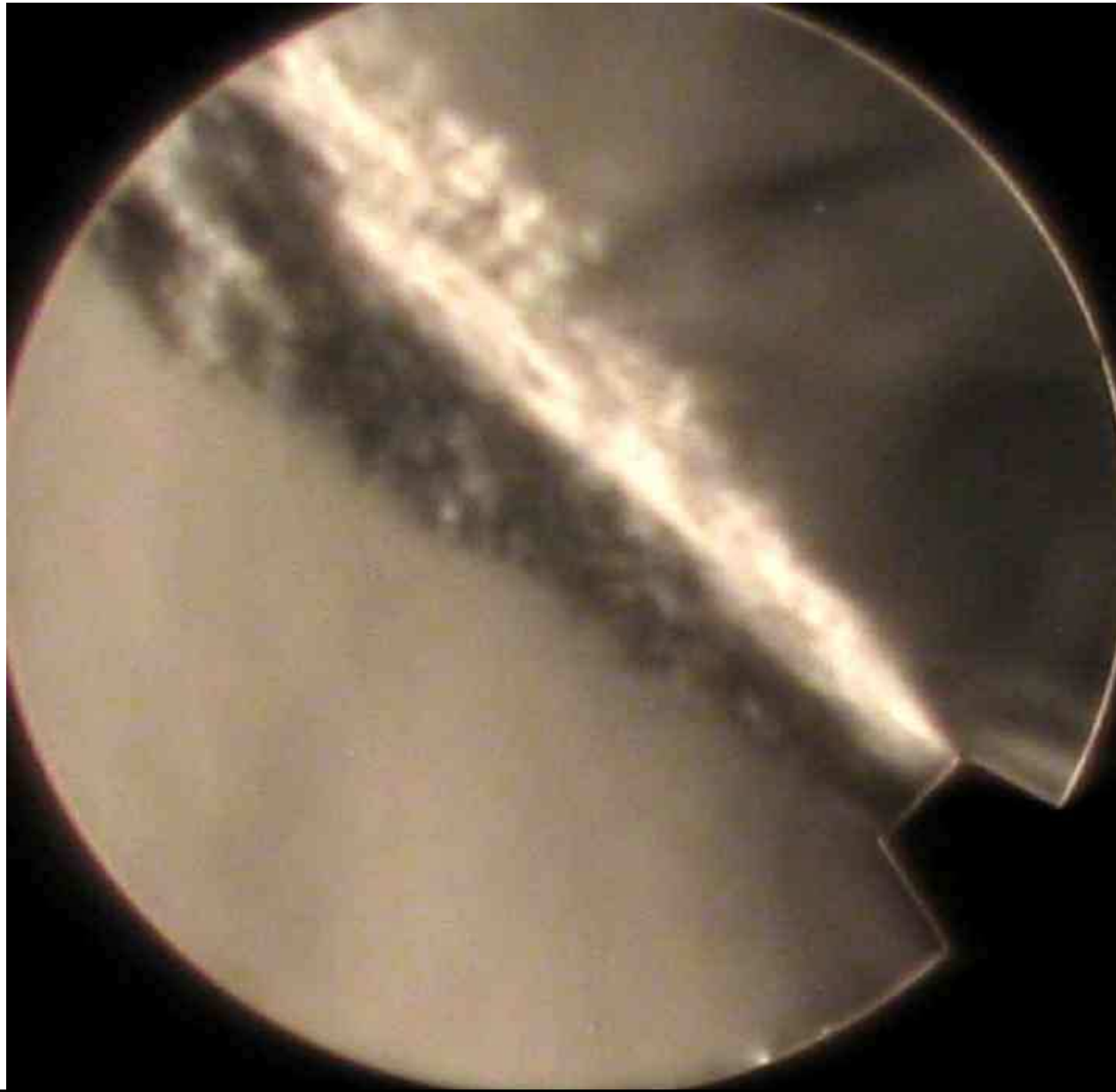
Skin friction drag

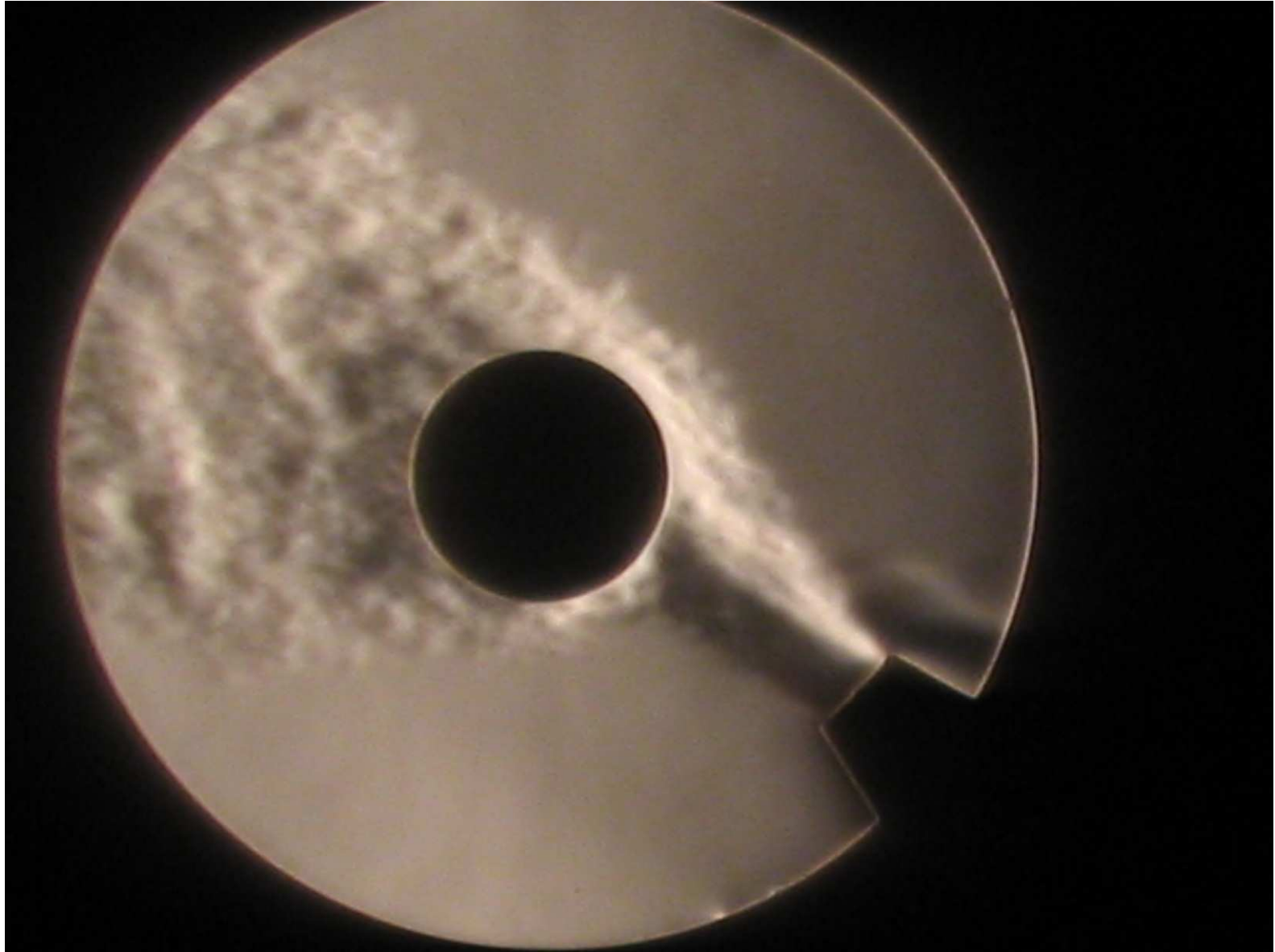


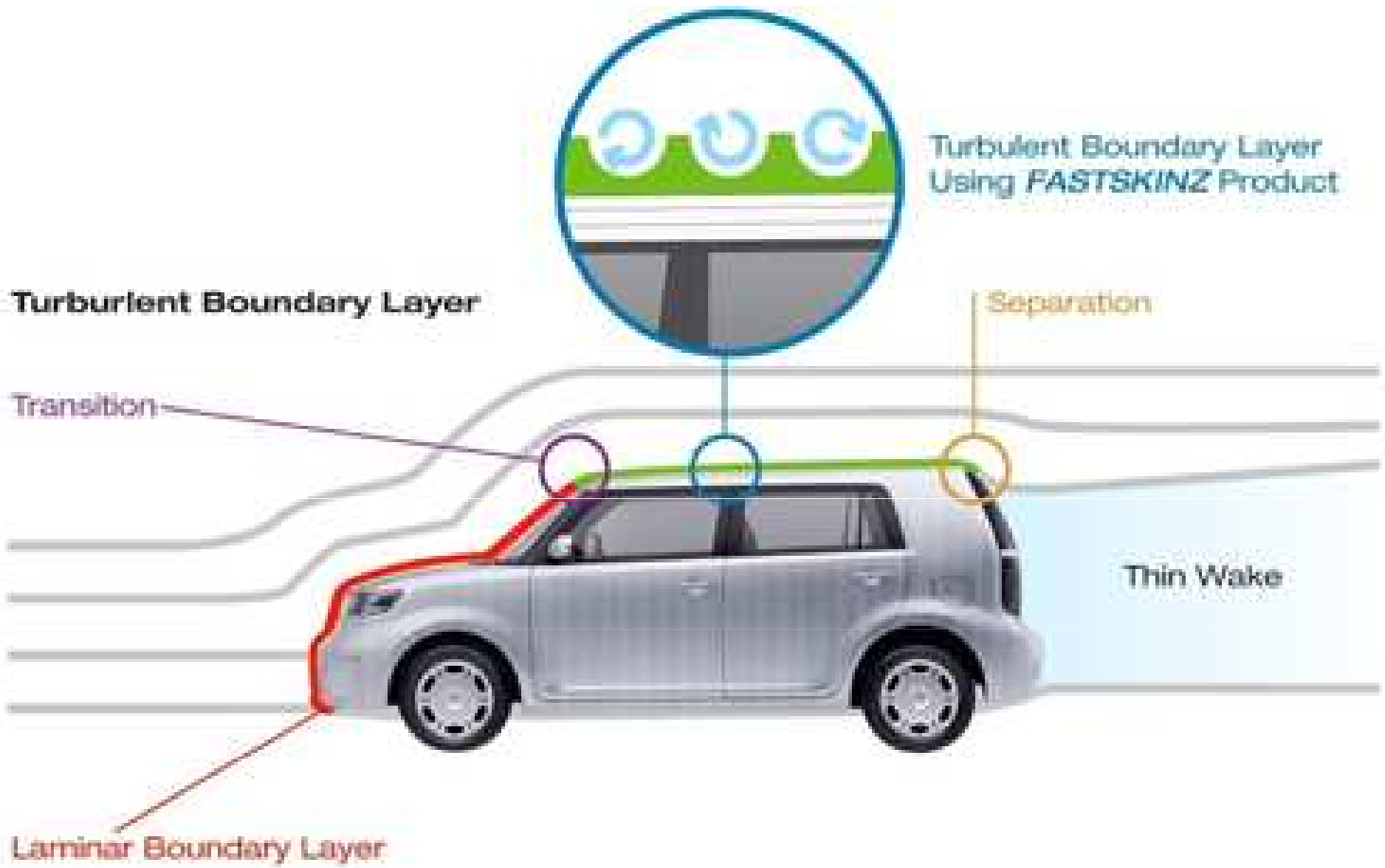
Pressure drag





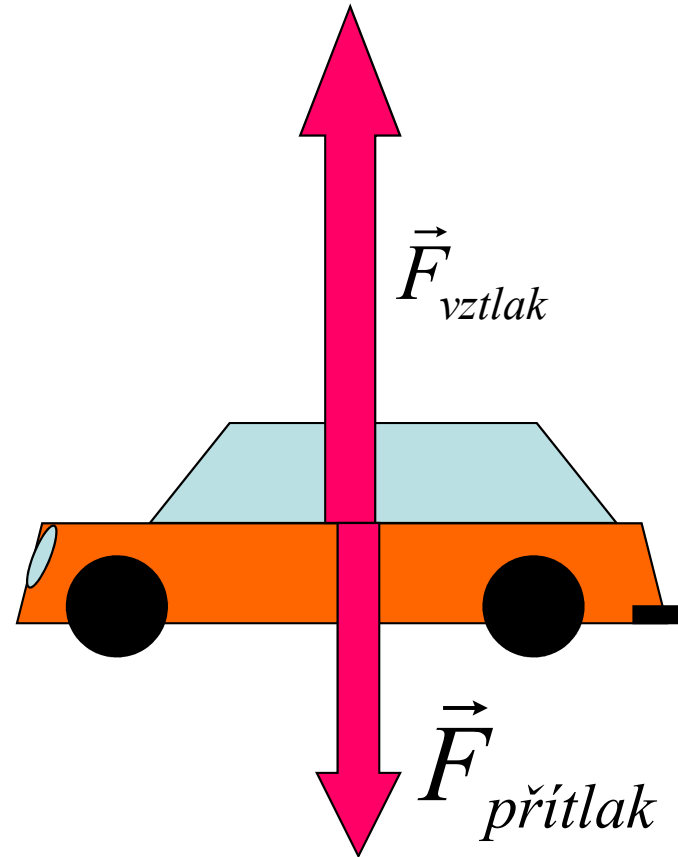
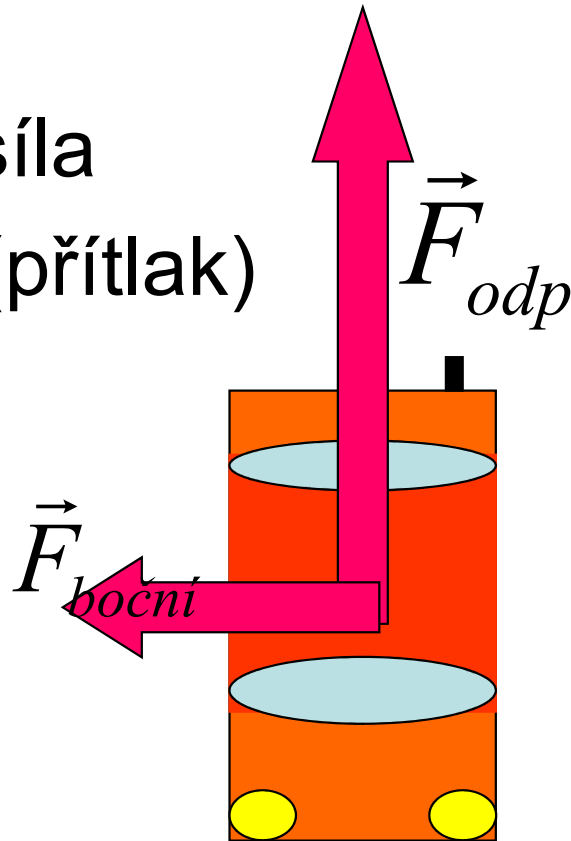






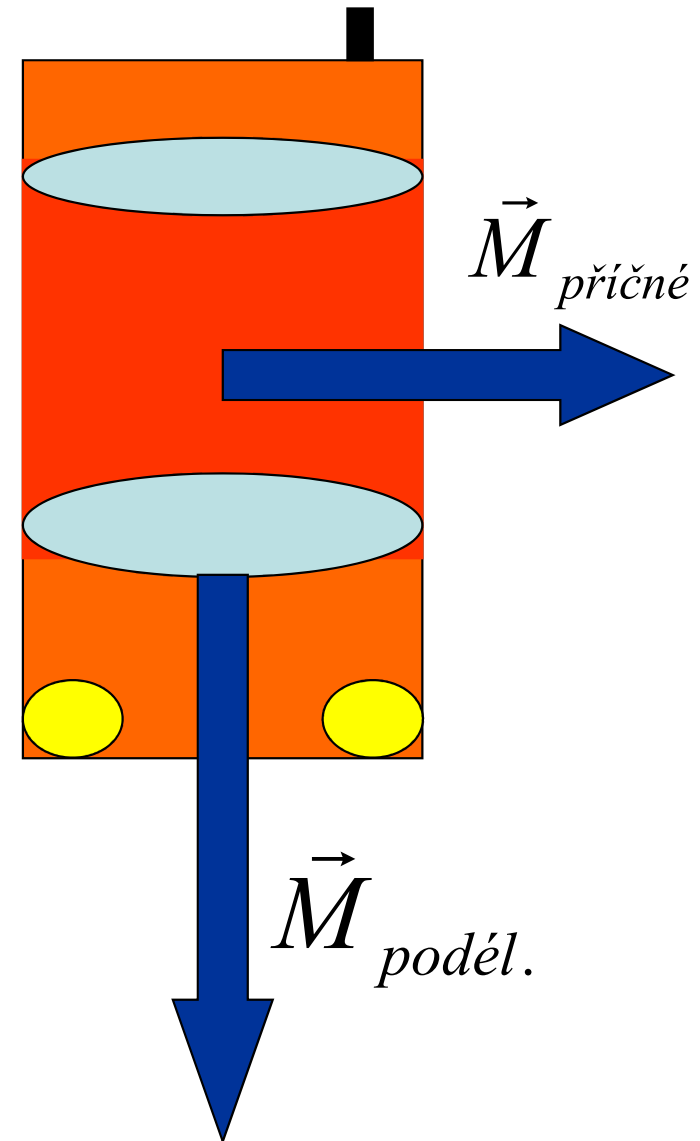
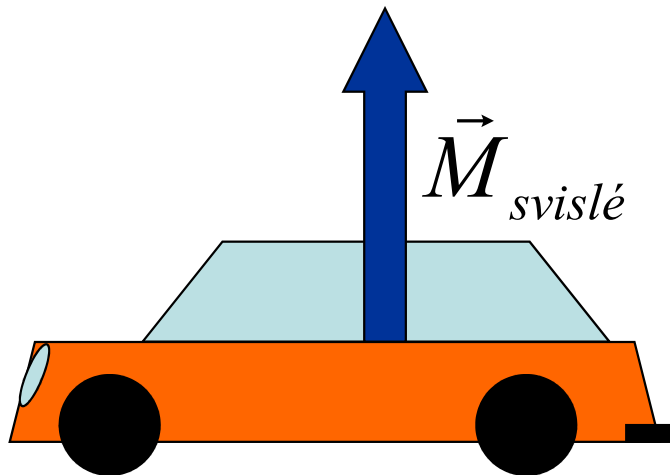
aerodynamická síla působící na karoséri osobního automobilu

- Odpor
- boční síla
- vztlak (přítlak)



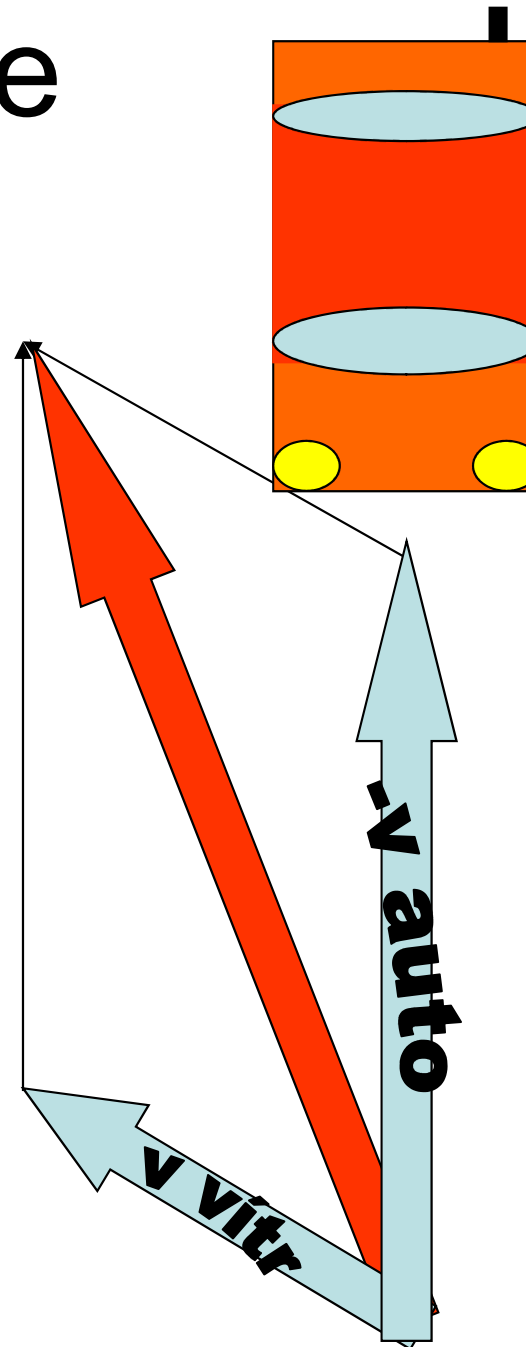
Aerodynamické silový moment působící na karoséri automobilu

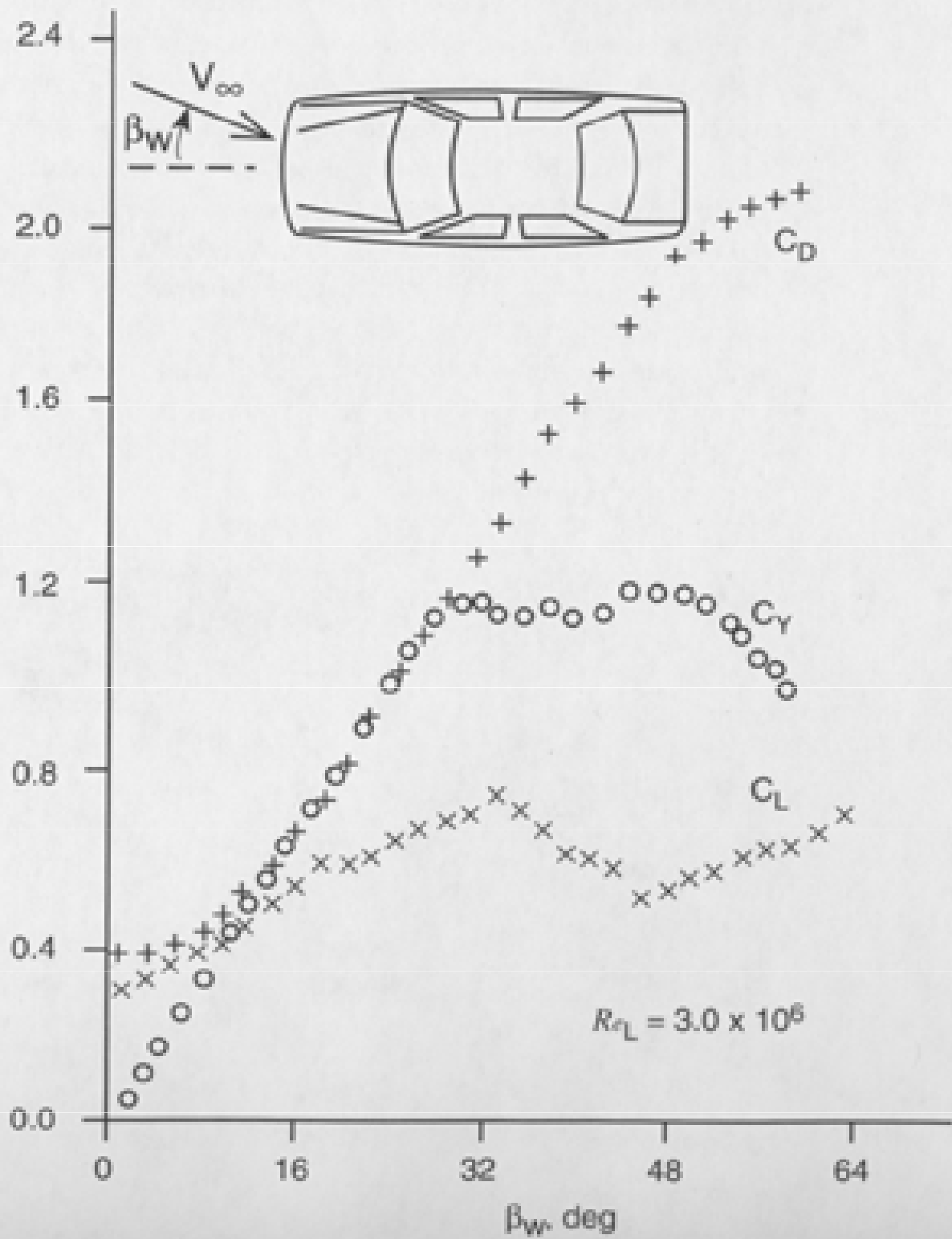
- moment síly v podélné ose
- moment síly ve svislé ose
- moment síly v příčné ose



obtékání karosérie

- směr nabíhajícího proudu vzduchu vůči ose automobilu = vektorový součet záporně vzaté rychlosti automobilu a rychlosti větru





koncept odpor, vztlak

- Na objekt obtékaný reálnou tekutinou působí síla, v ideální tekutině (bez volné hladiny) neexistuje odpor prostředí (ani vztlak)
- Vztažná soustava pro popis-soustava spojená s objektem, významný směr- směr nabíhajícího, objektem neovlivněného proudu tekutiny
- Síla ve směru nabíhajícího proudu tekutiny- odporová síla (odpor prostředí)
- Síla kolmá na směr nabíhajícího proudu tekutiny-odpor vztlaková síla (vztlak v prostředí).

proudění kolem objektu

- počítačové modelování (složitost matematického popisu a komplexnost objektu)
- experiment

charakter obtékání

- tvar objektu
- Reynoldsovo číslo
- Machovo číslo
- Froudovo číslo

$$Re = \frac{\rho v l}{\eta}$$

$$Ma = \frac{v}{c}$$

$$Fr = \frac{v}{\sqrt{gl}}$$

l charakteristický rozměr, g tíhové zrychlení, ρ hustota
 η dynamická viskozita, v rychlost, c rychlost vuku

charakter obtékání

- proudění s $Re < 100$, viskózní síly
- proudění s $Re > 100$,
- Pro velká Re koncept mezní vrstvy kde dominuje efekt viskosity a okolí, kde lze proudění uvažovat za proudění neviskózní tekutiny. Ludwig Prandtl 1875-1953

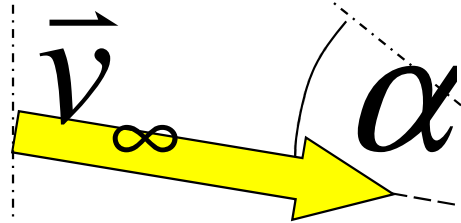
Hybridní automobil vyšší třídy

- Lexus GS 450hRED
- délka 4,826m
- šířka 1,821m
- výška 1,425
- pohotovostní hmotnost 1875 kg

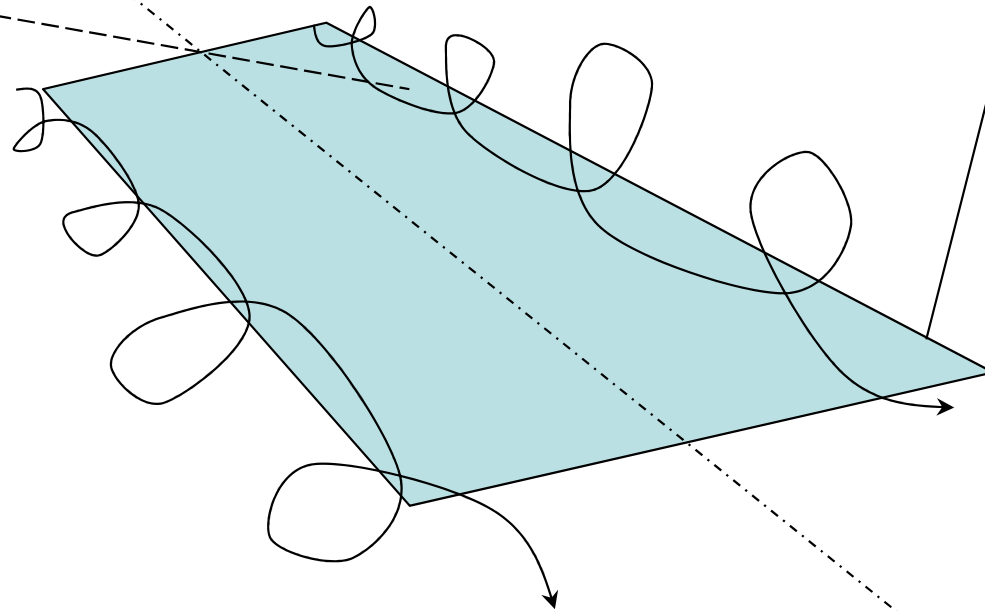
Koeficient odporu $c_d=0,27$
spotřeba
dálnice/město 9,4/10,7



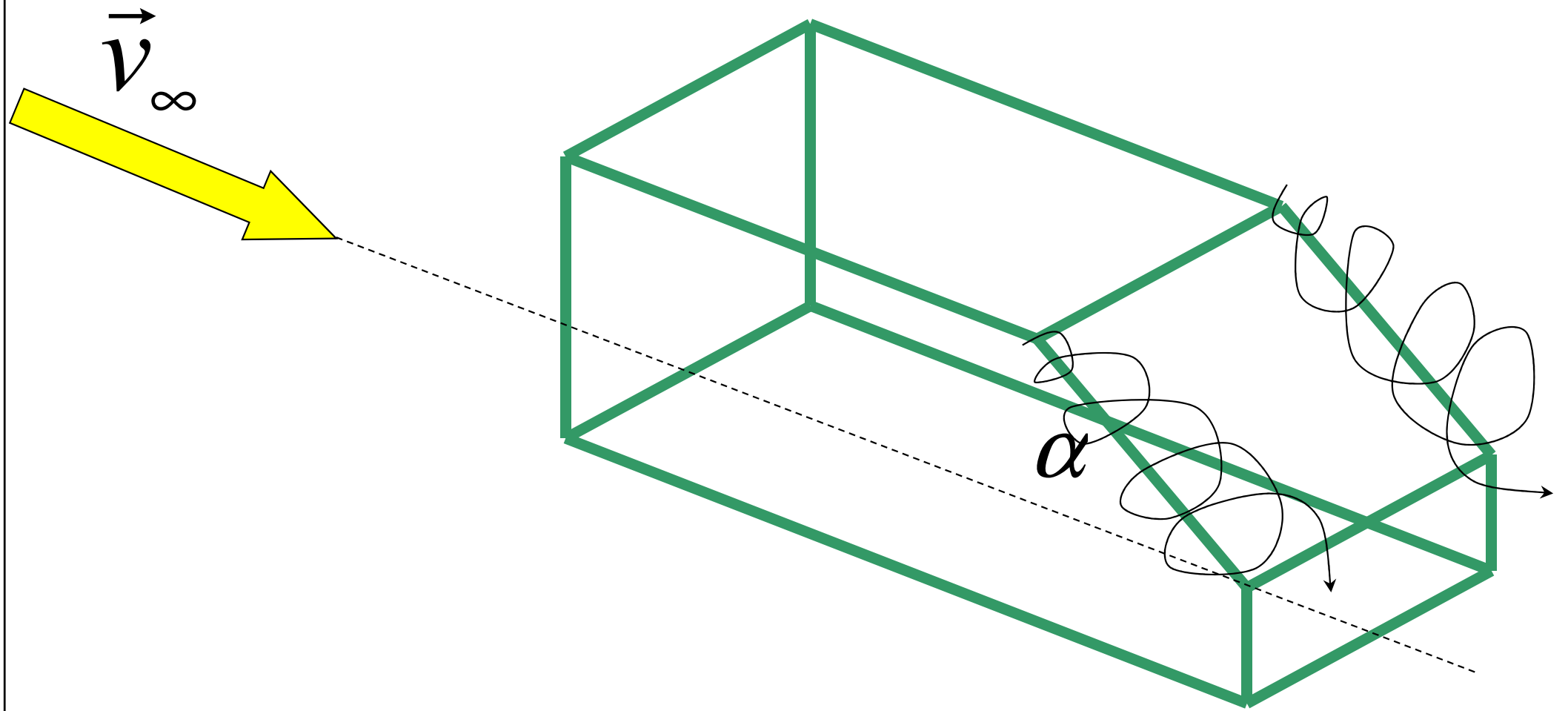
Obtékání se vznikem víru



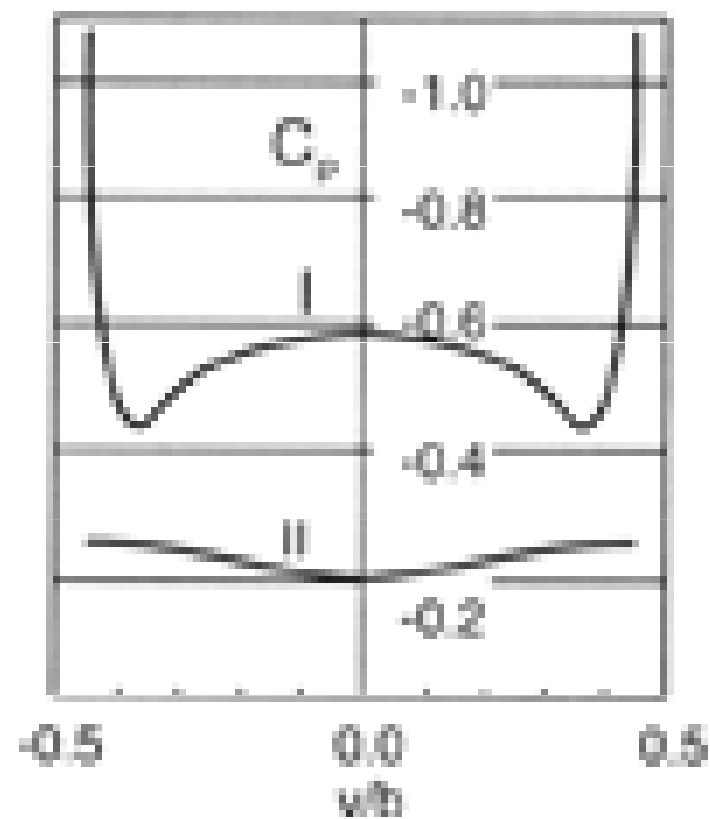
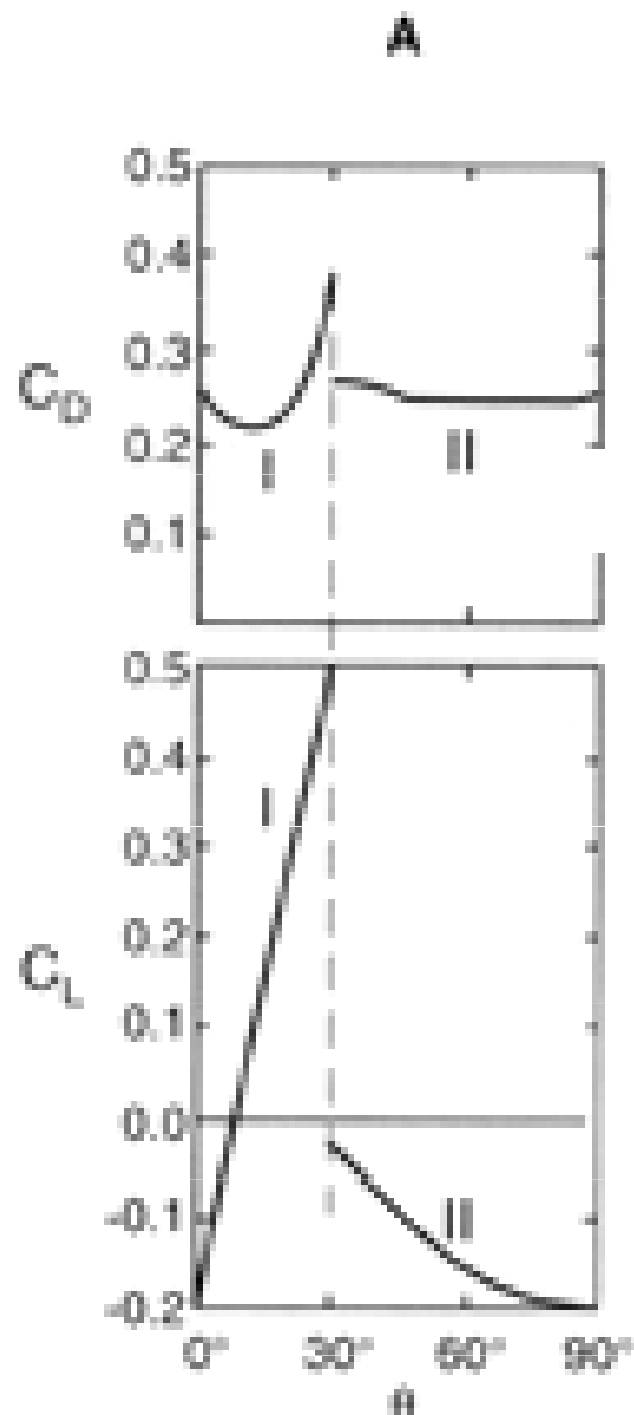
rovná deska

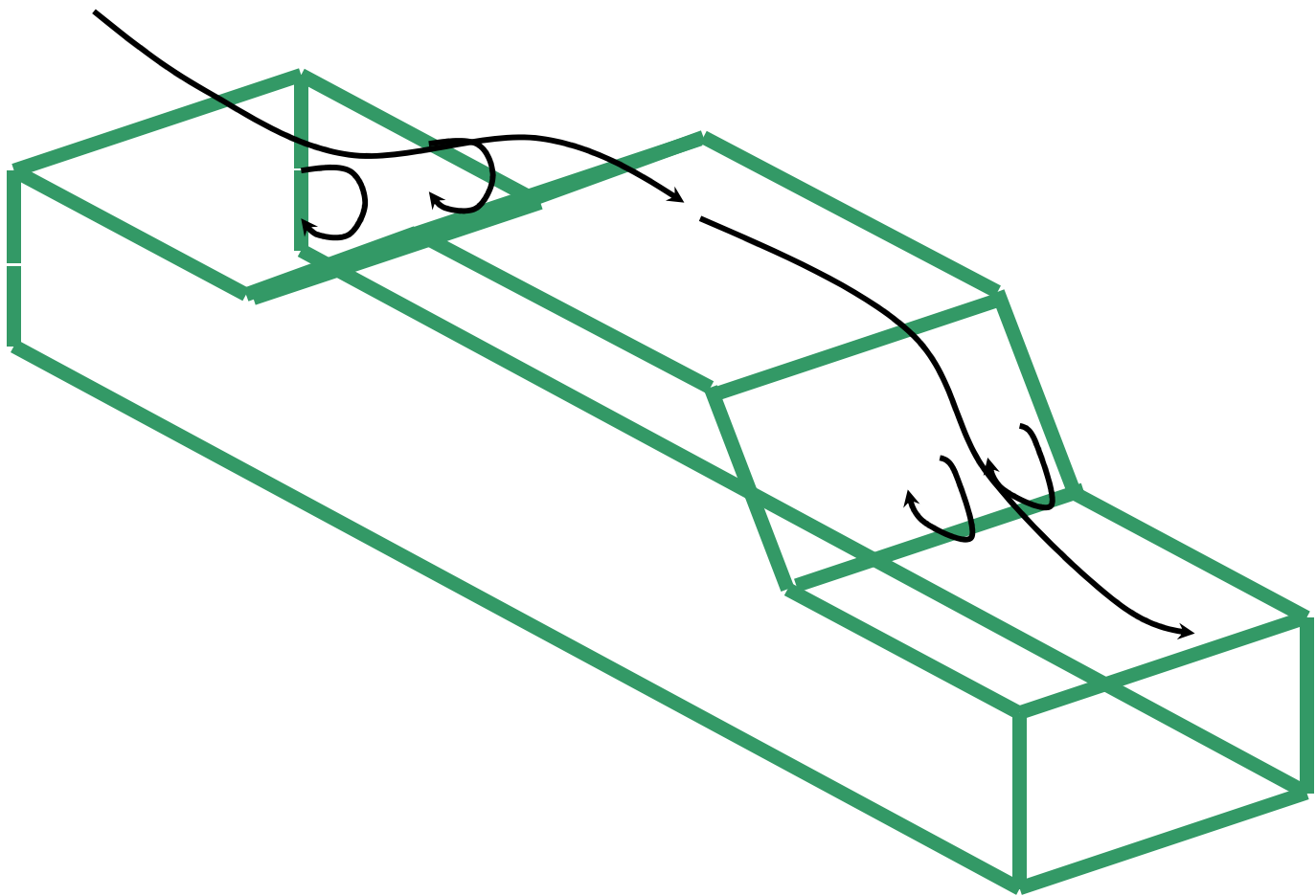
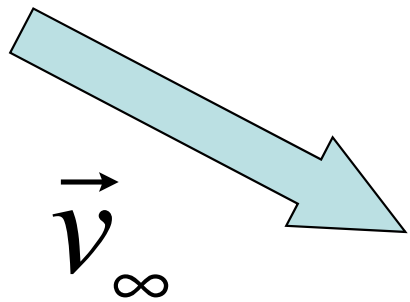


Obtékání objektu se skosenou stěnou

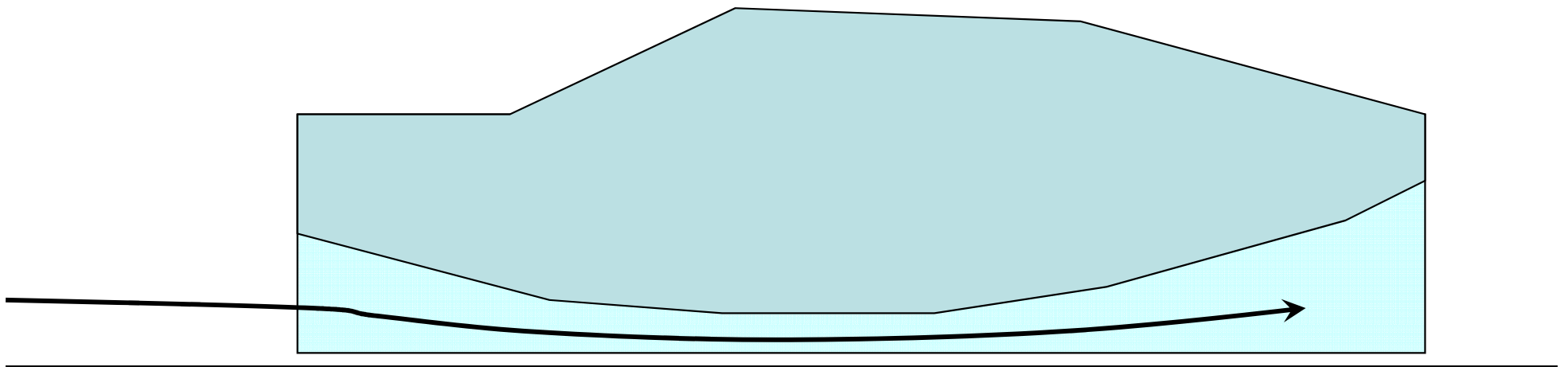


Obtékání s nosným vírem

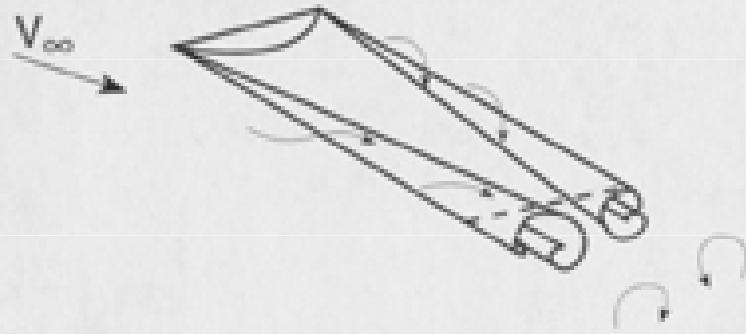




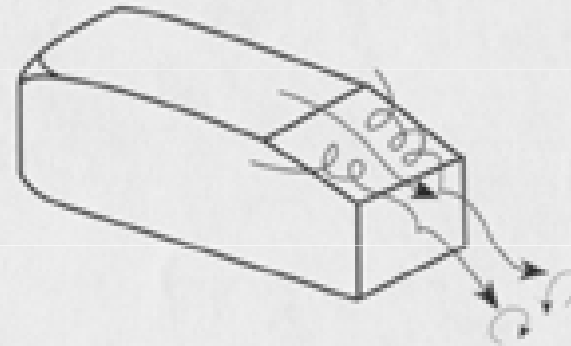
Bernoulliův přítlak



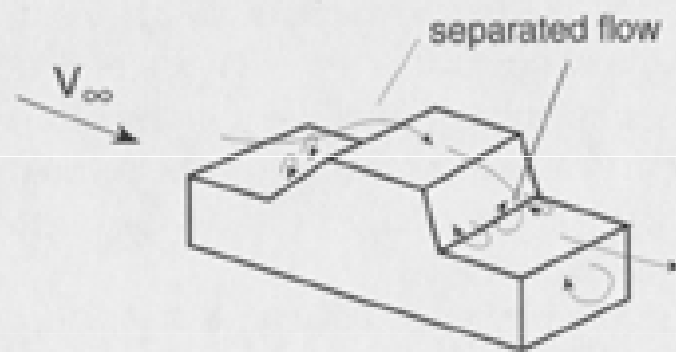
A. Flat plate at angle of attack



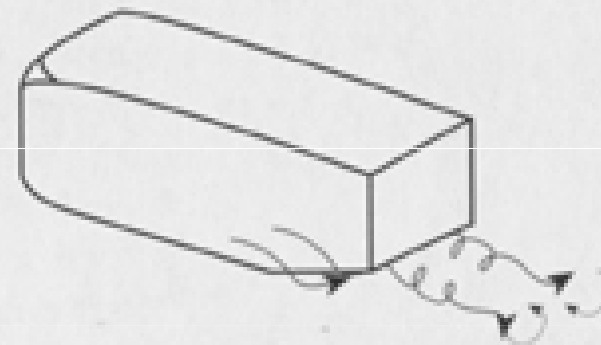
B. Slanted upper surface



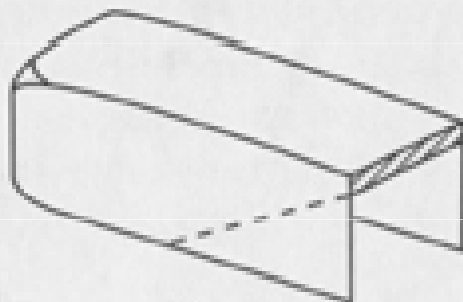
C. "Three box" body



D. Tapered lower surface



E. Basic venturi

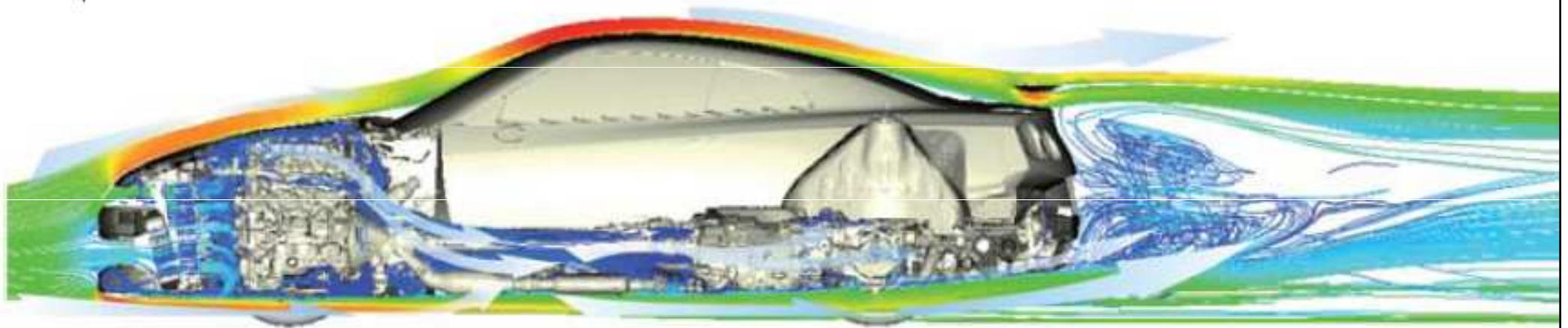


	C_x	A m ²
Audi A8	0,28	2,25
Porsche 911	0,33	1,86
Mercedes c 200 D	0,30	2,05

Effect of some modifications on car aerodynamics

Lowering vehicle height by 30 mm.	approx. -5 (better car aerodynamics)
Smooth wheel covers	-1...-3 (better car aerodynamics)
Wide tires	+2...+4 (worse car aerodynamics)
Windows flush with exterior	approx. -1 (better car aerodynamics)
Sealing body gaps	-2...-5 (better vehicle aerodynamics)
Underbody panels	-1...-7 (better vehicle aerodynamics)
Concealed headlamps	+3...+10 (worse vehicle aerodynamics)
Outside rearview mirrors	+2...+5 (worse aerodynamics)
Airflow through radiator and engine compartment	+4...+14 (worse vehicle aerodynamics)
Brake cooling devices	+2...+5 (worse car aerodynamics)
Interior ventilation	approx. +1 (worse car aerodynamics)
Open windows	approx. +5 (worse vehicle aerodynamics)
Open sunroof	approx. +2 (worse vehicle aerodynamics)
Roof-mounted surfboard rack	approx. +40 (worse vehicle aerodynamics)

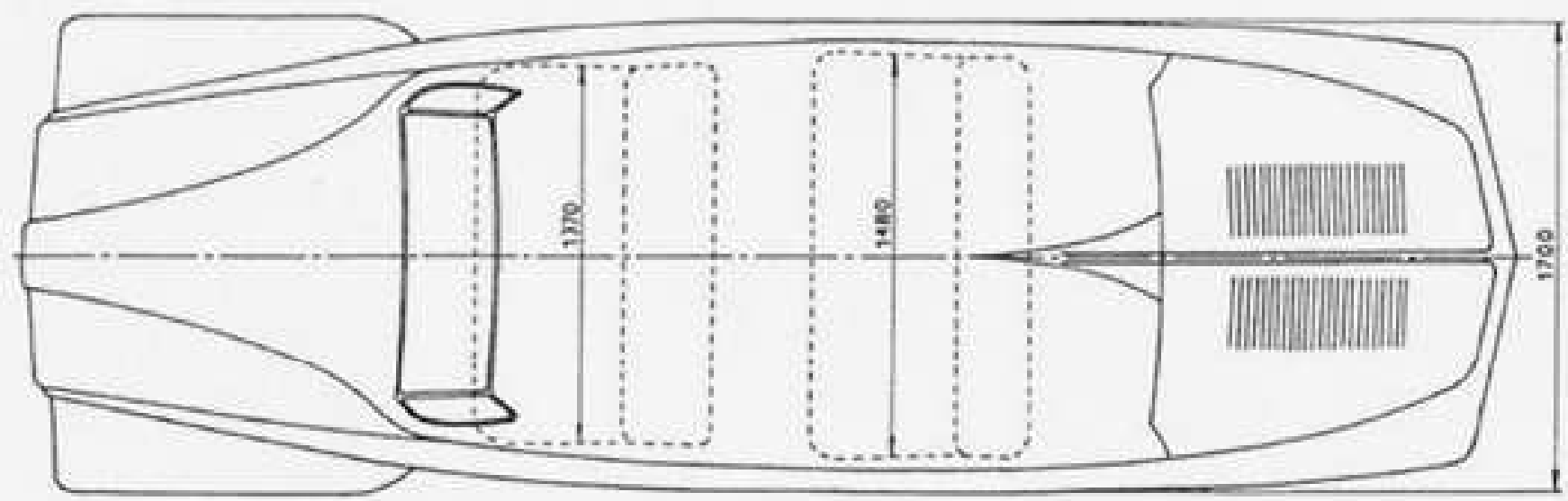
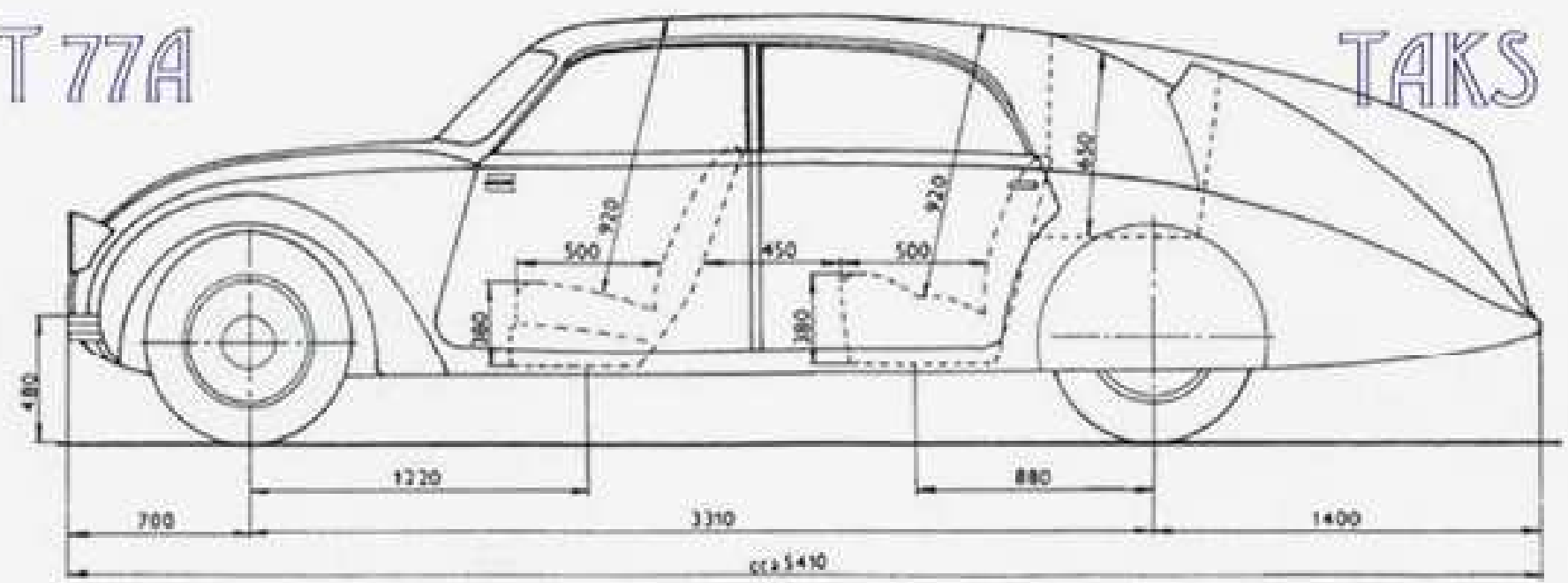
Airflow in profile for the Nissan R35 GTR



- <http://www.thetruthaboutcars.com/2010/02/an-illustrated-history-of-automotive-aerodynamics-part-3-finale/>
- http://en.wikipedia.org/wiki/Automobile_drag_coefficient#See_also

T 77A

TAKS



- By Chuck Squatriglia _
- See related story: [Design Under Constraint: How Limits Boost Creativity](#)
- 03.10.09
- Everything about the Tatra T77a was cool, from its flowing lines to the V8 engine mounted way out in back. It was built in Prague, and it had a Cd of 0.212 — amazing even today but phenomenal when the car was built in 1936. All these years later it still looks better than anything in Chrysler's lineup.
-

Read More

http://www.wired.com/cars/coolwheels/multimedia/2009/03/gallery_aerodynamic?slide=6&slideView=2#ixzz18B2Adbt7



$c_x = 0,212$

HANS LEDVINKA,
ERICH UBERLACKER
TATRA 77, 1934—35
The Tatra 77 was the first mass-produced limousine with a streamlined body in the world, with an air-cooled eightcylinder engine mounted at the rear, and it caused a sensation at the 1934 Berlin Autosalon. Its teardrop shape proved that aerodynamics could significantly improve speed. The car also had a central headlamp that turned with the front wheels.



$c_x = 0,212$



$c_x=0,163$



TATRA "77" LA VOITURE ÉLÉGANTE



Die aerodynamischen Tatra-Wagen mit luftgekühltem Heckmotor sind die Verwirklichung der technischen Idee des sicheren, eleganten, bequemen, zuverlässigen und wirtschaftlichen Schnellverkehrsmittele

$c_x=0,212$



$C_x=0,163$

DER **WAGEN DER ZUKUNFT**



" TATRA TYPE 77 "



RICHARD DIX

LESLIE BANKS

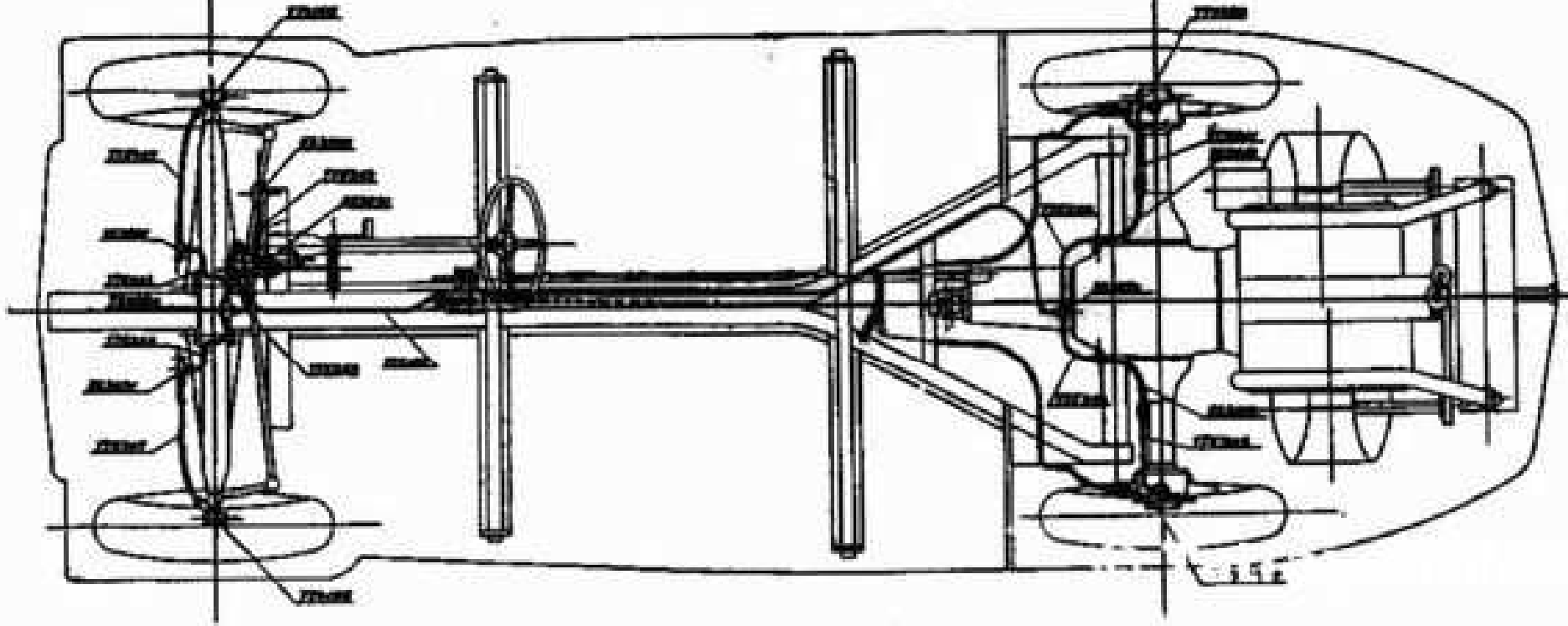
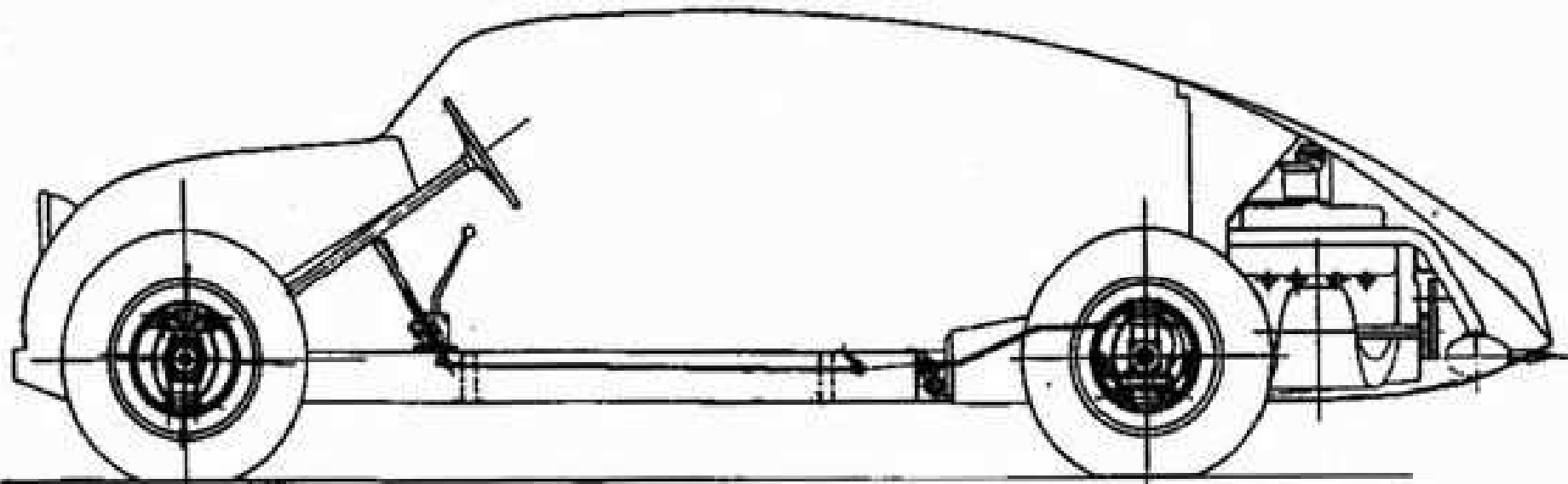
MADGE EVANS

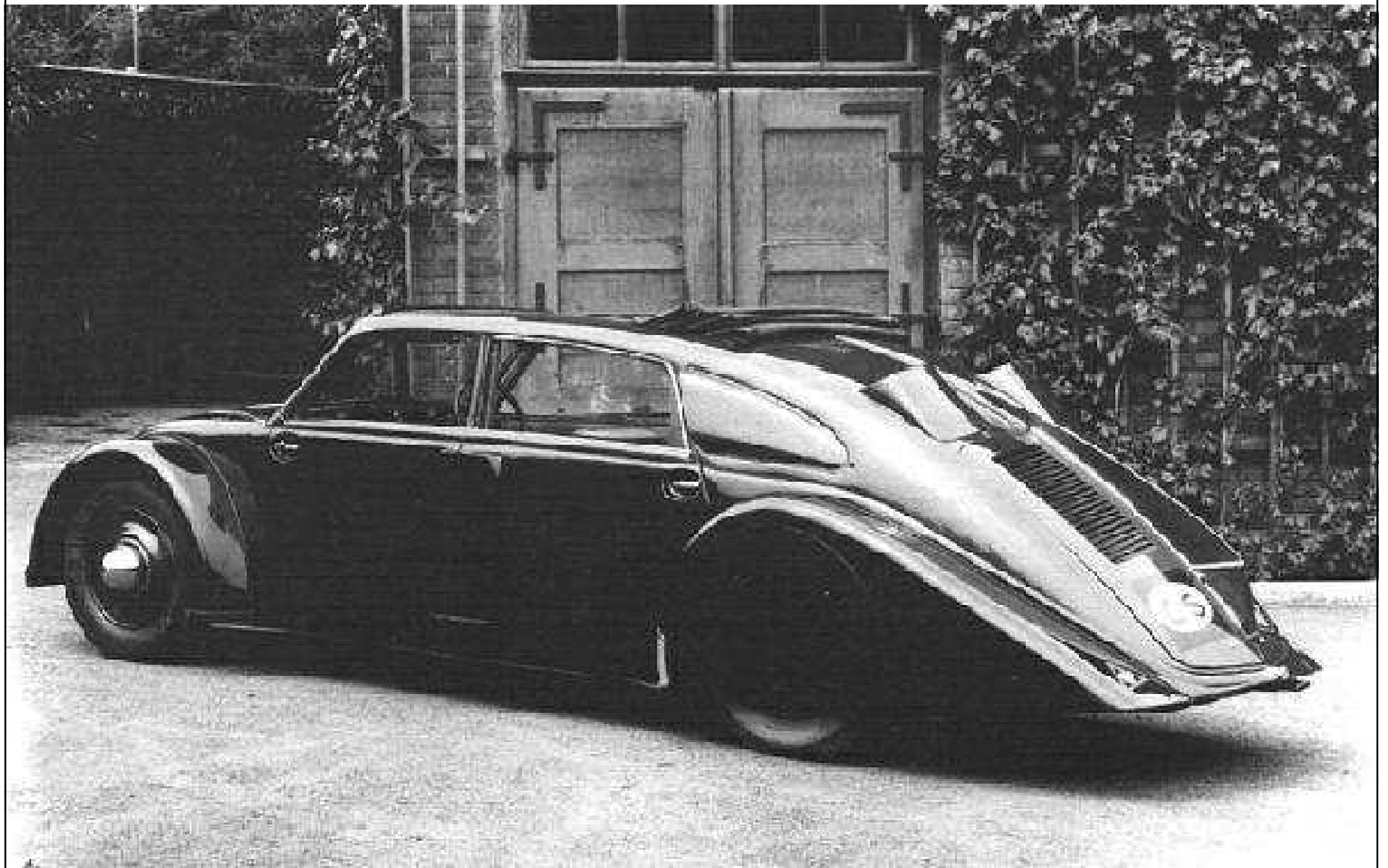
HELEN VINSON

C. AUBREY SMITH

Transatlantic

PRODUCTION GAUMONT-BRITISH

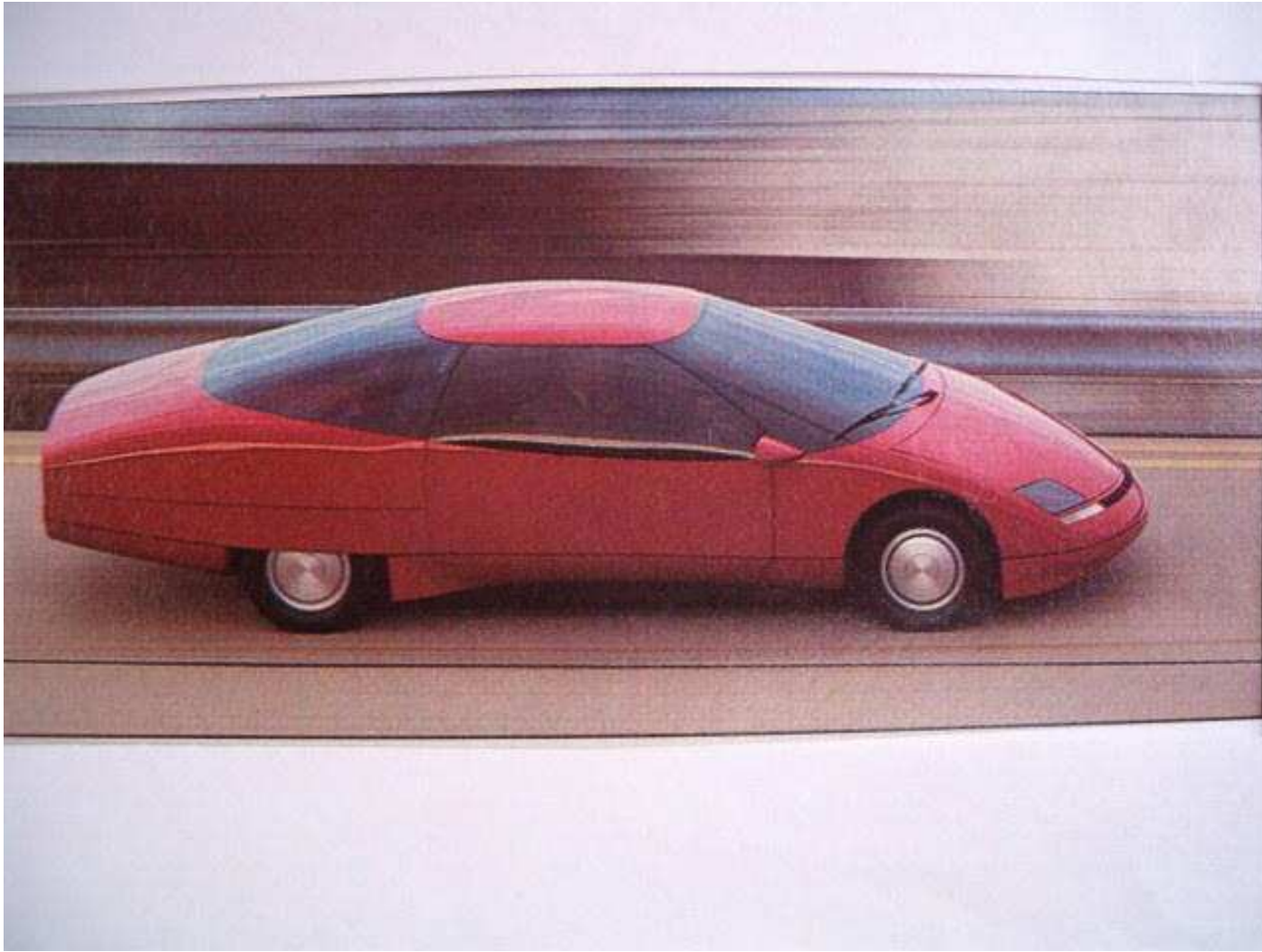


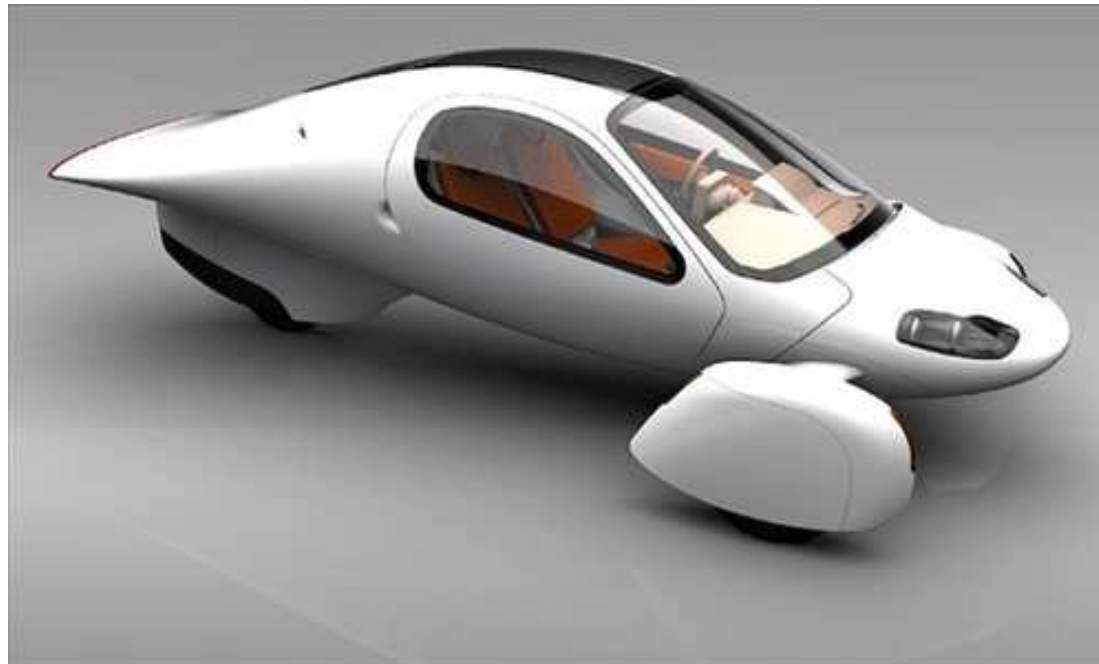












aptera Cd 0.15



cd 0.57 26,5 sq.ft.



EV 1 cd 0.195



cx 0,195



1,38 l / 100 km, 36 g C per km



- The L1 concept is shorter than a VW Fox and lower than a [Lamborghini](#). When it goes into production in 2013, it will be the most aerodynamic car in the world and, at just 840lb, the lightest.
- It is built of the most exotic materials, with slippery carbon-fibre coachwork, a fighter aircraft's cockpit canopy and rear-view television cameras instead of wing mirrors.
- Its tiny, 800cc engine is one half of a VW 1.6-litre TDI turbodiesel unit, which delivers maximum power of 29 brake horsepower together with a 14 horse power electric motor to provide extra oomph for overtaking.



$cx = 0.39$

- The L1 is capable of 99mph and 0-62mph acceleration in just 14.3sec and emits carbon dioxide at the parsimonious rate of just 39g/km, meaning free road tax in the UK.
- In fact if the average British motorist swapped his 35mpg hatchback for an L1, he would reduce his annual fuel bill from about £1,430 to about £277.



cd=0.25



Koeficienty aerodynamických odporů

- <http://www.martin-tlusty.euweb.cz/htm/CarAerodCz.htm>
- http://www.recumbents.com/car_aerodynamics/
- <http://www.electrifyingtimes.com/gmprecept.html>

Force [N]

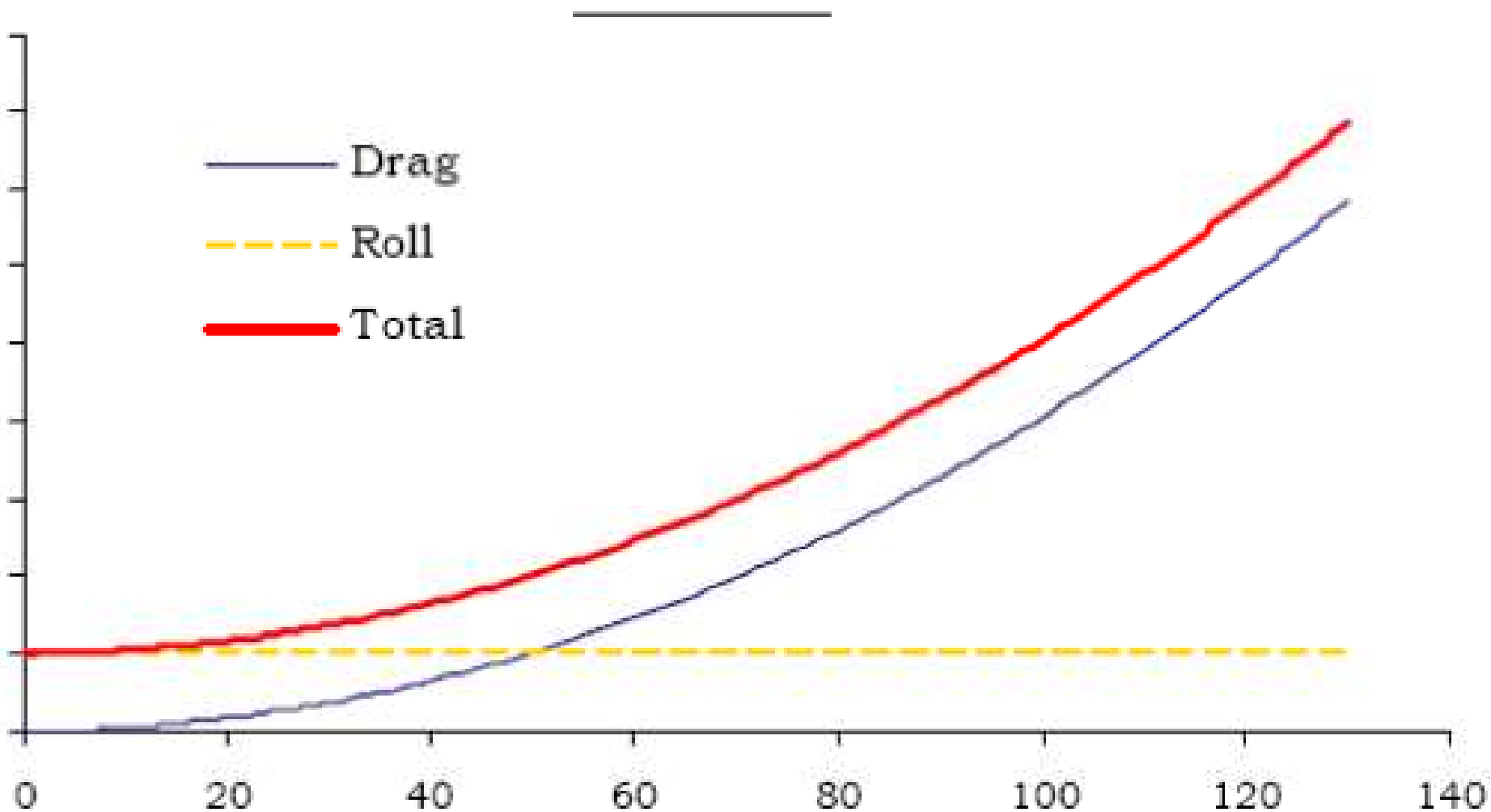
Resistance

900
800
700
600
500
400
300
200
100
0

- Drag
- - - Roll
- Total

0 20 40 60 80 100 120 140

Speed [km/h]



vliv spodku vozu

- 25% celkového aerodyn. odporu.

- rear end
- • Minimized body seams
- • Optimized rear view mirrors
- • Substitution of rear view mirrors with cameras
- • Smooth underbody