Experimental Observations: Cylinder

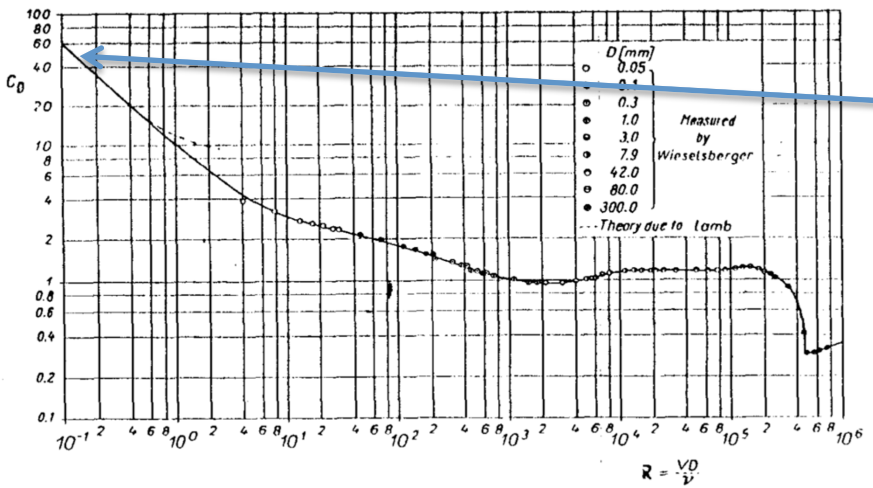
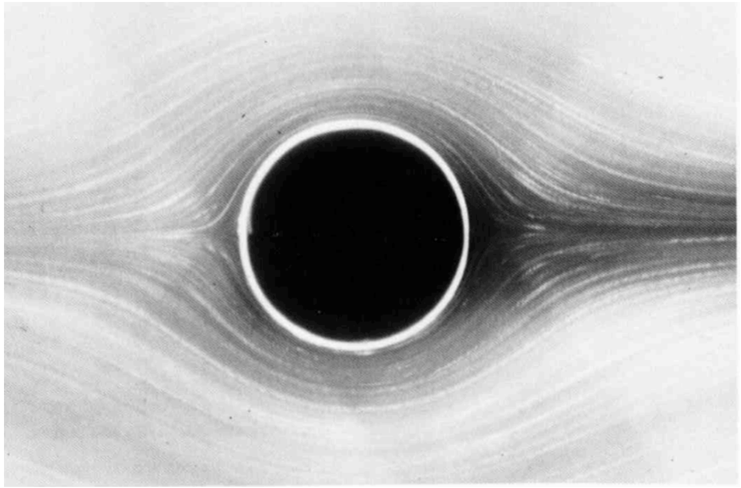


Fig. 1.4. Drag coefficient for circular cylinders as a function of the Reynolds number

Re = 0.16



From Schlichting, “Boundary Layer Theory”

Experimental Observations: Cylinder

Re = 1.54

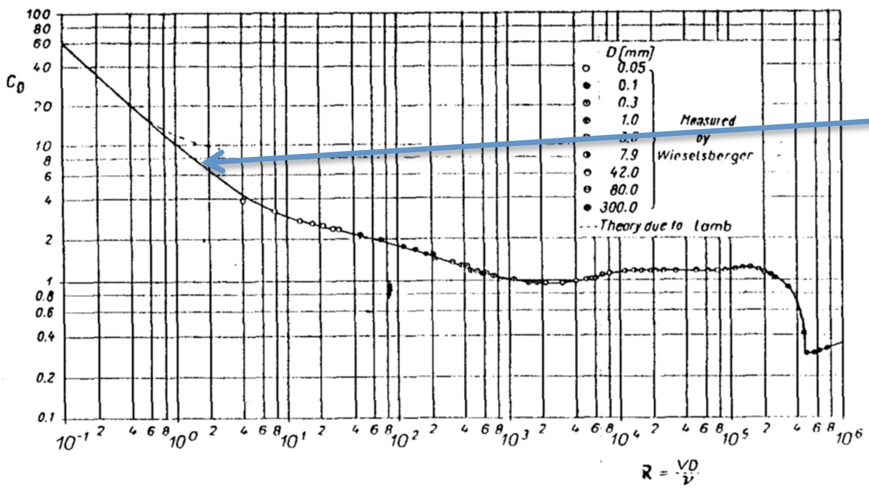
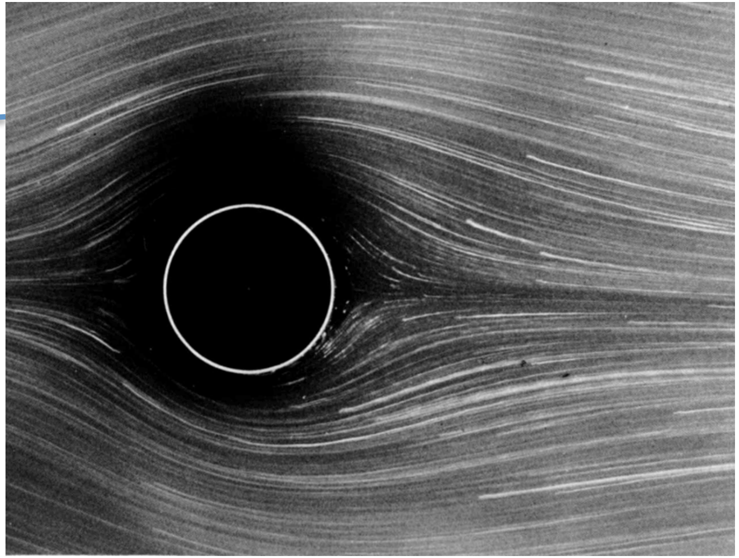


Fig. 1.4. Drag coefficient for circular cylinders as a function of the Reynolds number



From Schlichting, “Boundary Layer Theory”

Experimental Observations: Cylinder

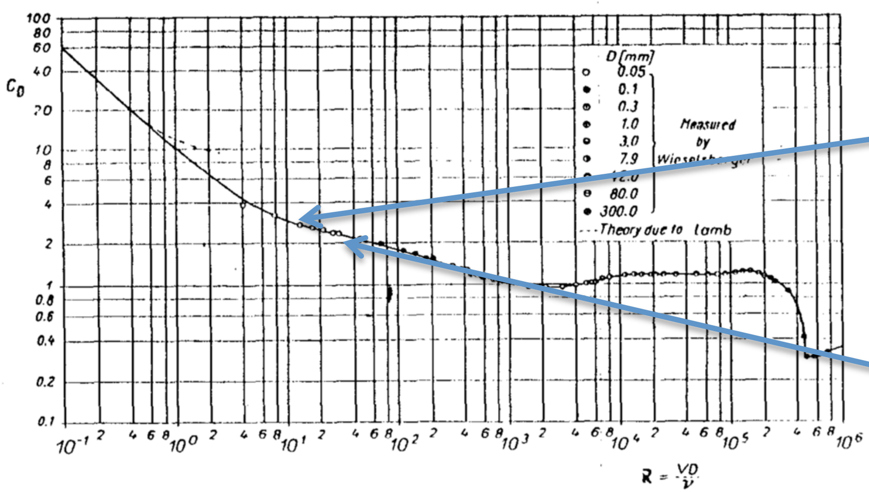
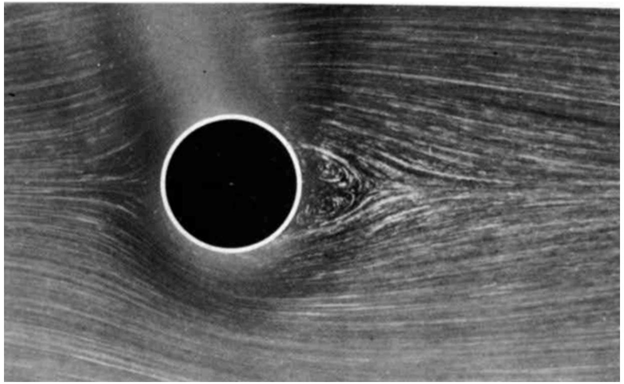
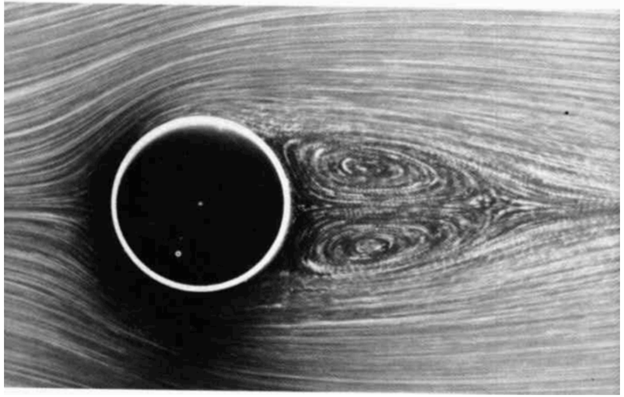


Fig. 1.4.   Drag coefficient for circular cylinders as a function of the Reynolds number

Re = 13



Re = 26



Experimental Observations: Cylinder

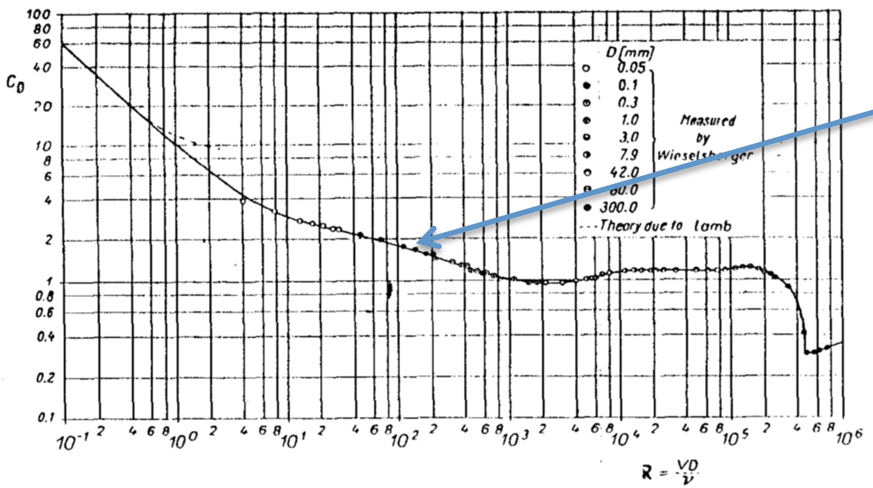


Fig. 1.4.   Drag coefficient for circular cylinders as a function of the Reynolds number

Re = 140

Experimental Observations: Cylinder

Re = 2000

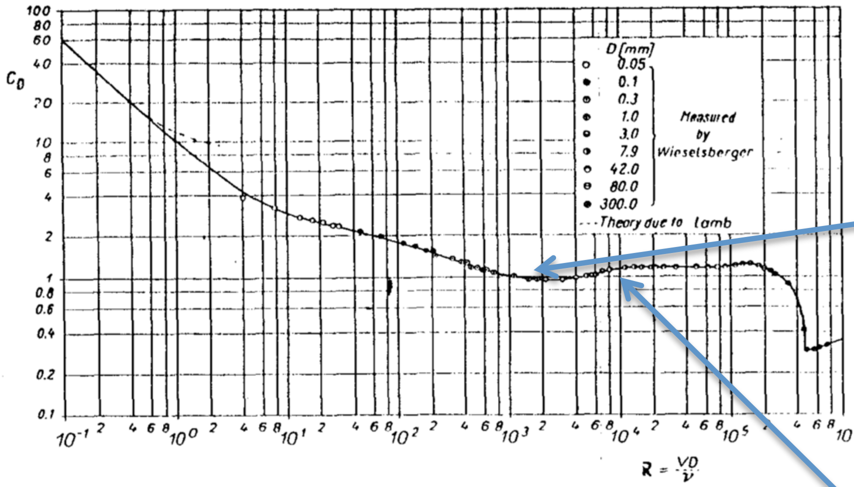
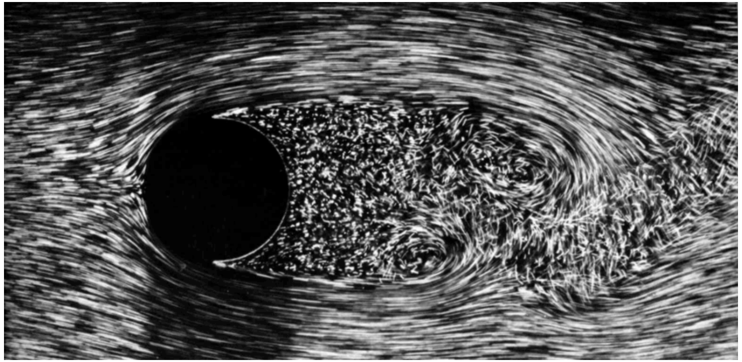
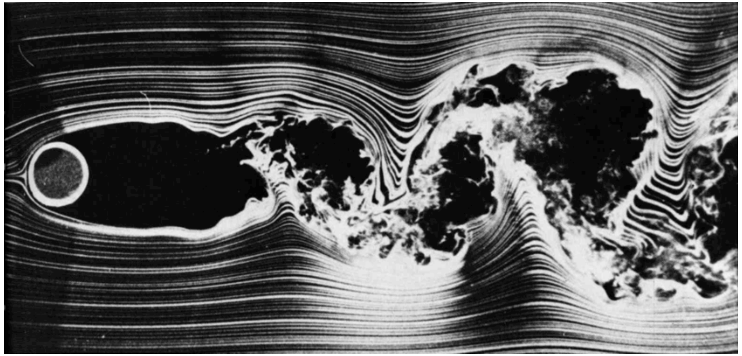


Fig. 1.4. Drag coefficient for circular cylinders as a function of the Reynolds number





Re = 10,000

Experimental Observations: Cylinder

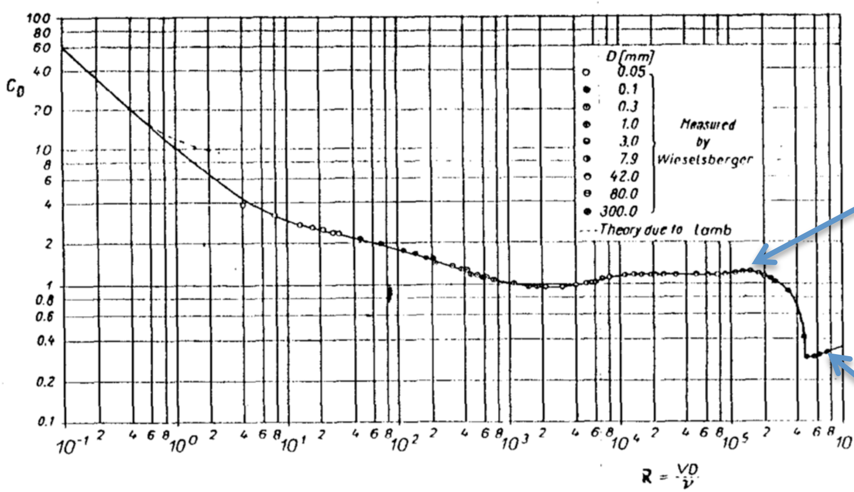
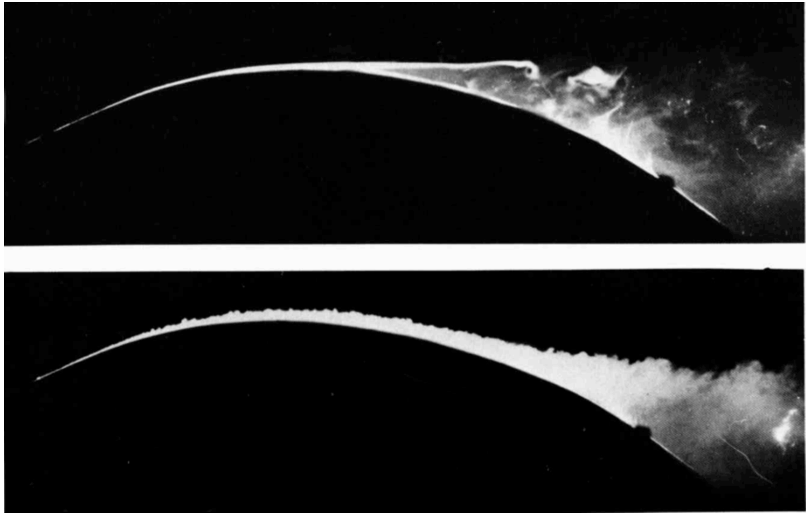


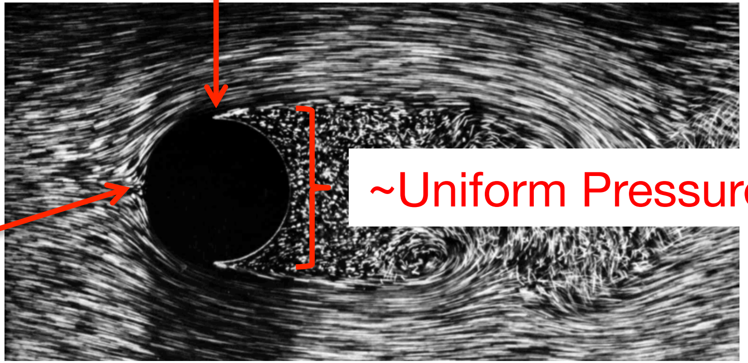
Fig. 1.4. Drag coefficient for circular cylinders as a function of the Reynolds number



Flow Separation

- Primary mechanism of drag for non-airfoil objects at high Re

Velocity > U (low pressure)



~Uniform Pressure Wake

Velocity = 0
(high pressure)

- Drag Coef:

Fd = 0.5*density*V^2 *A*Cd

Some Tables in Book (2D Objects)

Shape	C_D based on frontal area	Shape	C_D based on frontal area	Shape	C_D based on frontal area
Square cylinder:		Half cylinder:		Plate:	
	2.1		1.2		2.0
	1.6		1.7	Thin plate normal to a wall:	1.4
Half tube:		Equilateral triangle:			
	1.2		1.6	Hexagon:	
	2.3		2.0		→1.0 ↑0.7

Table 7.2

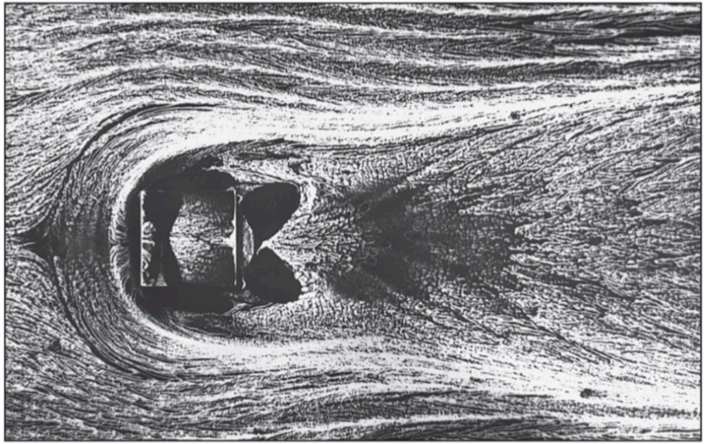
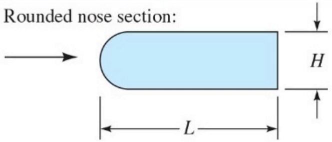


Fig. 8.37

Some Tables in Book (2D Objects)

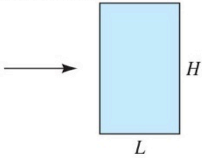
Shape	C_D based on frontal area

Rounded nose section:



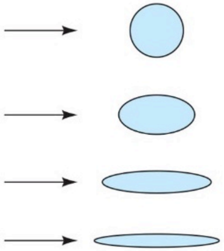
L/H:	0.5	1.0	2.0	4.0	6.0
C_D:	1.16	0.90	0.70	0.68	0.64

Flat nose section:



L/H:	0.1	0.4	0.7	1.2	2.0	2.5	3.0	6.0
C_D:	1.9	2.3	2.7	2.1	1.8	1.4	1.3	0.9

Elliptical cylinder:



	Laminar	Turbulent
1:1	1.2	0.3
2:1	0.6	0.2
4:1	0.35	0.15
8:1	0.25	0.1

Table 7.2

Some Tables in Book (3D Objects)

Body	C_D based on frontal area
Cube: (flat face to flow)	1.07
Cube: (edge to flow)	0.81
Cup: (open side away from flow)	1.4
Cup: (open side facing flow)	0.4
Disk:	1.17
Parachute (Low porosity):	1.2

Streamlined train (approximately 5 cars):

$C_D A = 8.5\ \text{m}^2$

Bicycle:

Upright: $C_D A = 0.51\ \text{m}^2$; Racing: $C_D A = 0.30\ \text{m}^2$

Cone: [60]

θ:	10°	20°	30°	40°	60°	75°	90°
C_D:	0.30	0.40	0.55	0.65	0.80	1.05	1.15

Short cylinder, laminar flow:

L/D:	1	2	3	5	10	20	40	∞
C_D:	0.64	0.68	0.72	0.74	0.82	0.91	0.98	1.20

Porous parabolic dish [23]:

Porosity:	0	0.1	0.2	0.3	0.4	0.5
← C_D:	1.42	1.33	1.20	1.05	0.95	0.82
→ C_D:	0.95	0.92	0.90	0.86	0.83	0.80

Average person:

→ $C_D A = 9\ \text{ft}^2$ ↑ $C_D A = 1.2\ \text{ft}^2$

Pine and spruce trees [24]:

U, m/s:	10	20	30	40
C_D:	1.2 ± 0.2	1.0 ± 0.2	0.7 ± 0.2	0.5 ± 0.2

Tractor-trailer truck:

Without deflector: 0.96; with deflector: 0.76

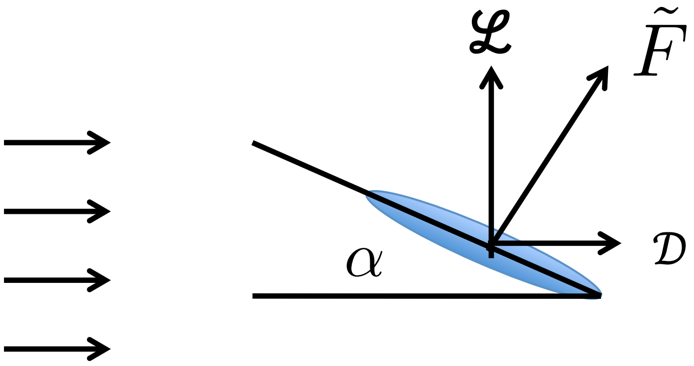
Body	Ratio	C_D based on frontal area
Rectangular plate:	b/h 1	1.18
	5	1.2
	10	1.3
	20	1.5
	∞	2.0

Body	Ratio	Laminar	Turbulent
Ellipsoid:	L/d 0.75	0.5	0.2
	1	0.47	0.2
	2	0.27	0.13
	4	0.25	0.1
	8	0.2	0.08

Body	Ratio	C_D based on frontal area
Flat-faced cylinder:	L/d 0.5	1.15
	1	0.90
	2	0.85
	4	0.87
	8	0.99
Buoyant rising sphere [50], $135 < Re_d < 1E5$		$C_D \approx 0.95$

Table 7.3

Non-dimensional analysis revisited



α = "angle of attack"

$\mathcal{L}, \mathcal{D}$ = fnc(α, ρ, μ, U, L)

$$\boxed{\frac{\mathcal{L}, \mathcal{D}}{1/2\rho U^2 A} = \text{fnc}(\alpha, \text{Re})}$$

Lift is a result of asymmetry in the flow.

Other Effects on Drag: Roughness

- Look familiar?
- Transition region
- Suggested Formula

$$C_D = 1.328 Re_L^{-1/2} \text{ for } \mathrm{Re}_L < 5\mathrm{e}5$$
$$C_D = 0.031 Re_L^{-1/7} - 1440 Re_L^{-1} \text{ for } 5\mathrm{e}5 < \mathrm{Re}_L < 1\mathrm{e}7$$
$$C_D = 0.031 Re_L^{-1/7} \text{ for } \mathrm{Re}_L > 1\mathrm{e}7$$