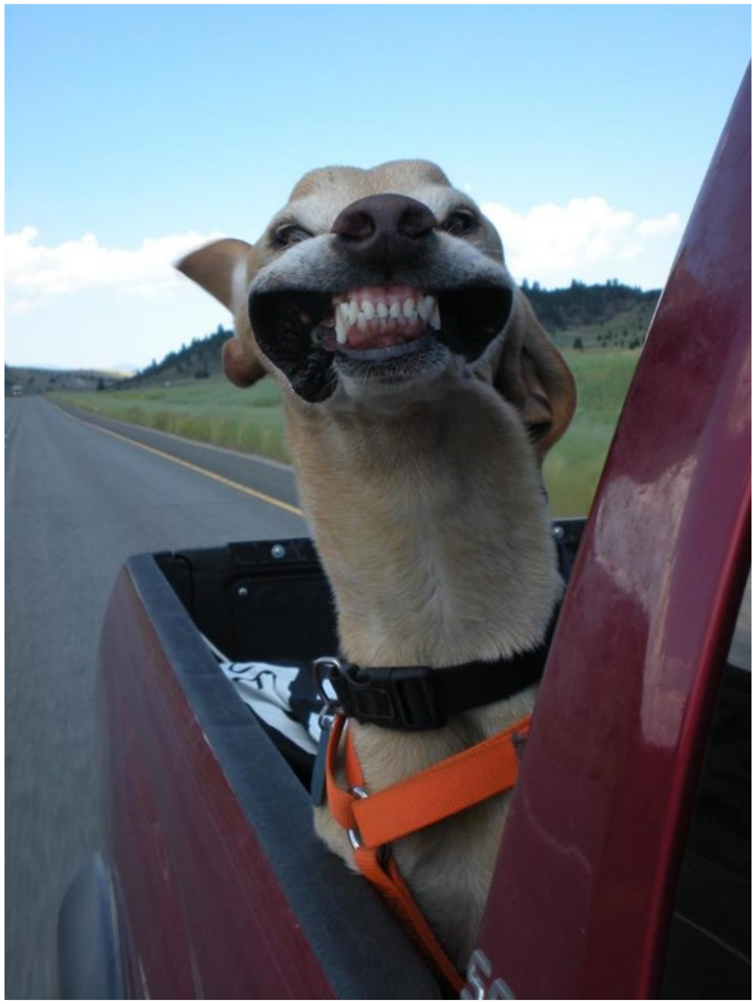
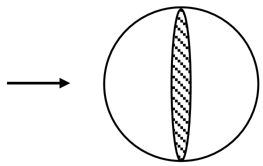
Lift and Drag



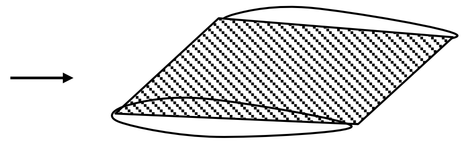
A mathematical limerick:

$$\frac{12 + 144 + 20 + 3\sqrt{4}}{7} + (5 \times 11) = 9^2 + 0$$

Lift and Drag



bluff body
(use the frontal projected area)



streamlined body
(use the planform area)

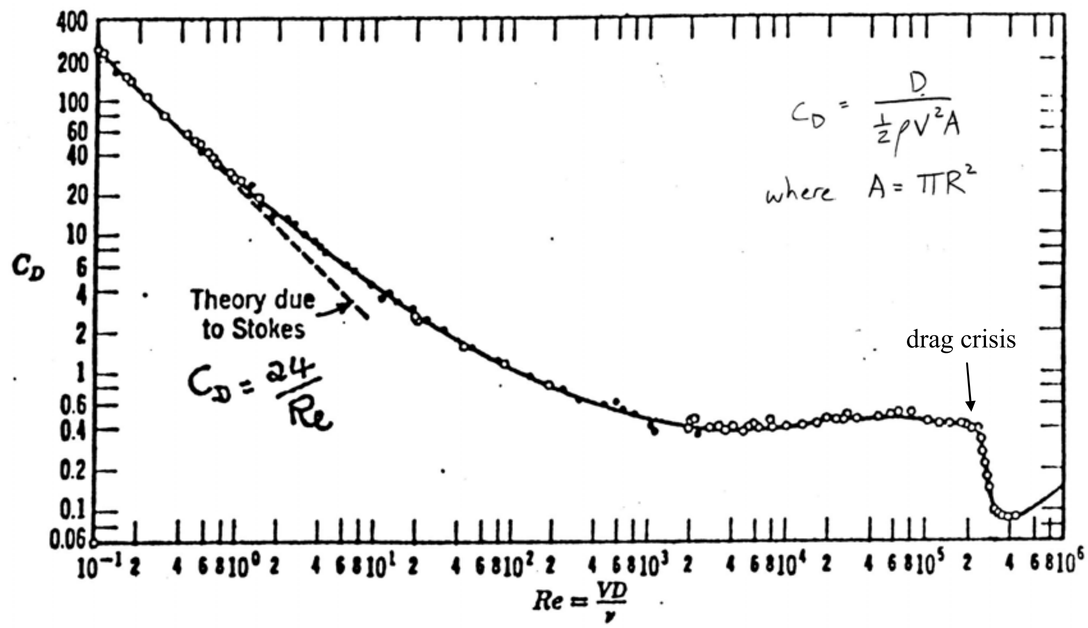


Fig. 8.32 Drag coefficient of a sphere as a function of Reynolds number (Ref. 13).

Commonly used curve fits to the curve shown above are:

$Re_D < 1$:	C_D =	$24/Re_D$ (Stokes' drag law)
$Re_D < 5$:	C_D =	$24/Re_D\,(1+3/16Re_D)$ (Oseen's approximation)
$0 \le Re_D \le 2*10^5$:	C_D =	$24/Re_D + 6/(1+Re_D^{0.5}) + 0.4$
$Re_D < 2*10^5$:	C_D =	0.44 (Newton's Law)

Lift and Drag

Table 7.2 Drag of Two-Dimensional Bodies at Re ≥ 10^4

$$C_D = \frac{D}{\frac{1}{2}\rho U_\infty^2 A}$$

Shape	C_D based on frontal area	Shape	C_D based on frontal area
Square cylinder: (flat face to flow)	2.1	Half-cylinder: (flat face downstream)	1.2
Square cylinder: (corner to flow)	1.6	Half-cylinder: (flat face to flow)	1.7
Half tube: (concave side downstream)	1.2	Equilateral triangle: (apex to flow)	1.6
Half tube: (concave side to flow)	2.3	Equilateral triangle: (flat face to flow)	2.0
Plate:	2.0	Thin plate normal to a wall:	1.4
Hexagon:	→ 1.0 ↑ 0.7		

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

Rounded 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

Lift and Drag

Table 7.3 Drag of Three-Dimensional Bodies at Re ≥ 10^4

Body	C_D based on frontal area
Cube: (face to flow)	1.07
Cube: (edge to flow)	0.81
Cup: (concave to flow)	1.4
Cup: (convex to flow)	0.4
Disk:	1.17
Parachute (Low porosity):	1.2

Cone:

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: → $C_DA \approx 9\ ft^2$ ↑ $C_DA \approx 1.2\ ft^2$

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

Body	Ratio	C_D based on frontal area	Body	Ratio	C_D based on frontal area
Rectangular plate:	b/h 1	1.18	Flat-faced cylinder:	L/d 0.5	1.15
	5	1.2		1	0.90
	10	1.3		2	0.85
	20	1.5		4	0.87
	∞	2.0		8	0.99

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

Lift and Drag

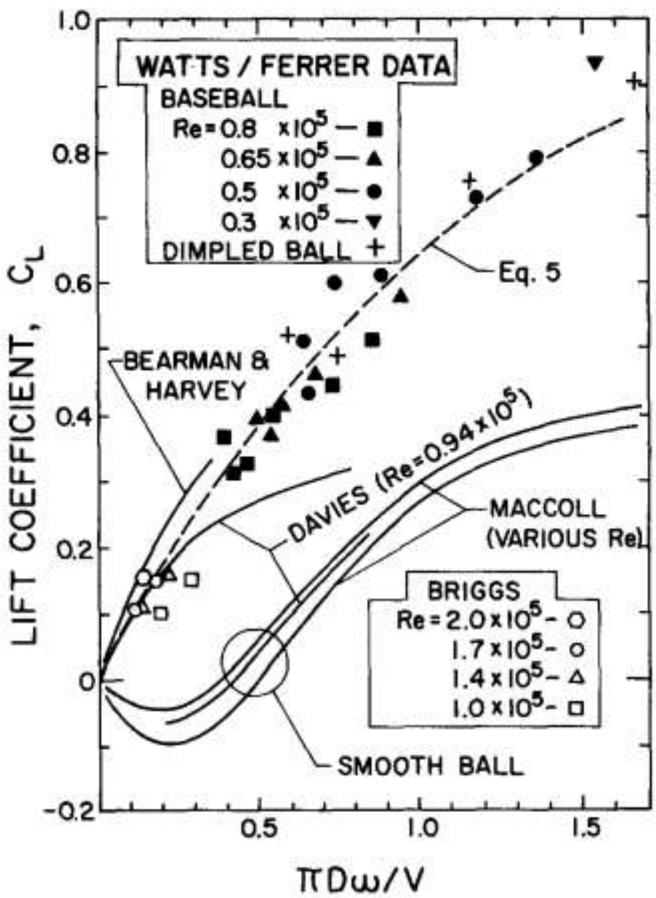
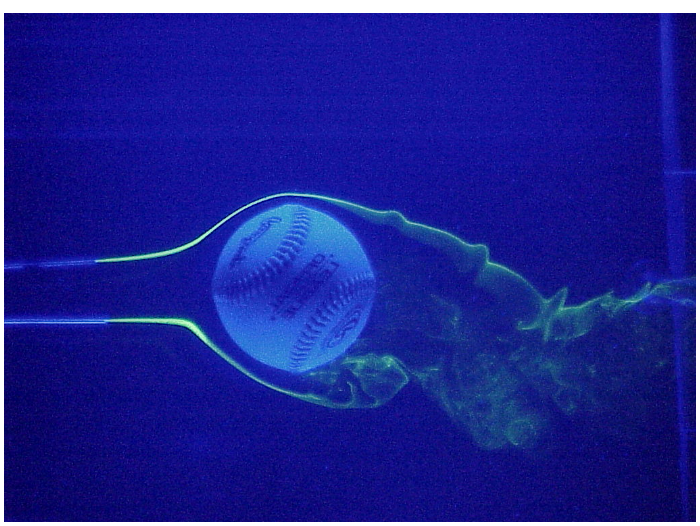


Figure 2.15 - Lift coefficient data comparing several data sets.

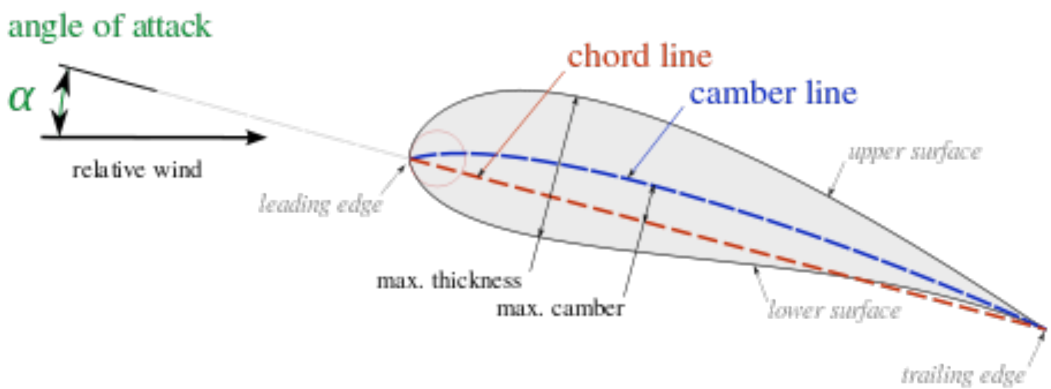
Copied from Kensrud, J.R., 2010, *Determining Aerodynamic Properties of Sports Balls in Situ*, M.S. Thesis, Washington State University.



http://www.youtube.com/watch?v=Ulp6dsF4iVA

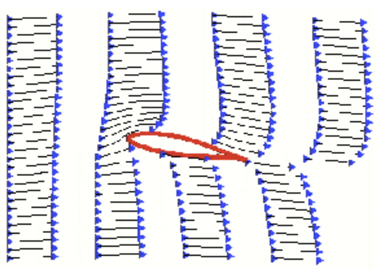
Lift and Drag

Airfoils

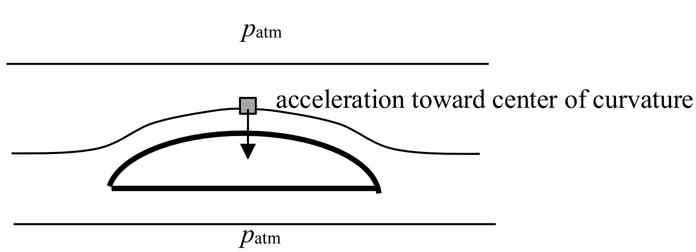


(Image from: https://en.wikipedia.org/wiki/Airfoil)

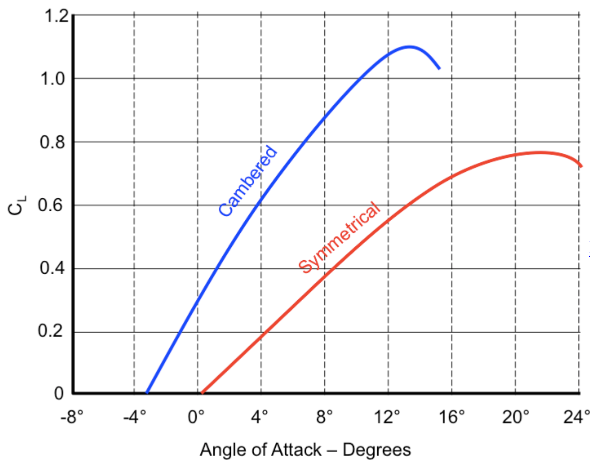
What generates lift?

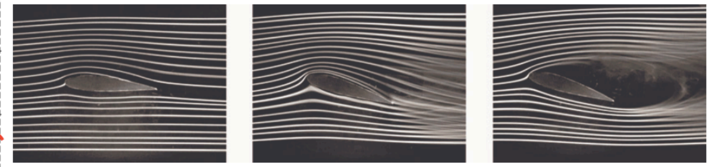


(Image from: http://www.aviation-history.com/theory/lift.htm)



Lift and Drag

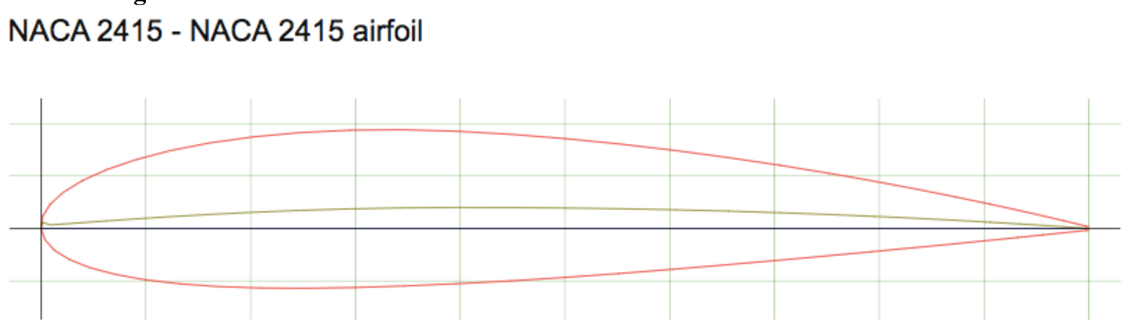


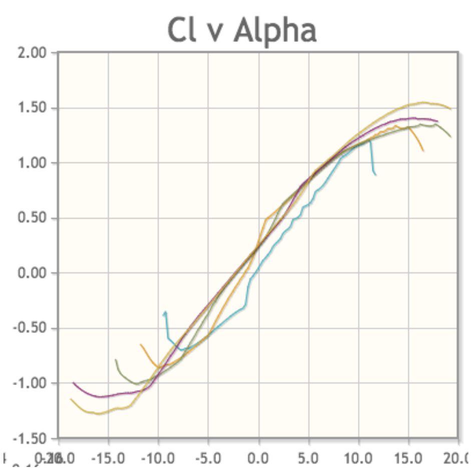


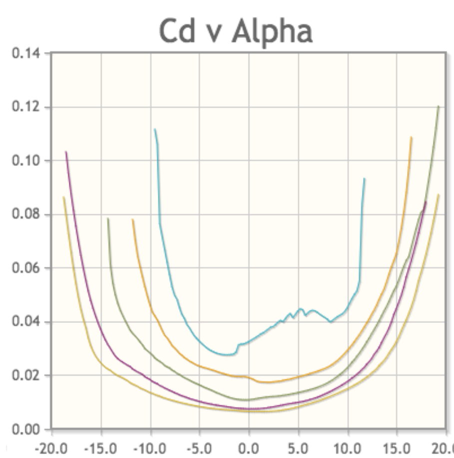
(Image from: http://www3.eng.cam.ac.uk/outreach/Project-resources/Wind-turbine/howwingswork.pdf)

(Image from: http://www.aviationchief.com/angle-of-attack.html)

Lift and Drag Coefficients







Different line colors correspond to different Reynolds numbers based on chord length.

angle of attack, α

NACA (National Advisory Committee for Aeronautics) Airfoil Database:
http://airfoiltools.com/search/index?m%5Bgrp%5D=naca4d&m%5Bsort%5D=1
UIUC Airfoil Database:
https://m-selig.ae.illinois.edu/ads/coord_database.html
XFOIL Subsonic Airfoil Development System:
http://web.mit.edu/drela/Public/web/xfoil/