UNIVERSITI KUALA LUMPUR
KAMPUS CAWANGAN MALAYSIAN SPANISH INSTITUTE

FINAL EXAMINATION
JULY 2023 SEMESTER

COURSE CODE	: SCB 47603
COURSE NAME	: AUTOMOTIVE AERODYNAMICS
PROGRAMME LEVEL	: BACHELOR
DATE	: 25 SEPTEMBER 2023
TIME	: 9.00 AM – 12.00 PM
DURATION	: 3 HOURS

INSTRUCTIONS TO CANDIDATES

1. Please CAREFULLY read the instructions given in the question paper.
2. This question paper has information printed on both sides of the paper.
3. Answer only FOUR (4) questions.
4. Please write your answers on answer booklet provided.
5. Answer all questions in English language ONLY.
6. List of formulae has been appended for your reference.

THERE ARE 7 PAGES OF QUESTIONS EXCLUDING THIS PAGE.

INSTRUCTION: Answer only FOUR (4) questions only.
Please use the answer booklet provided.

Question 1

(a) Describe the difference between pressure drag and skin friction drag. Sketch the expected flow visualization between both plates shown in Figure 1. Properly label the location of low pressure and high pressure.

i. flat plate parallel to fluid flow
ii. flat plate perpendicular to fluid flow

(8 marks)

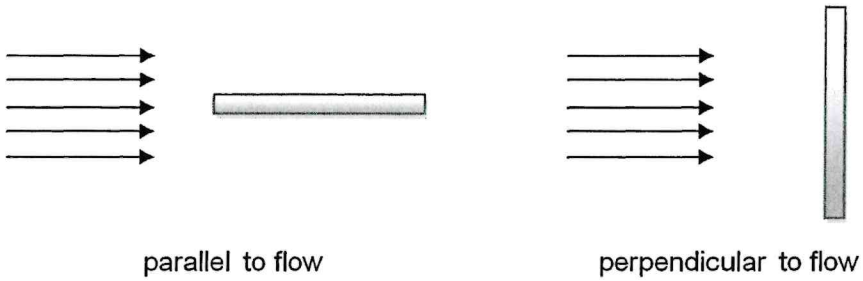


Figure 1

(b) Using your knowledge on flow field visualization surrounding a vehicle, sketch the typical 2D centre flow field visualization for the vehicle shown in Figure 2. Label properly the locations of:

i. flow separation,
ii. boundary layers,
iii. points of reattachment, and
iv. vortices or wakes

(8 marks)

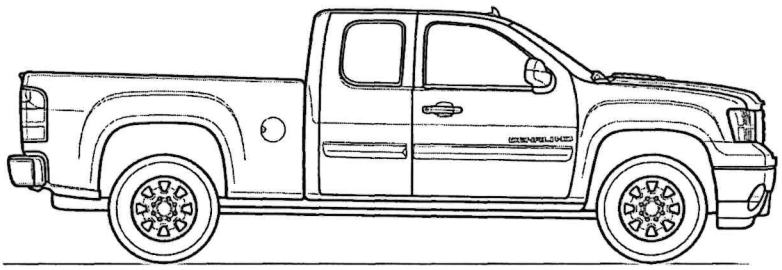
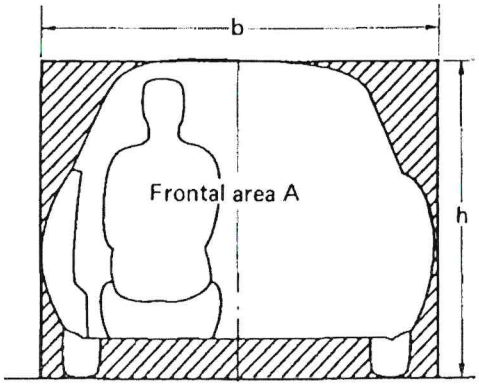


Figure 2

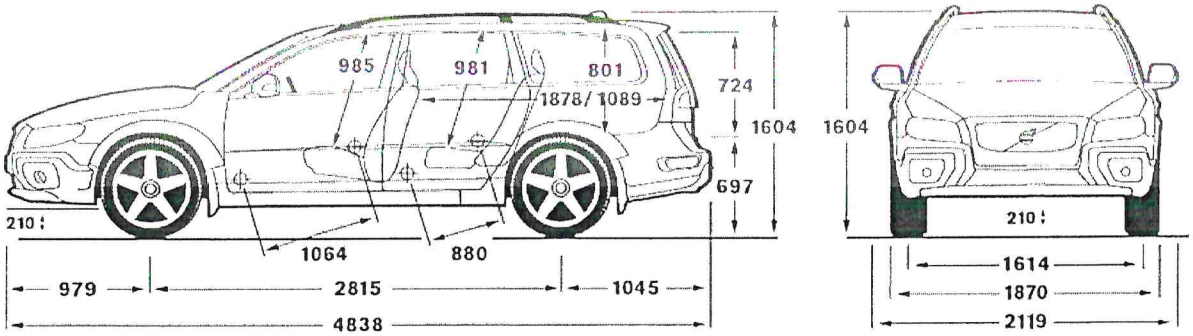
(c) Determine the drag coefficient (C_D) of a car in a wind tunnel shown in Figure 3 with airspeed of 110 km/h wind velocity if the following data were achieved.

(9 marks)

Wind velocity	= 110 km/h
Drag force	= 550 N
Air Temperature	= 35 °C
Air Pressure	= 87 kPa
Gas Constant	= 287 J K^{-1} kg^{-1}
Ideal Gas Law	= (PV=mRT)



$A \approx 0.81 \cdot (b \cdot h)$



All dimensions in mm

Figure 3

Question 2

(a) Describe the fluid flow phenomena occurring on the front car bonnet A, B and C as shown in Figure 1. Is this a desirable phenomenon? Discuss the effects on overall vehicle performance.

(6 marks)

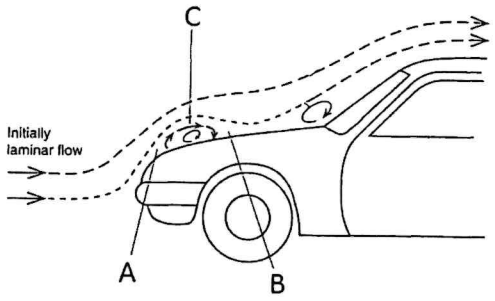


Figure 4

(b) Briefly explain and label each section A, B, C, D and E of the open circuit wind tunnel shown in Figure 5.

(10 marks)

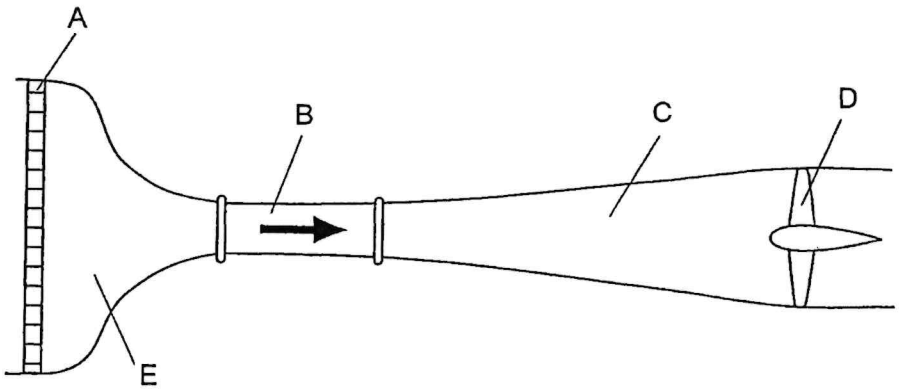


Figure 5

(c) A billboard sign shown in Figure 6 is to be designed to withstand a hurricane of up to 150 km/h. It was designed with a 50 cm diameter pole.

i. Determine the drag coefficient & drag force at the billboard wall and 50 cm diameter pole.

(6 marks)

ii. Determine the total moment in (*Nm*) at the base on the ground due to the aerodynamic loading.

(3 marks)

Take density of air ρ = 1.20 kg/m^3

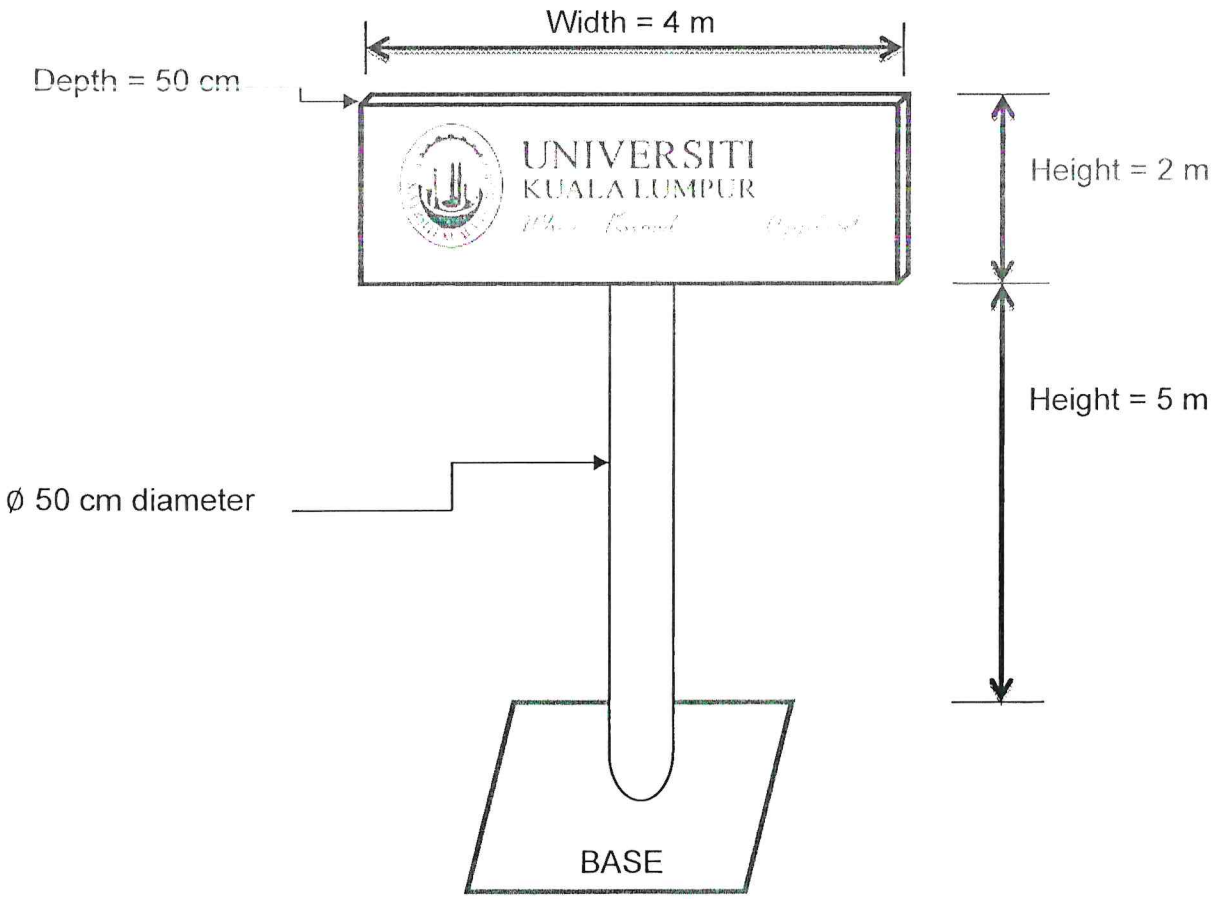


Figure 6

Question 3

(a) What can you suggest to the next generation vehicle designer to improve the overall aerodynamic drag coefficient of the vehicle shown in Figure 7? Sketch your design.

(10 marks)

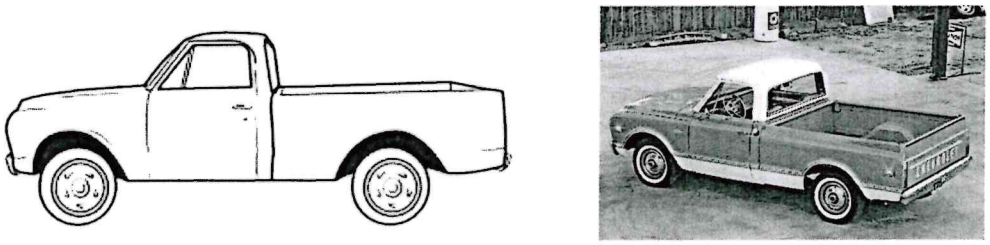


Figure 7

(c) An aircraft has a weight of 2400 kg and has a cruising speed of 215 km/h. The wing dimensions are: chord length = 1.2 m and wingspan = 12 m. The wing section has been tested in the wind tunnel and resulting Lift and Drag coefficient has been established in Figure 8. Take density of air ρ = 1.20 kg/m^3

i. Determine the required angle of attack of the wing at cruising speed.

(5 marks)

ii. What is the corresponding drag force at cruising speed?

(5 marks)

iii. What is the required engine power for the aircraft at cruising speed?

(5 marks)

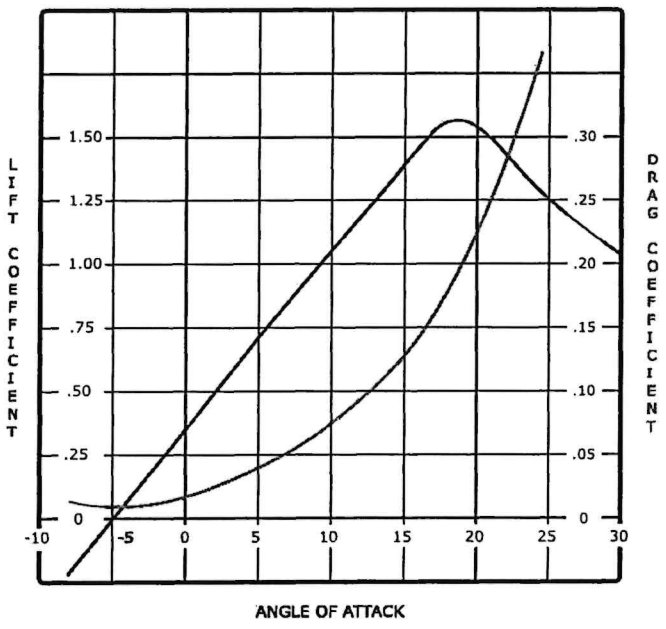


Figure 8

Question 4

(a) Choose the best configuration with the lowest drag coefficient for the design shown in Figure 9. Discuss your answer.

(10 marks)

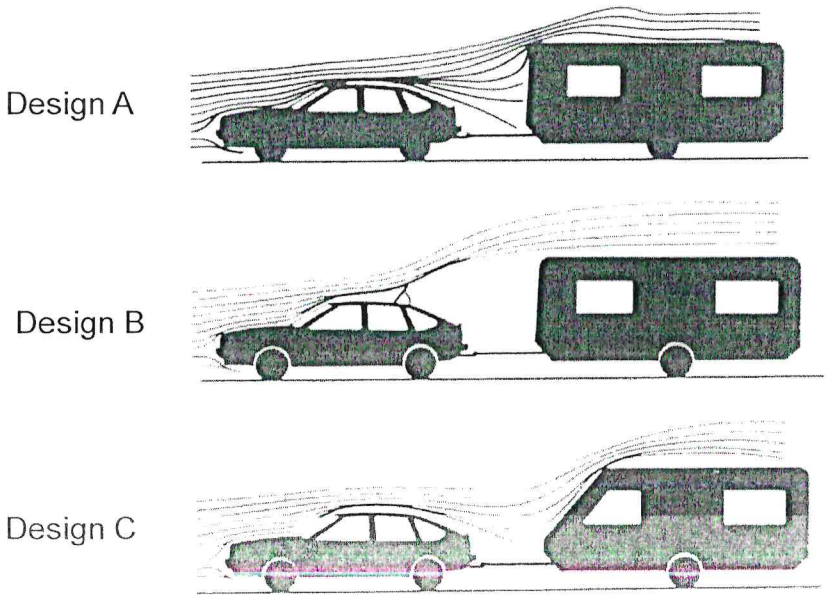


Figure 9

(a) The average pressure and shear stress acting on the surface of the flat circular disc with a diameter of 0.75 m plate are as indicated in the Figure 10. Determine the lift and drag generated by the plate. Sketch also the expected lift and drag vector direction.

(15 marks)

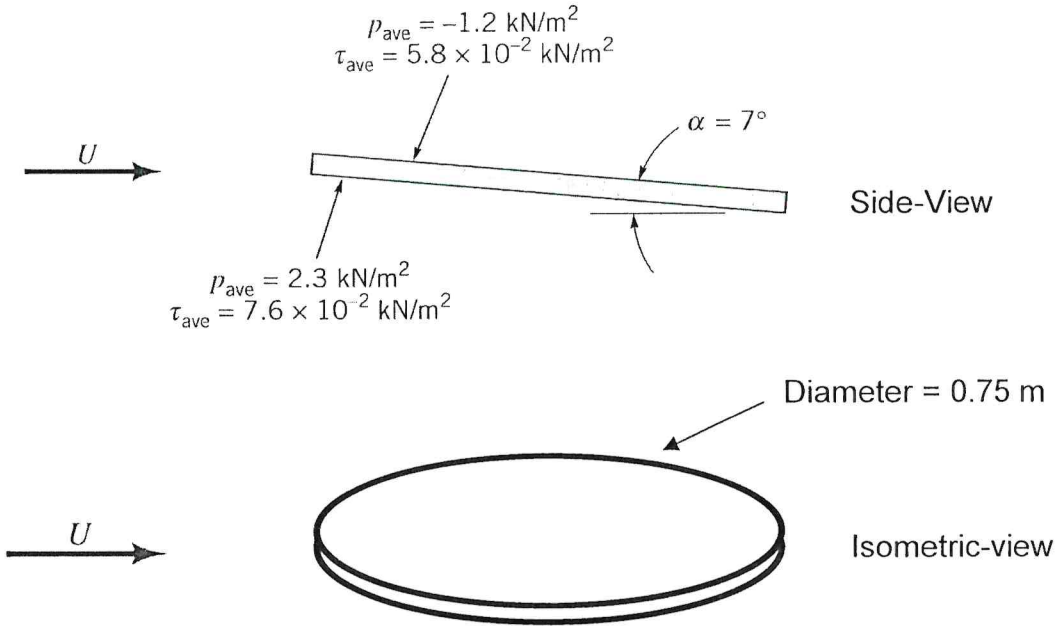


Figure 10

Question 5

(d) An MPV shown in Figure 11 is to be fitted with overhead carrier for luggage. The vehicle travels 40,000 km per year at 100 km/h average speed. The carrier has a dimension of Length (L) of 200 cm; Height (H) is 80 cm; and Width (W) of 120 cm.

Data

Heating Value of Petrol = 45000 kJ/kg

Density of Petrol = 750 kg/m^3

Petrol Price = RM 2.05 /L

Density of air = 1.2 kg/m^3

Engine efficiency = 30 %

i. Find the increase in drag force endured by the MPV.

(6 marks)

ii. Determine the increase in the amount of fuel used by the vehicle per year.

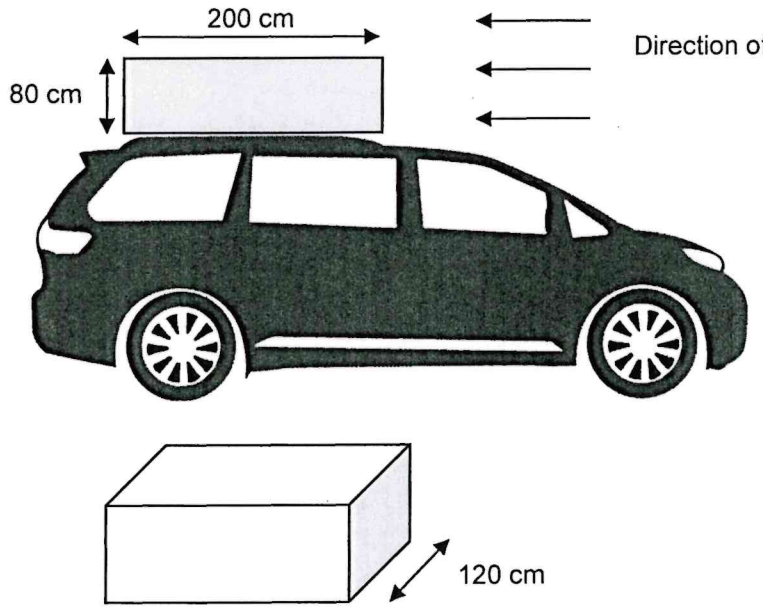
(6 marks)

iii. If petrol cost is RM 2.30 per liter, calculate the extra cost of installing luggage carrier.

(6 marks)

iv. Sketch any design change you would recommend for the luggage carrier.

(7 marks)



- Length (L) = 200 cm
- Height (H) = 80 cm
- Width (W) = 120 cm.

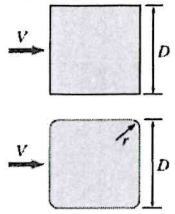
Figure 11

END OF EXAMINATION PAPER

2D Objects

Drag coefficients C_D of various two-dimensional bodies for $Re > 10^4$ based on the frontal area $A = bD$, where b is the length in direction normal to the page (for use in the drag force relation $F_D = C_D A \rho V^2/2$ where V is the upstream velocity)

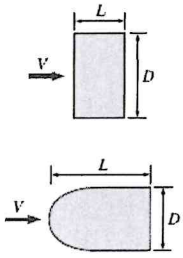
Square rod



Sharp corners: $C_D = 2.2$

Round corners ($r/D = 0.2$): $C_D = 1.2$

Rectangular rod



Sharp corners:

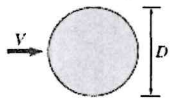
Round front edge:

L/D	C_D
0.0*	1.9
0.1	1.9
0.5	2.5
1.0	2.2
2.0	1.7
3.0	1.3

* Corresponds to thin plate

L/D	C_D
0.5	1.2
1.0	0.9
2.0	0.7
4.0	0.7

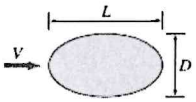
Circular rod (cylinder)



Laminar: $C_D = 1.2$

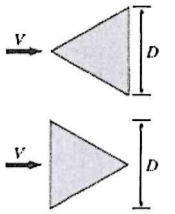
Turbulent: $C_D = 0.3$

Elliptical rod



L/D	C_D Laminar	C_D Turbulent
2	0.60	0.20
4	0.35	0.15
8	0.25	0.10

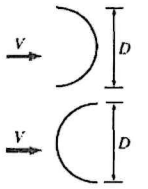
Equilateral triangular rod



$C_D = 1.5$

$C_D = 2.0$

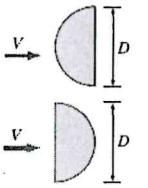
Semicircular shell



$C_D = 2.3$

$C_D = 1.2$

Semicircular rod



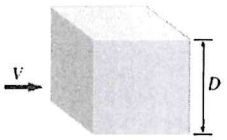
$C_D = 1.2$

$C_D = 1.7$

3D Objects

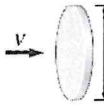
Representative drag coefficients C_D for various three-dimensional bodies for $Re > 10^4$ based on the frontal area (for use in the drag force relation $F_D = C_D A \rho V^2/2$ where V is the upstream velocity)

Cube, $A = D^2$



$C_D = 1.05$

Thin circular disk, $A = \pi D^2/4$



$C_D = 1.1$

Cone (for $\theta = 30°$), $A = \pi D^2/4$

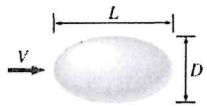
$C_D = 0.5$

Sphere, $A = \pi D^2/4$

Laminar: $Re \lesssim 2 \times 10^5$, $C_D = 0.5$

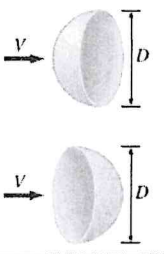
Turbulent: $Re \gtrsim 2 \times 10^6$, $C_D = 0.2$

Ellipsoid, $A = \pi D^2/4$



L/D	C_D Laminar $Re \lesssim 2 \times 10^5$	C_D Turbulent $Re \gtrsim 2 \times 10^6$
0.75	0.5	0.2
1	0.5	0.2
2	0.3	0.1
4	0.3	0.1
8	0.2	0.1

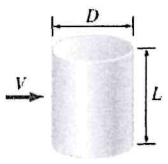
Hemisphere, $A = \pi D^2/4$



$C_D = 0.4$

$C_D = 1.2$

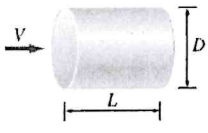
Short cylinder, vertical, $A = LD$



L/D	C_D
1	0.6
2	0.7
5	0.8
10	0.9
40	1.0
∞	1.2

Values are for laminar flow ($Re \lesssim 2 \times 10^5$)

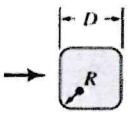
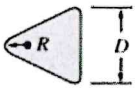
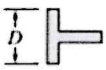
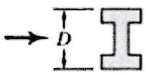
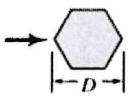
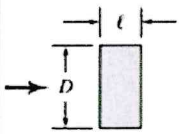
Short cylinder, horizontal, $A = \pi D^2/4$



L/D	C_D
0.5	1.1
1	0.9
2	0.9
4	0.9
8	1.0

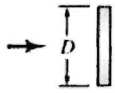
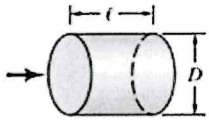
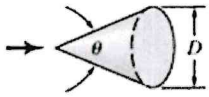
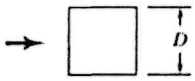
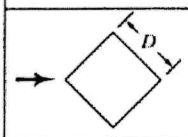
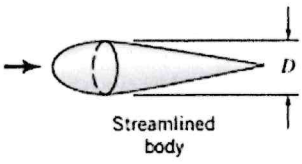
APPENDIX

2D Objects

Shape	Drag coefficient $C_D = \frac{\mathcal{D}}{\frac{1}{2}\rho U^2 A}$	Reynolds number $Re = \rho UD/\mu$
 Square rod with rounded corners	R/D | C_D 0 | 2.2 0.02 | 2.0 0.17 | 1.2 0.33 | 1.0	$Re = 10^5$
 Rounded equilateral triangle	R/D | C_D → | ← 0 | 1.4 | 2.1 0.02 | 1.2 | 2.0 0.08 | 1.3 | 1.9 0.25 | 1.1 | 1.3	$Re = 10^5$
Semicircular shell	→ 2.3 ← 1.1	$Re = 2 \times 10^4$
Semicircular cylinder	→ 2.15 ← 1.15	$Re > 10^4$
 T-beam	→ 1.80 ← 1.65	$Re > 10^4$
 I-beam	2.05	$Re > 10^4$
Angle	→ 1.98 ← 1.82	$Re > 10^4$
 Hexagon	1.0	$Re > 10^4$
 Rectangle	ℓ/D | C_D ≤0.1 | 1.9 0.5 | 2.5 0.65 | 2.9 1.0 | 2.2 2.0 | 1.6 3.0 | 1.3	$Re = 10^5$

Typical drag coefficients for regular two-dimensional objects

3D Objects

Shape	Drag coefficient C_D	Reynolds number $Re = \rho UD/\mu$
Solid hemisphere	→ 1.17 ← 0.42	$Re > 10^4$
Hollow hemisphere	→ 1.42 ← 0.38	$Re > 10^4$
 Thin disk	1.1	$Re > 10^3$
 Circular rod parallel to flow	ℓ/D | C_D 0.5 | 1.1 1.0 | 0.93 2.0 | 0.83 4.0 | 0.85	$Re > 10^5$
 Cone	θ, degrees | C_D 10 | 0.30 30 | 0.55 60 | 0.80 90 | 1.15	$Re > 10^4$
 Cube	1.05	$Re > 10^4$
 Cube	0.80	$Re > 10^4$
 Streamlined body	0.04	$Re > 10^5$

Typical drag coefficients for regular three-dimensional objects