Name: ------------------ **Quiz: No. 13** **Time: 15 minutes**

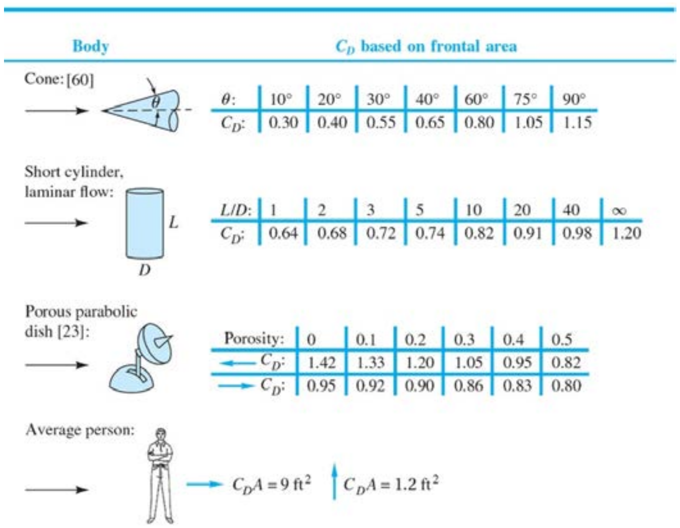
ME:5160, Fall 2024

The exam is closed book and closed notes.

A hot-film probe is mounted on a cone-and-rod system in an airstream (ρ = 1.347 kg/m^3, μ = 1.78E-5 kg/m.s.) of 45 m/s, as in the Figure below. Estimate the maximum cone vertex angle allowable if the flow-induced bending moment at the root of the rod is not to exceed 30 N.cm.

Equations: $C_D = \frac{F_D}{\frac{1}{2}\rho A V^2}$

Table: Drag of three-dimensional bodies



Body: Cone: [60] — C_D based on frontal area

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

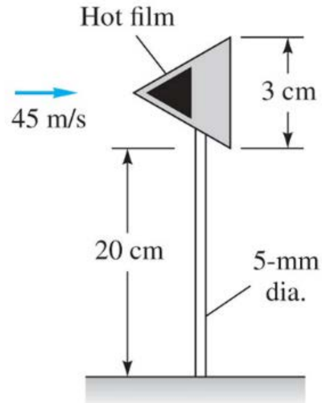
Body: Short cylinder, laminar flow:

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

Body: 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

Body: Average person: → $C_D A = 9$ ft^2 ↑ $C_D A = 1.2$ ft^2



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Solution:

KNOWN: wind velocity, body shapes and sizes, maximum bending moment

(1) FIND: θ

ASSUMPTIONS: smooth surfaces such that the values in the Table are valid

ANALYSIS:

For the rod:

(2.5)

$$Re_{D,rod} = \frac{\rho V D_{rod}}{\mu} = \frac{(1.347)(45)(0.005)}{(1.78E-5)} = 1.7E4 < 5E5 \rightarrow \quad Laminar$$

From the Table:

(0.5) (0.5)

$$\frac{L_{rod}}{D_{rod}} = \frac{(200)}{(5)} = 40 \quad \rightarrow \quad C_{D,rod} = 0.98$$

$$F_{rod} = C_{D,rod}\left(\frac{1}{2}\rho A_{rod} V^2\right)$$

(0.5)

$$A_{rod} = L_{rod} D_{rod}$$

(0.5)

$$F_{rod} = (0.98)(0.5)(1.347)(0.2)(0.005)(45)^2 = 1.34\ N$$

(0.5)

$$M_{rod} = F_{rod} \times r_{rod}$$

(0.5)

$$r_{rod} = 10\ cm$$

$$M_{rod} = (1.34)(10) = 13.4\ N.cm$$

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For the cone:

$$F_{cone} = C_{D,cone}\left(\frac{1}{2}\rho A_{cone} V^2\right)$$

$$A_{cone} = \frac{\pi}{4} D_{cone}^2 \quad \textbf{(0.5)}$$

$$M_{cone} = F_{cone} \times r_{cone}$$

$$r_{cone} = 20 + \frac{3}{2} = 21.5\ cm \quad \textbf{(0.5)}$$

$$M_{cone} = C_{D,cone}(0.5)(1.347)\left(\frac{\pi}{4}\right)(0.03)^2(45)^2(21.5) = (20.73)C_{D,cone} \quad \textbf{(0.5)}$$

$$M_{total} = M_{rod} + M_{cone} = 13.4 + 20.73C_{D,cone} = 30\ N.cm \quad \textbf{(0.5)}$$

$$C_{D,cone} = \frac{(30) - (13.4)}{(20.73)} = 0.8 \quad \textbf{(0.5)}$$

(0.5)

From the Table:

$$\theta = 60° \quad \textbf{(0.5)}$$