Design of a Sounding Rocket

Lesson 3: Aerodynamic Design of Sounding rockets

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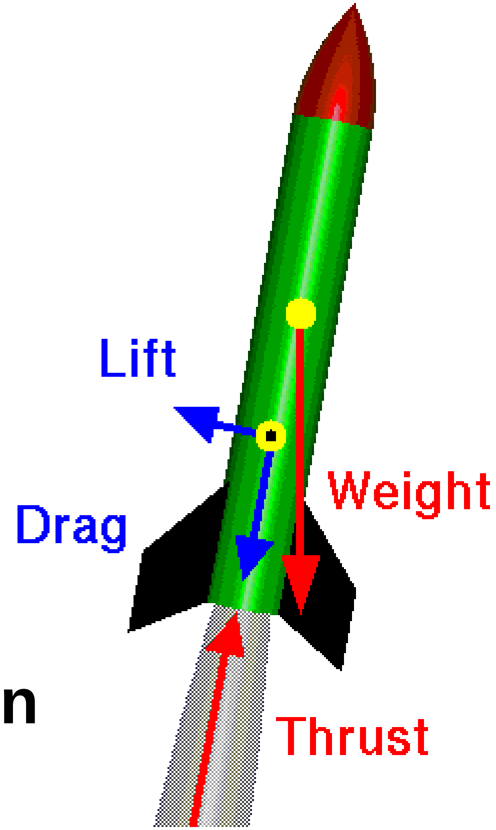
Forces acting on the rocket

Weight, Thrust, Drag, Lift

Sounding rocket： uncontrolled

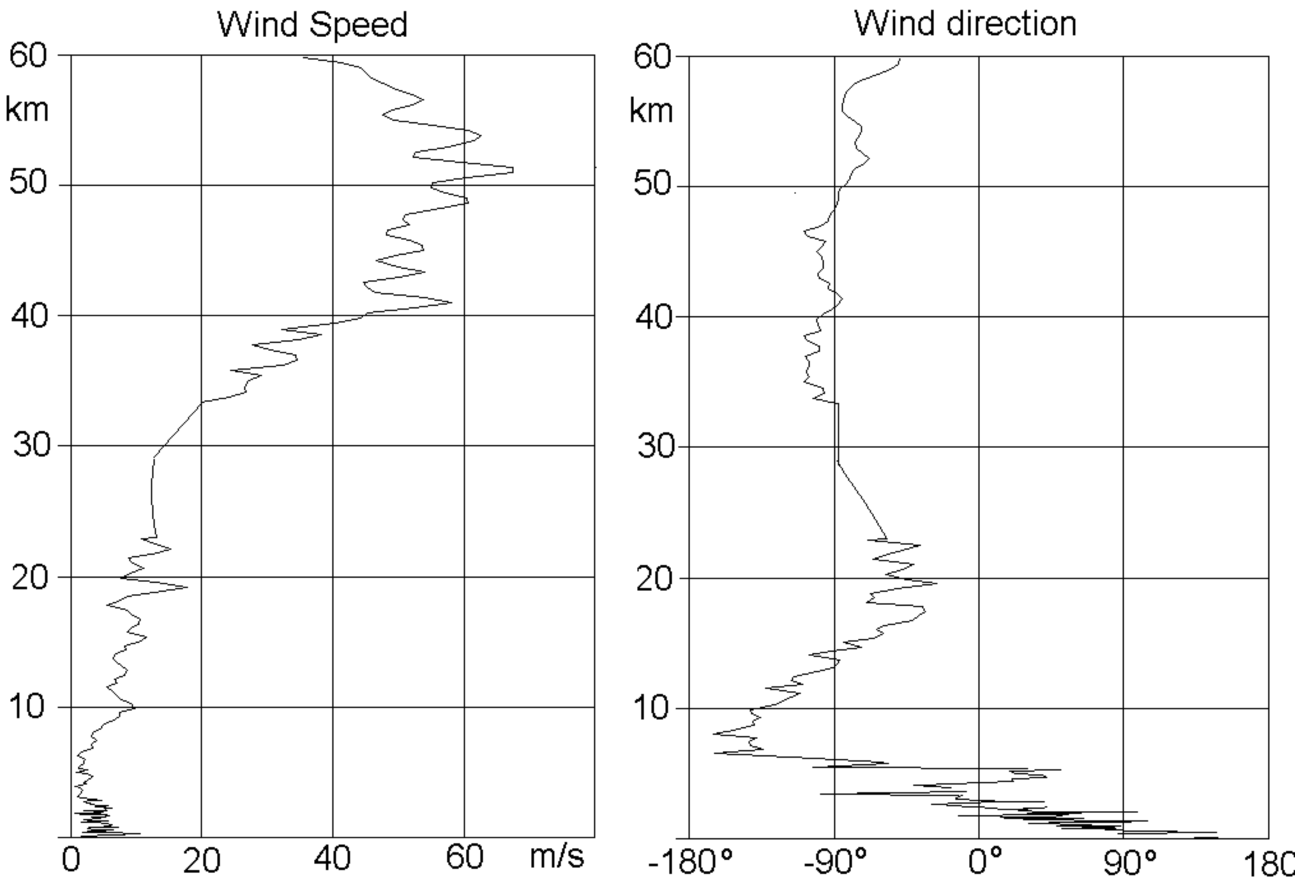
Aerodynamic forces: **Lift** and **Drag**

Aerodynamic forces: **Pressure** and **Friction**



Source: NASA

Earth Atmosphere



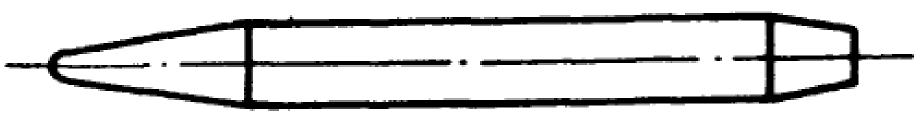
1. The missions of aerodynamic design

Sounding rocket：uncontrolled

- Stable flight
- Protect the rocket from aerodynamic loads, heating loads…
- Low cost (low drag)

2. Aerodynamic design of sounding rockets

Normal configurations of sounding rocket



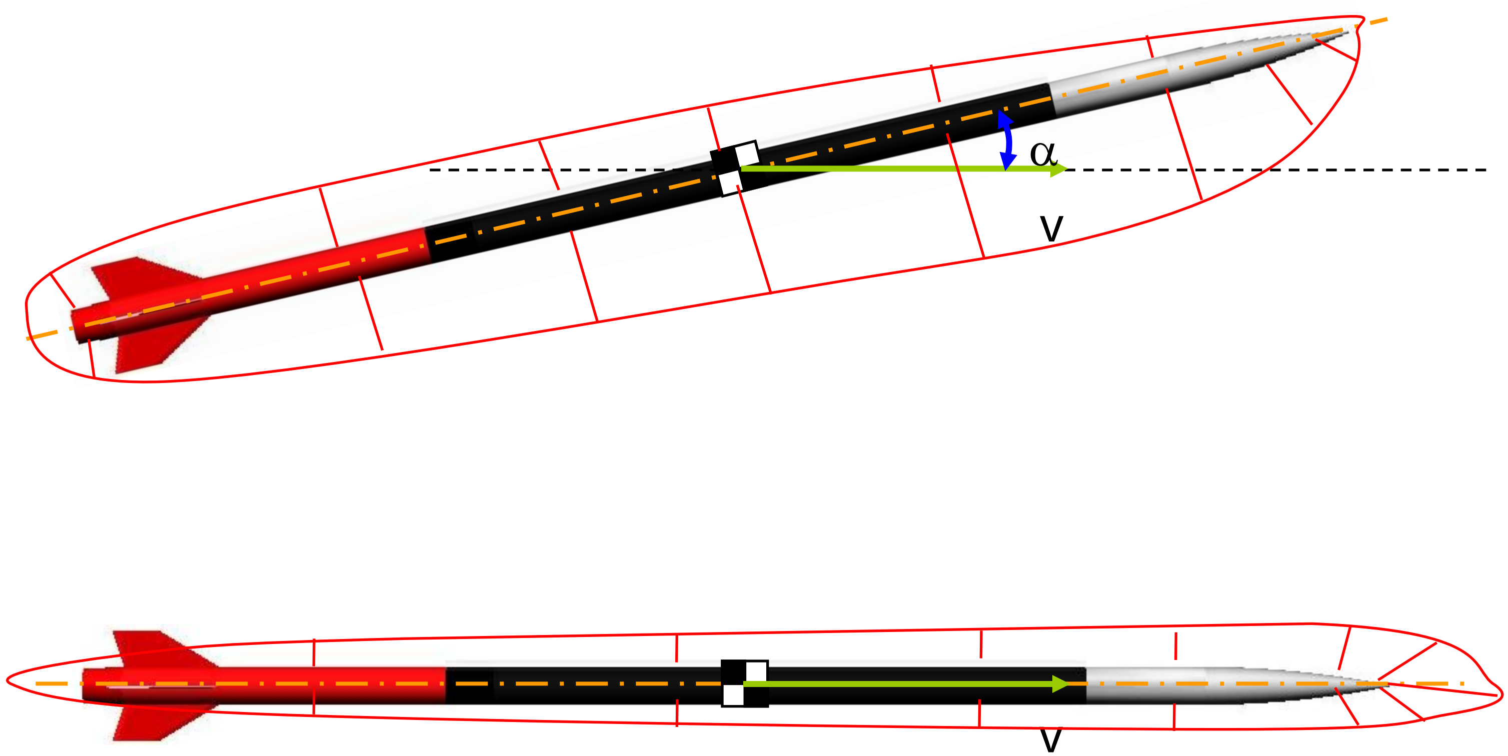
(a)

Single stage

(b)

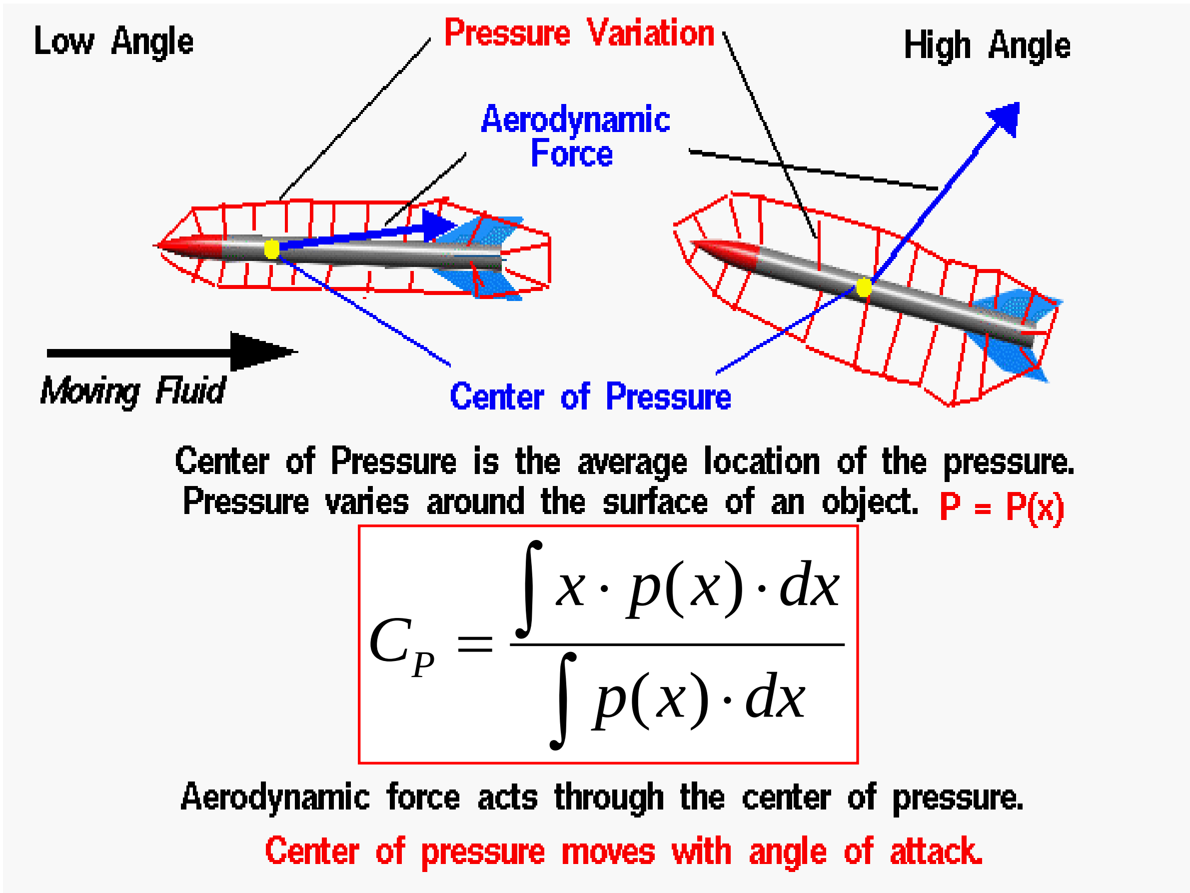
Two stages

Pressure Distribution Around a Rocket



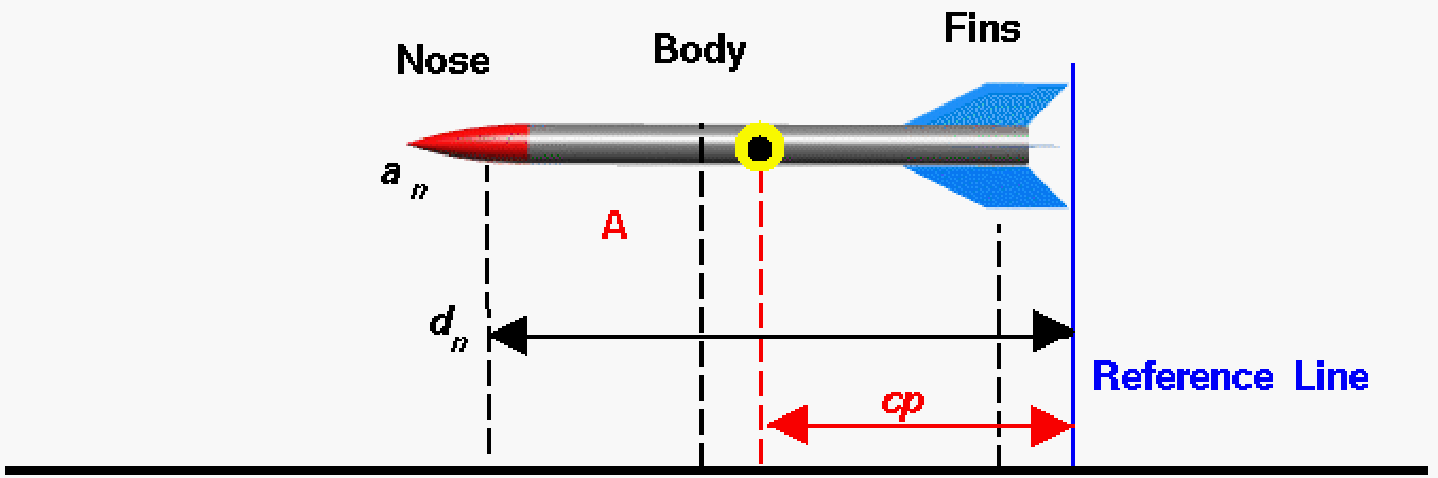
Source: Rønningen

Center of Pressure



Source: NASA

Determine Center of Pressure



Each component has some area a_i
located some distance d_i from reference line.

Distance cp times the area A equals the sum of the
component distance times area.

$$cp\,A = d_n a_n + d_b a_b + d_f a_f$$

2. Aerodynamic design of sounding rockets

Head configurations

Drag: Wave drag and friction drag

Head: conic or parabolic

More L/D (length/diameter) less drag

Subsonic flight: parabolic head is preferred

Supersonic flight: conic head is prefered

2. Aerodynamic design of sounding rockets

Head configurations

For supersonic flight, skin friction drag and base drag are relatively small. Supersonic drag is dominated by the drag due to the shock wave on the nose.

$$(CD_0)_{Body,Wave} = 3.6/[(l_N/d)(M-1)+3]$$

$(C_{D_0})_{Body,\ Wave} = 3.6 / [(l_N / d) (M - 1) + 3]$, if $M > 1$ and $(C_{D_0})_{Body,\ Wave} = 0$, if $M < 1$

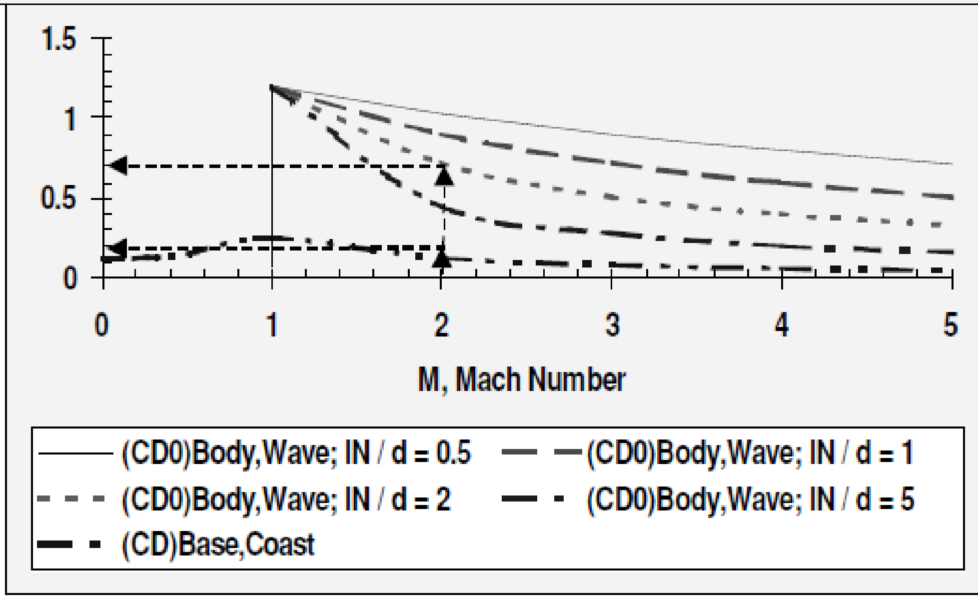
$(C_{D_0})_{Base,Coast} = 0.25 / M$, if $M > 1$ and $(C_{D_0})_{Base,Coast} = (0.12 + 0.13\ M^2)$, if $M < 1$

$(C_{D_0})_{Base,Powered} = (1 - A_e / S_{Ref}) (0.25 / M)$, if $M > 1$ and $(C_{D_0})_{Base,Powered} = (1 - A_e / S_{ref}) (0.12 + 0.13\ M^2)$, if $M < 1$

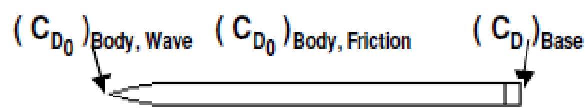
$(C_{D_0})_{Body,Friction} = 0.053 (l / d) [M / (q\ l)]^{0.2}$

$(C_{D_0})_{Body} = (C_{D_0})_{Body,\ Wave} + (C_{D_0})_{Base} + (C_{D_0})_{Body,Friction}$

Note: $(C_{D_0})_{Body,Wave}$ = body zero-lift wave drag coefficient, $(C_{D_0})_{Base}$ = body base drag coefficient, $(C_{D_0})_{Body,\ Friction}$ = body skin friction drag coefficient, $(C_{D_0})_{Body}$ = body zero-lift drag coefficient, l_N = nose length, d = missile diameter, l = missile body length, A_e = nozzle exit area, S_{Ref} = reference area, q = dynamic pressure



Example for Rocket Baseline:



$f_N = l_N / d = 2.4$, $A_e = 11.22\ in^2$, $S_{ref} = 50.26\ in^2$, $M = 2$, $h = 20K\ ft$, $q = 2725\ psf$, $l / d = 18$, $l = 12\ ft$

$(C_{D_0})_{Body,\ Wave} = 3.6 / [2.4 (2 - 1) + 3] = 0.67$

$(C_D)_{Base\ Coast} = 0.25 / 2 = 0.13$

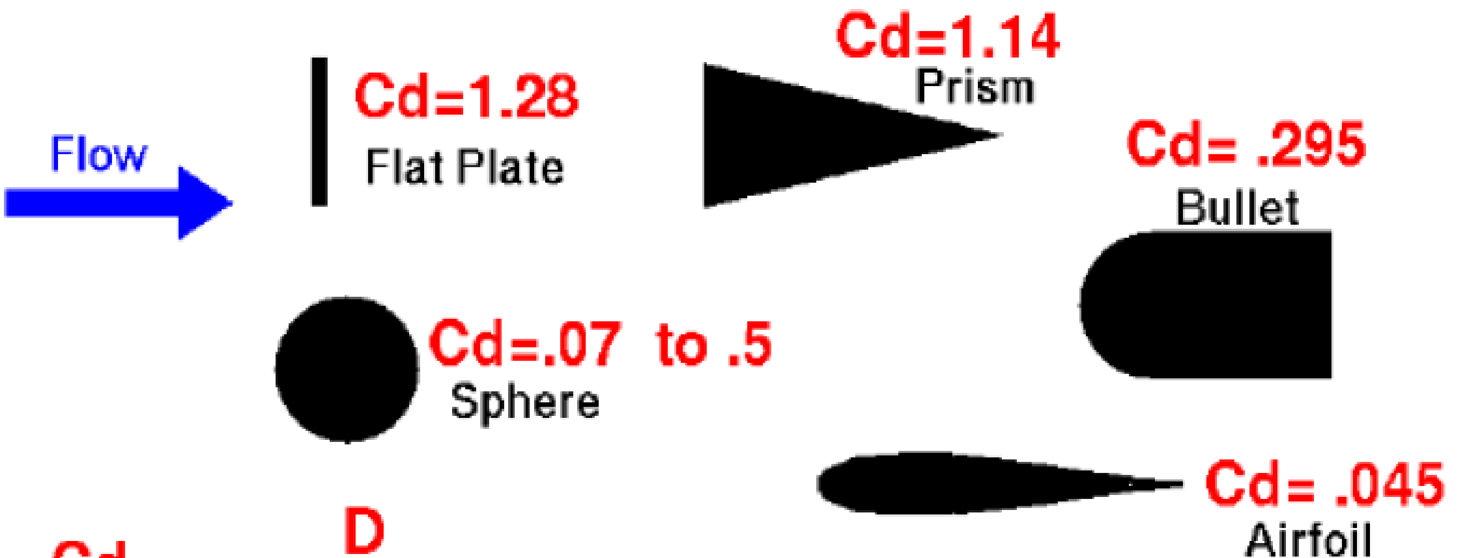
$(C_D)_{Base\ Powered} = (1 - 0.223) (0.25 / 2) = 0.10$

$(C_{D_0})_{Body,\ Friction} = 0.053 (18) \{ (2) / [(2725) (12)]\}^{0.2} = 0.14$

$(C_{D_0})_{Body,\ Coast} = 0.67 + 0.13 + 0.14 = 0.94$

$(C_{D_0})_{Body,\ Powered} = 0.67 + 0.10 + 0.14 = 0.91$

The shape of an object has a very great effect on the amount of drag.

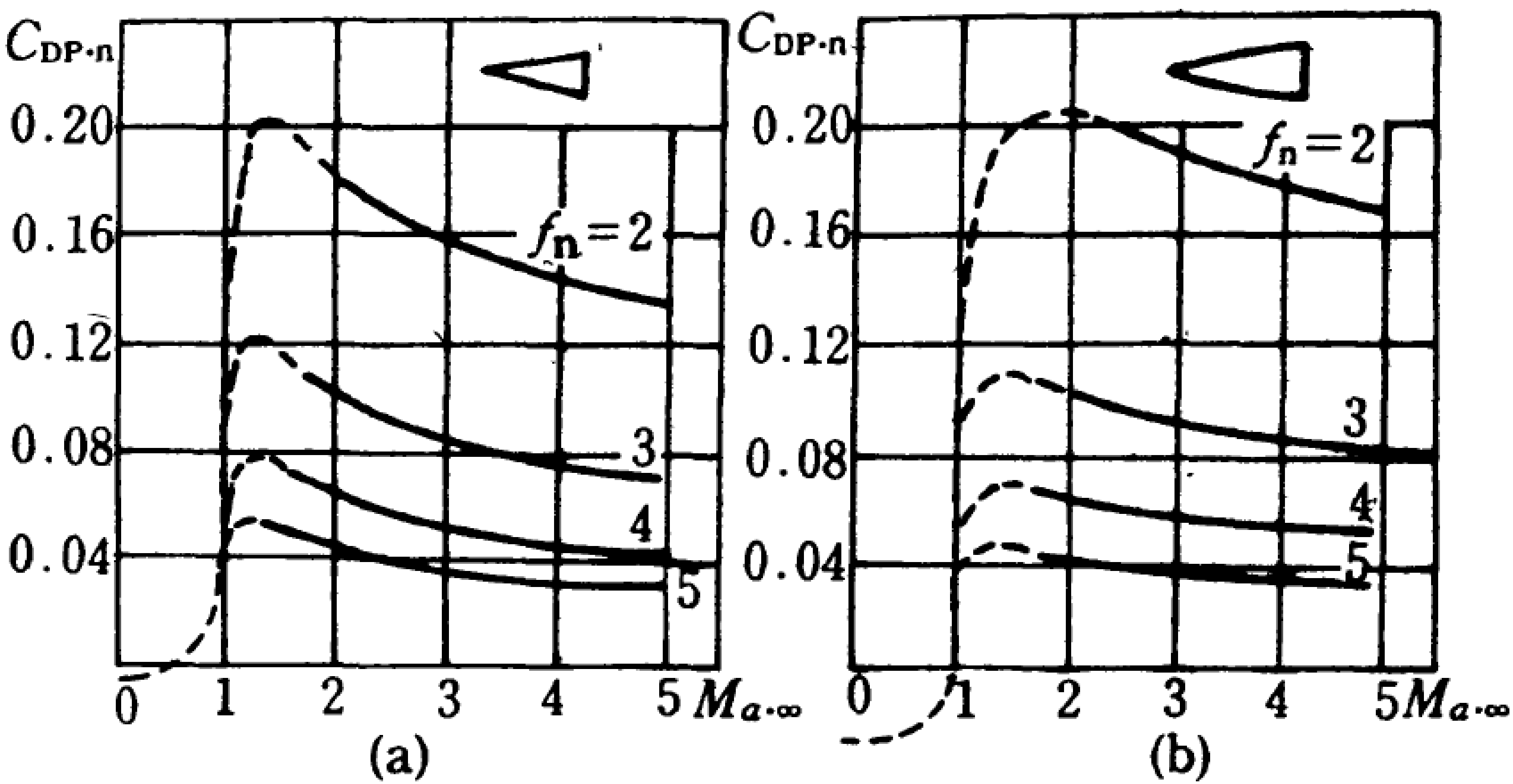


Almost factor 30 better than the flat plate!

$$Cd = \frac{D}{r\ A\ V^2/2}$$

A = frontal area

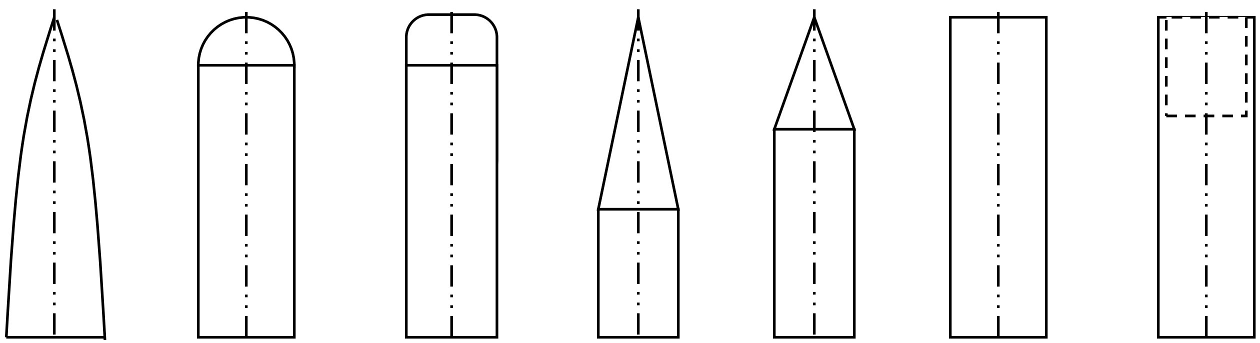
All objects have the same frontal area.



Conic head Parabolic head

C_D Values for Various Nose Designs

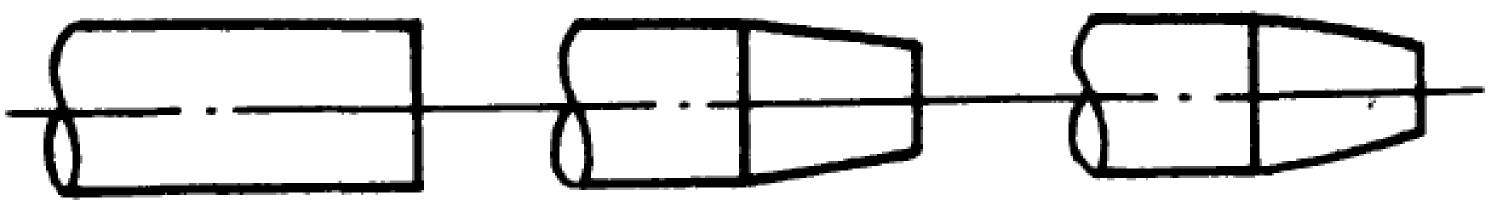
Cd for different nose design (subsonic velocity) and zero alpha:



Cd:	<0.05	>0.01	0.20	0.20	0.34	0.90	1.00
	4:1			3:1	1:1		

2. Aerodynamic design of sounding rockets

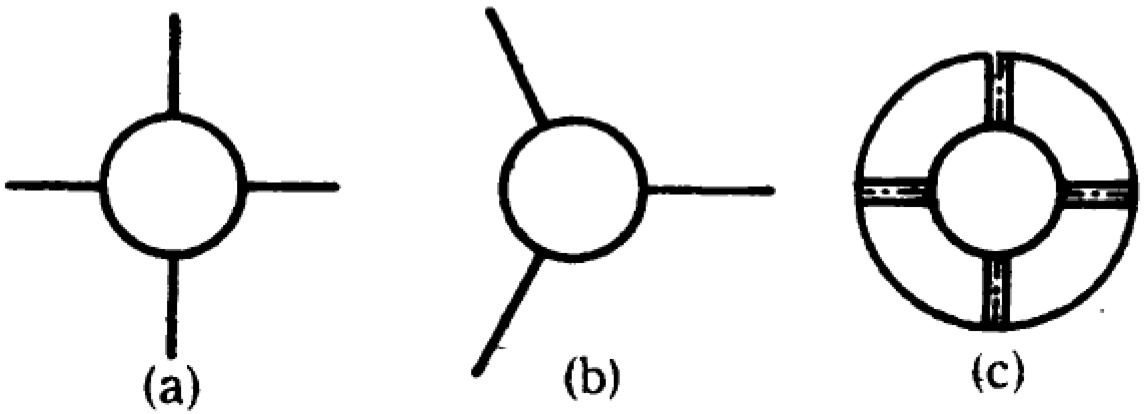
Tail configurations



(a) (b) (c)

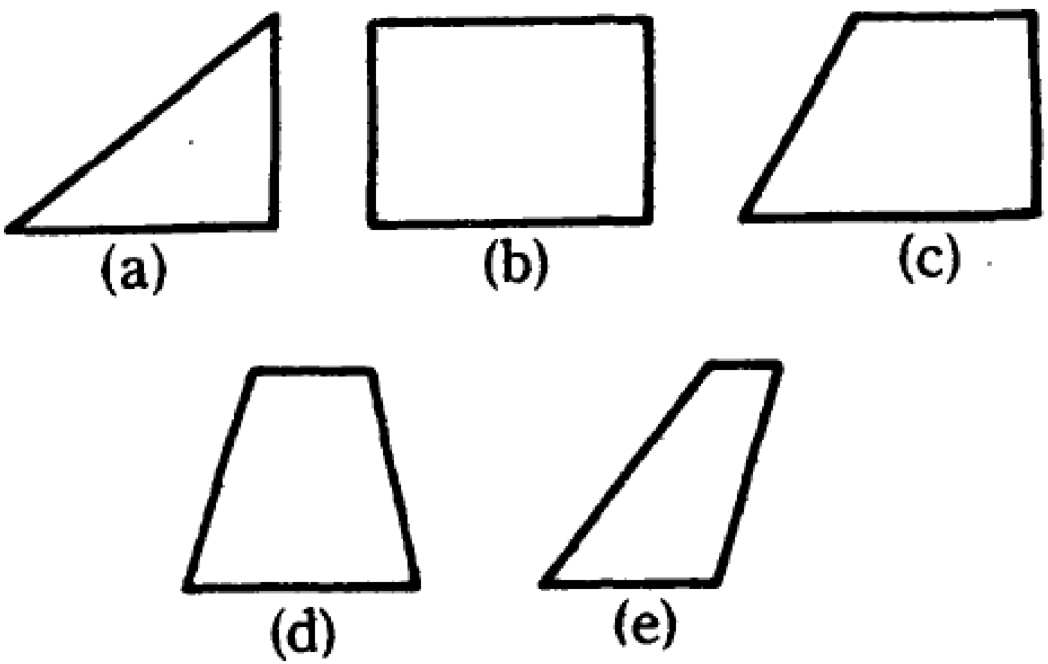
2. Aerodynamic design of sounding rockets

Fins: ensure the stability



2. Aerodynamic design of sounding rockets

Fins: ensure the stability



3. Computation of Aerodynamics

- **Engineering method (Datcom)**
- **Navier-Stokes**
  - Potential flow
  - Euler flow
  - Turbulent flow