

# APLICATIVO COMPUTACIONAL PARA CÁLCULO DO COEFICIENTE DE ARRASTO DE MINIFOGUETES

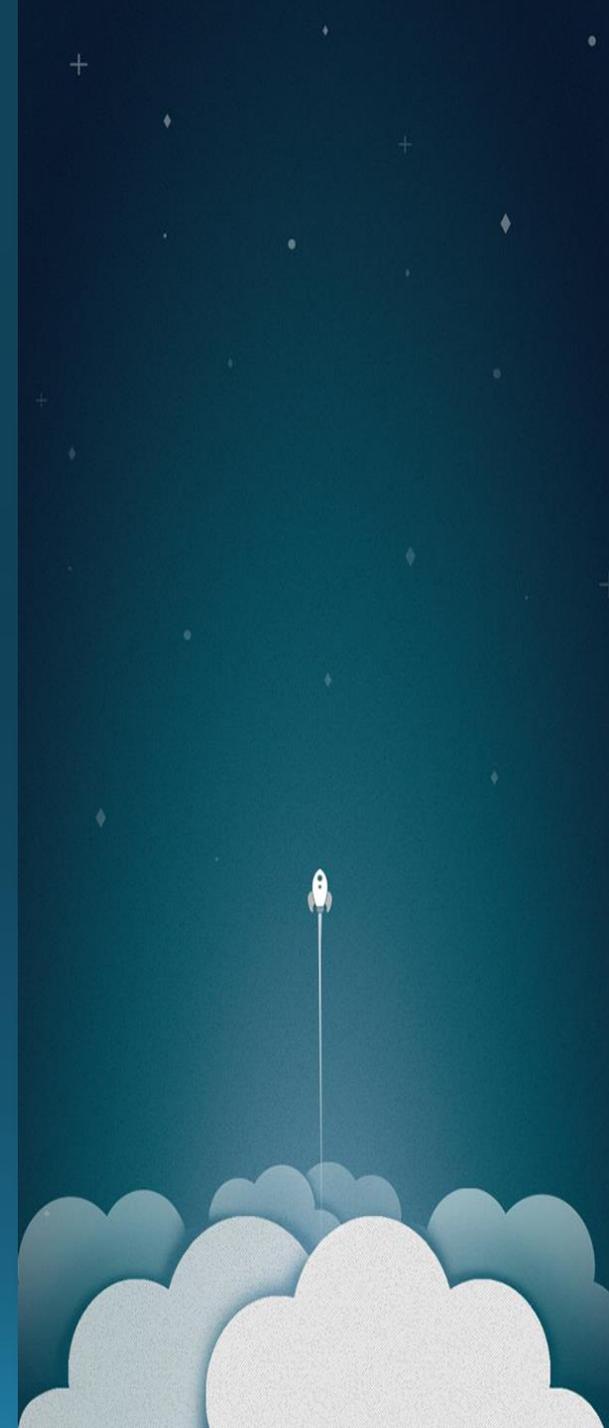
## CD 2.1

GRUPO DE FOGUETES CARL SAGAN

TOBIAS PINHEIRO QUELUZ

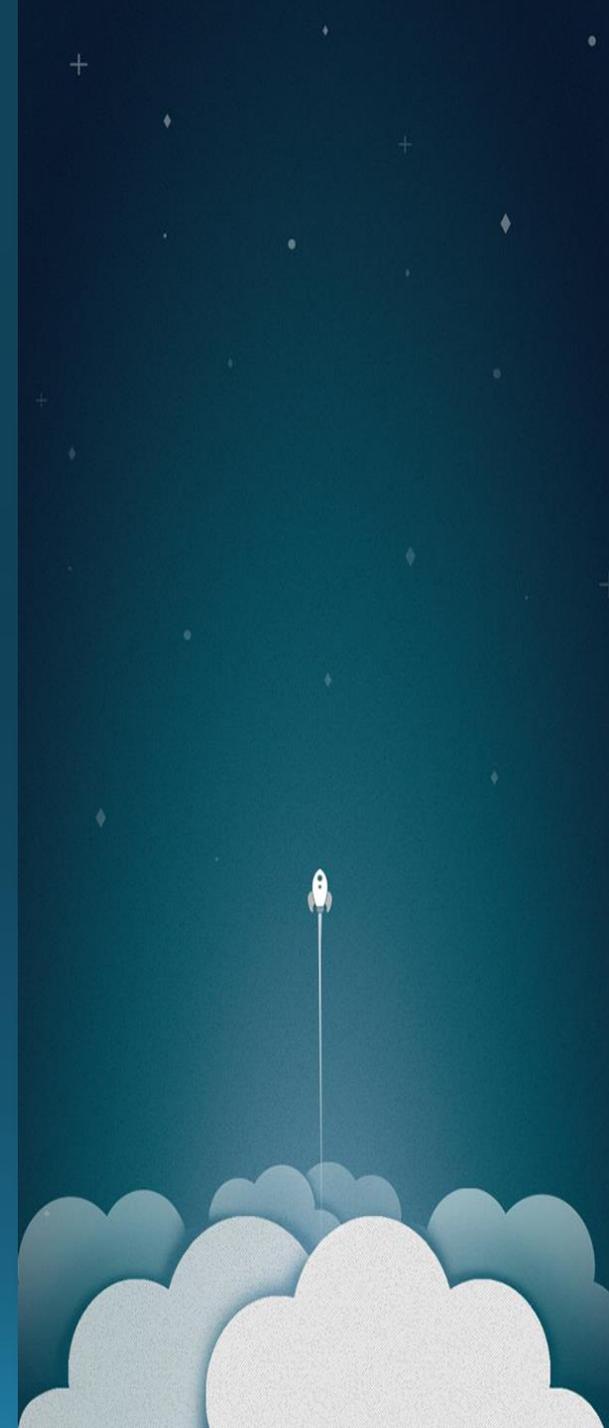
# INTRODUÇÃO

- A determinação teórica do coeficiente de arrasto não apresenta um modelo matemático padrão definido.
- Os programas computacionais existentes subestimam os valores de  $C_d$ .
- O método de obtenção do coeficiente não é divulgado ou apresentado de forma clara.

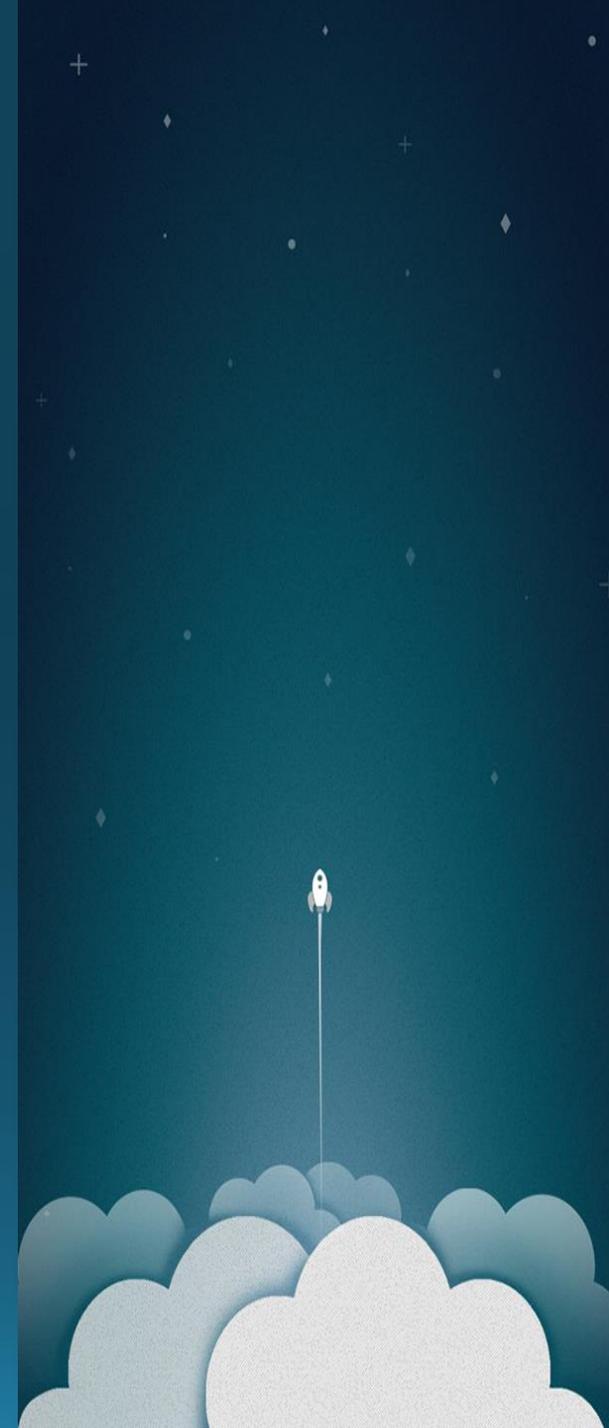
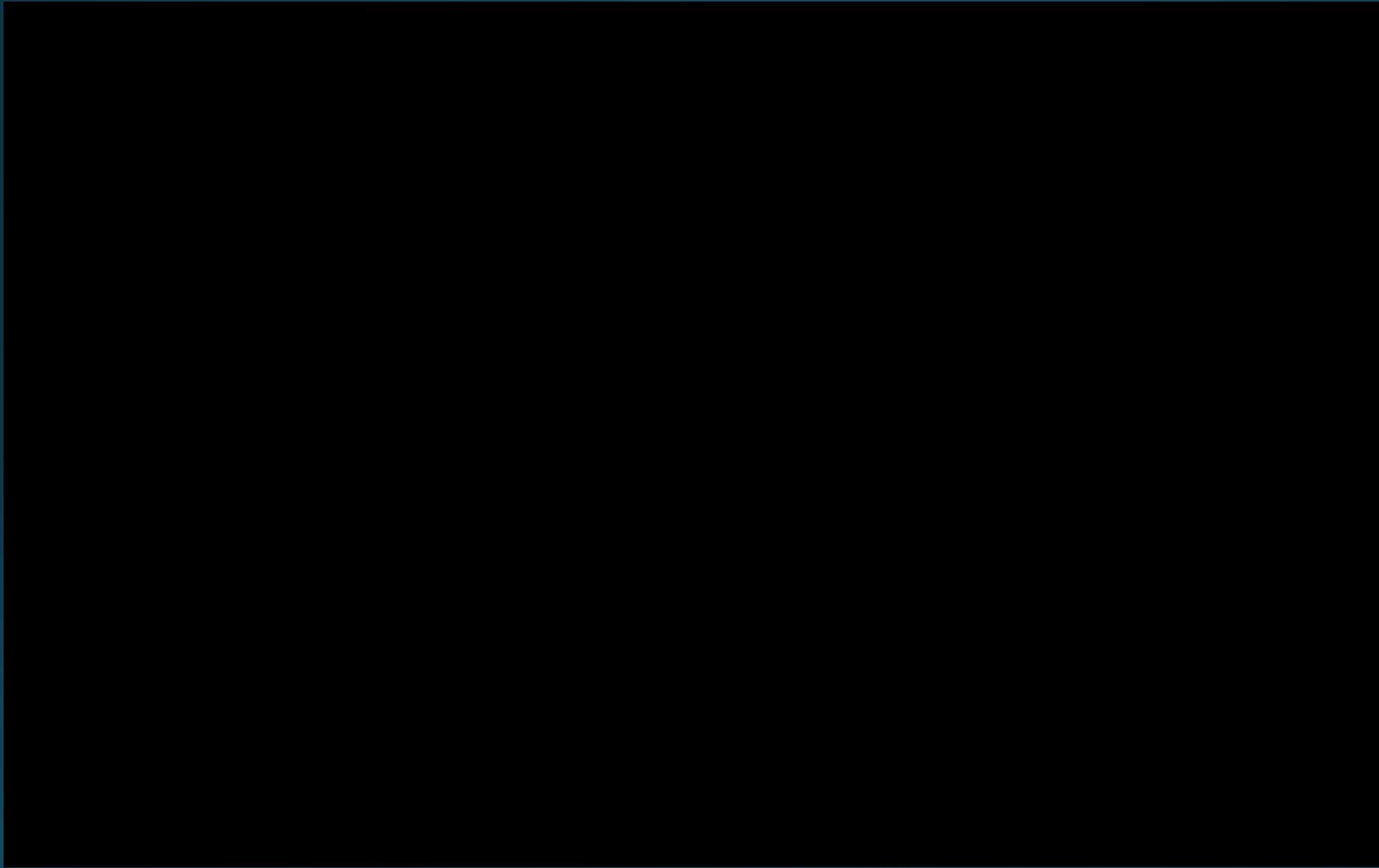


# COEFICIENTE DE ARRASTO

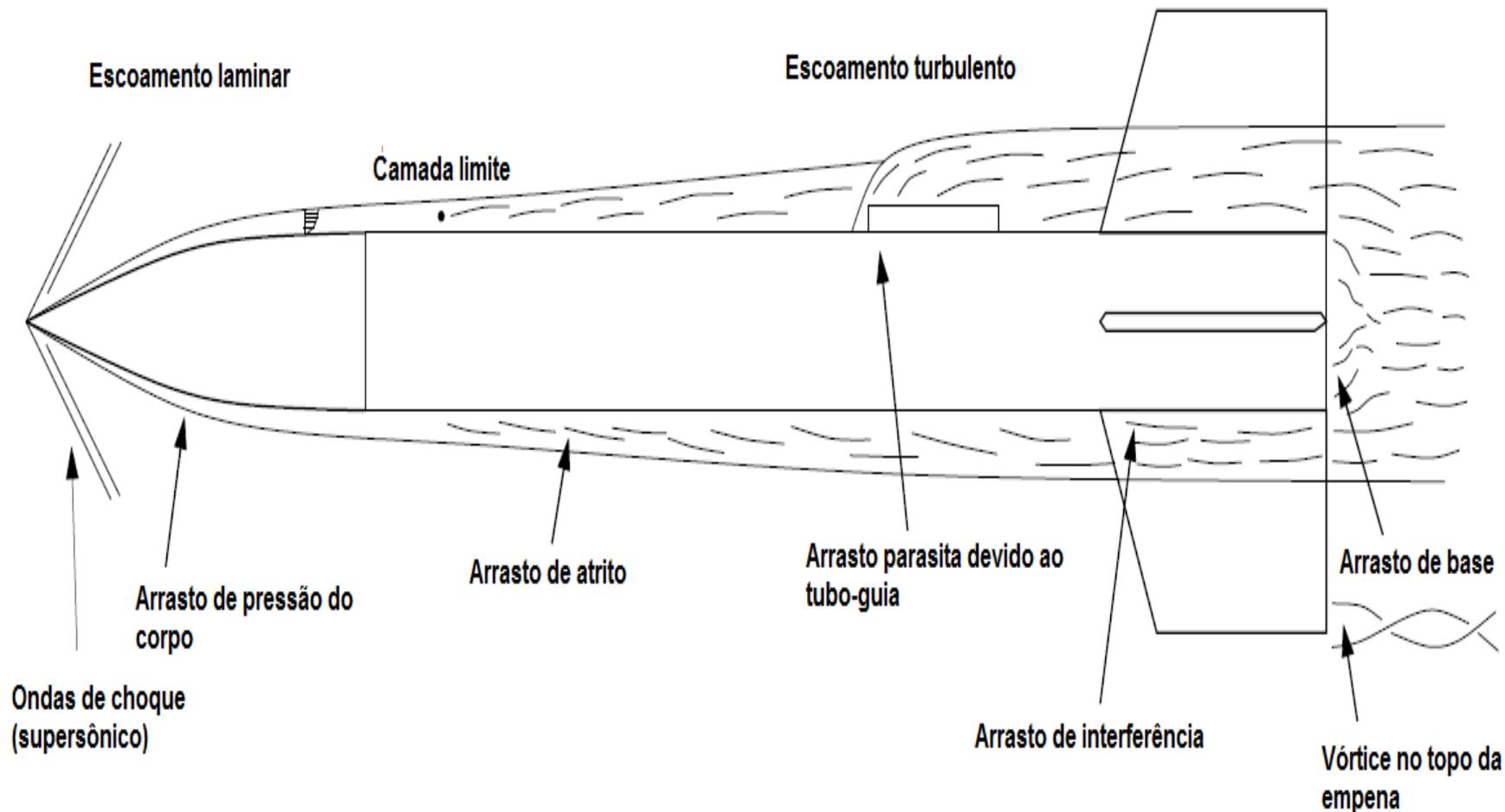
- Adimensional
- Utilizado para quantificar o arrasto ou resistência de um objeto em um meio fluido
- Pode ser determinado experimentalmente através de testes em túneis de vento



# TÚNEL DE VENTO



# COEFICIENTE DE ARRASTO

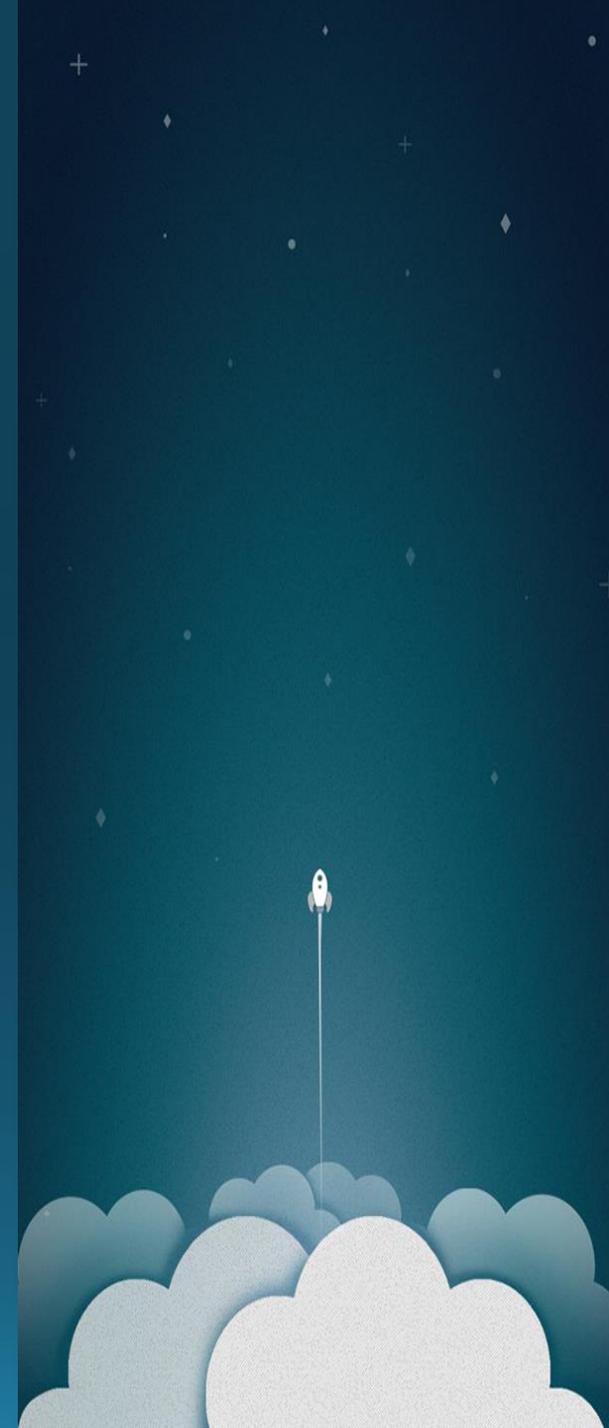


$$C_d = \frac{2D}{\rho V^2 A}$$



# CD 2.1

- Linguagem Fortran 90
- Calcula o coeficiente de arrasto de espaçomodelos em escoamento **subsônico/transônico/supersônico**
- Os narizes podem apresentar formato cônico, ogiva, elíptico ou parabólico.
- As empenas são trapezoidais e suas bordas podem ter um perfil arredondado ou quadrado.
- O efeito do tubo-guia e do escoamento de gases sobre o arrasto podem ser considerados.
- O ângulo de ataque de  $0^\circ$ .



# MODELO MATEMÁTICO

- *Coeficiente de arrasto de atrito ( $Cd_a$ ) – Hoult (2013)*
- *Coeficiente de arrasto de base ( $Cd_b$ ), de pressão ( $Cd_p$ ) e parasita ( $Cd_{pa}$ ) – Niskanen (2013)*
- *Coeficiente de arrasto de interferência ( $Cd_i$ ) – Cannon (2004)*



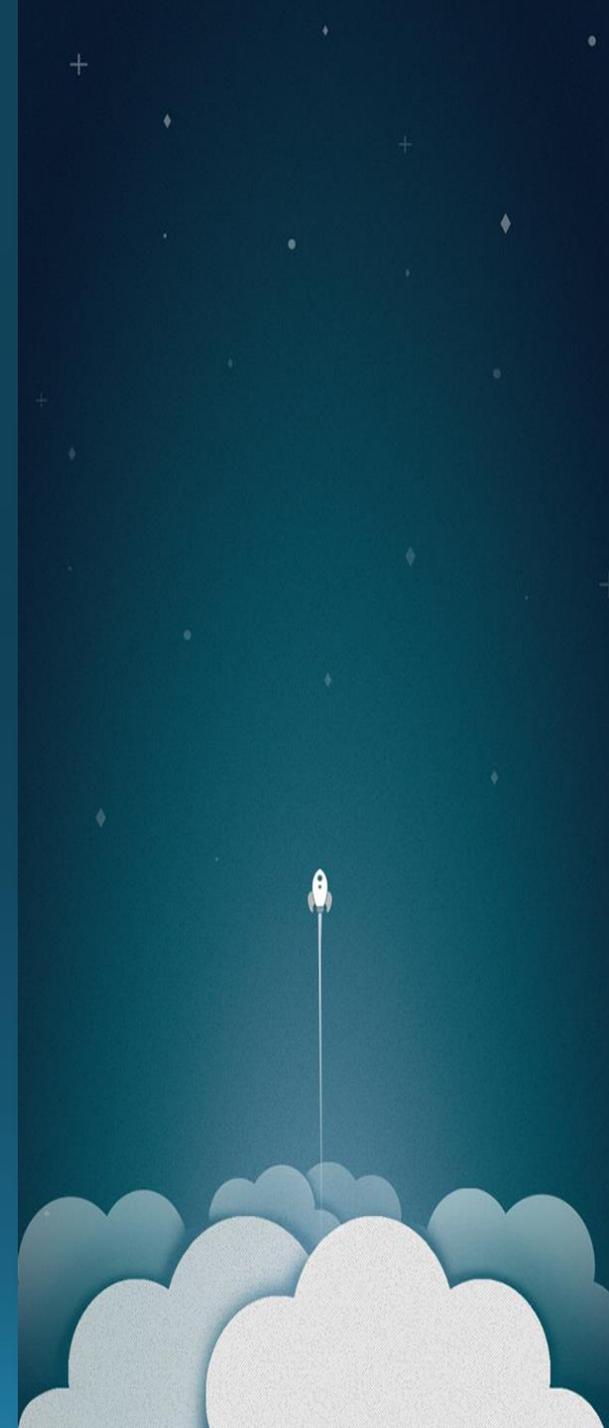
# CD DE ATRITO

$$C_{d_{componente}} = \frac{C_f S_{wet}}{S_{ref}}$$

$$C_f = \left( \frac{1.328}{\sqrt{Re_t}} \right) \cdot \frac{S_{wetl}}{S_{wet}} + \left( \frac{0.471}{(\log(Re_t) - 0.407)^{2.64}} \right) \cdot \left( 1 - \frac{S_{wetl}}{S_{wet}} \right) \cdot C$$

$$C = 1 - 0.09M^2 / C = (1 - 0.15M^2)^{-0.58}$$

$$Re = \frac{V\rho l}{\mu}; \quad M = \frac{V}{340}$$



# CD DE BASE

$$C_{d_{btubo-foguete}} = (0.12 - 0.13M^2) \cdot \frac{S_b}{S_{ref}}$$

$$C_{d_{btubo-foguete}} = \left( \frac{0.25}{M} \right) \cdot \frac{S_b}{S_{ref}}$$

$$C_{d_{bempenas}} = (0.5 \text{ ou } 1.0) \cdot C_{d_{btubo-foguete}}$$



# CD DE PRESSÃO

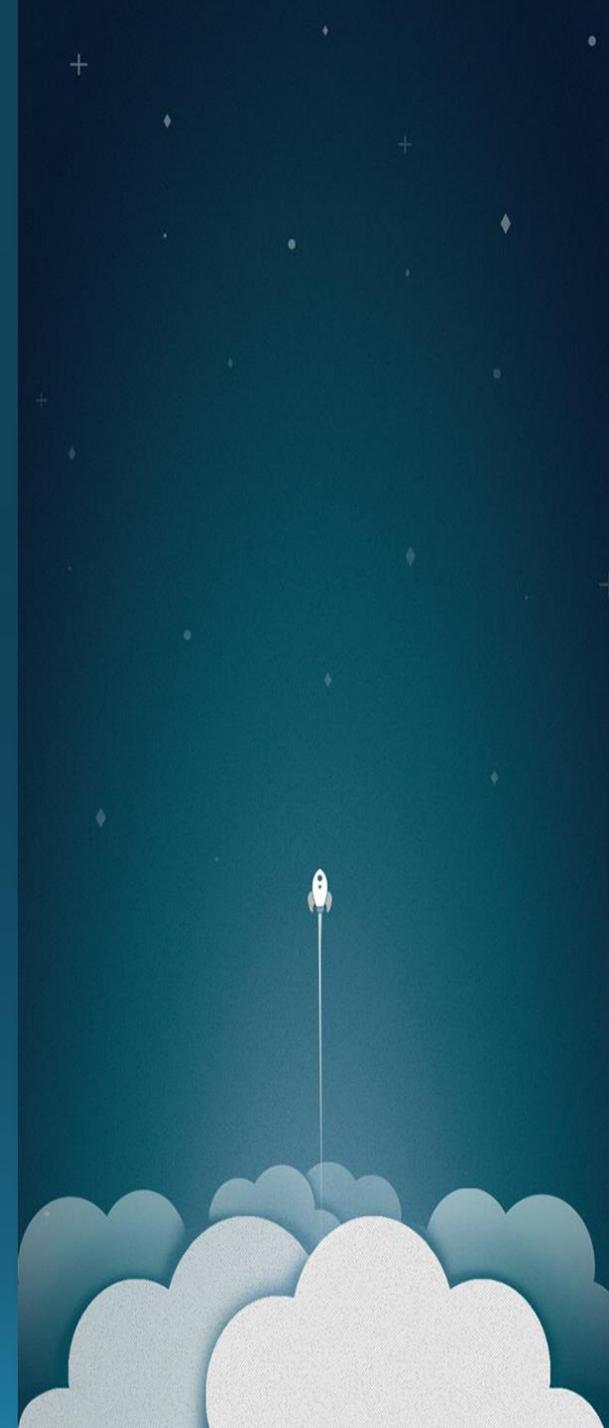
$$C_{d_{pnariz}} = 0.8(\sin\phi)^2 \cdot \frac{S_{wet}}{S_{ref}}$$

$$C_{d_{pnariz}} = 1.0 \sin \phi \cdot \frac{S_{wet}}{S_{ref}}$$

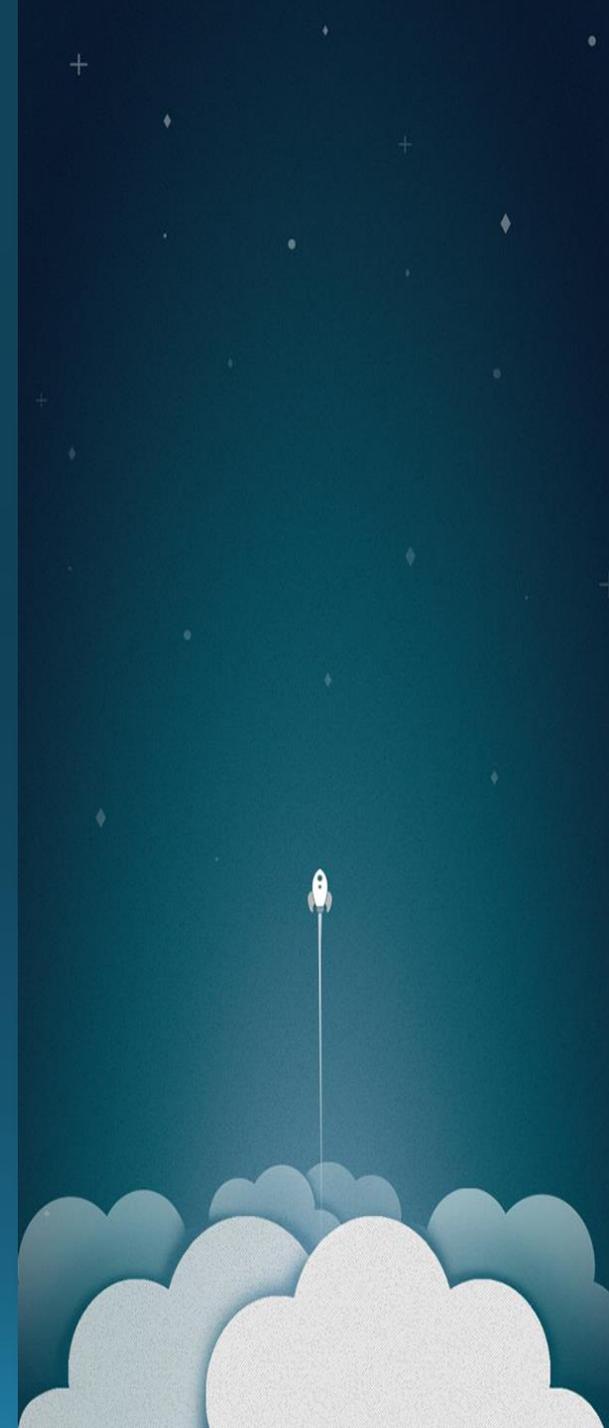
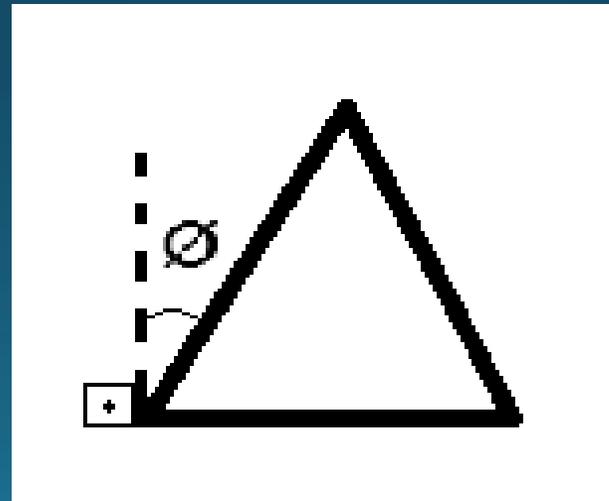
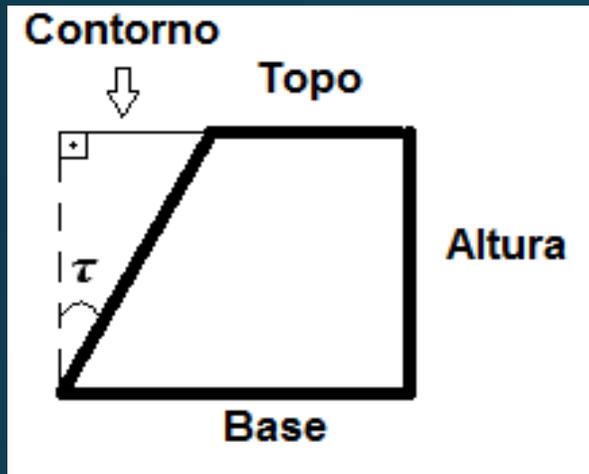
$$C_{d_{pnariz}} = \left( 2.1(\sin \phi)^2 - \frac{0.5 \sin \phi}{\sqrt{M^2 - 1}} \right) \cdot \frac{S_{wet}}{S_{ref}}$$

$$C_{d_{pempenas}} = [(1 - M^2)^{-0.417} - 1] \cdot (\cos\tau)^2 \cdot \left( \frac{S_{wet}}{S_{ref}} \right) \text{ (arredondado)}$$

$$C_{d_{pempenas}} = 0.85 \cdot \left[ 1 + \frac{M^2}{4} + \frac{M^4}{40} \right] \cdot (\cos\tau)^2 \cdot \left( \frac{S_{wet}}{S_{ref}} \right) \text{ (quadrado)}$$

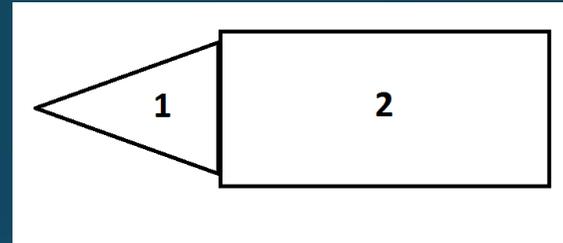


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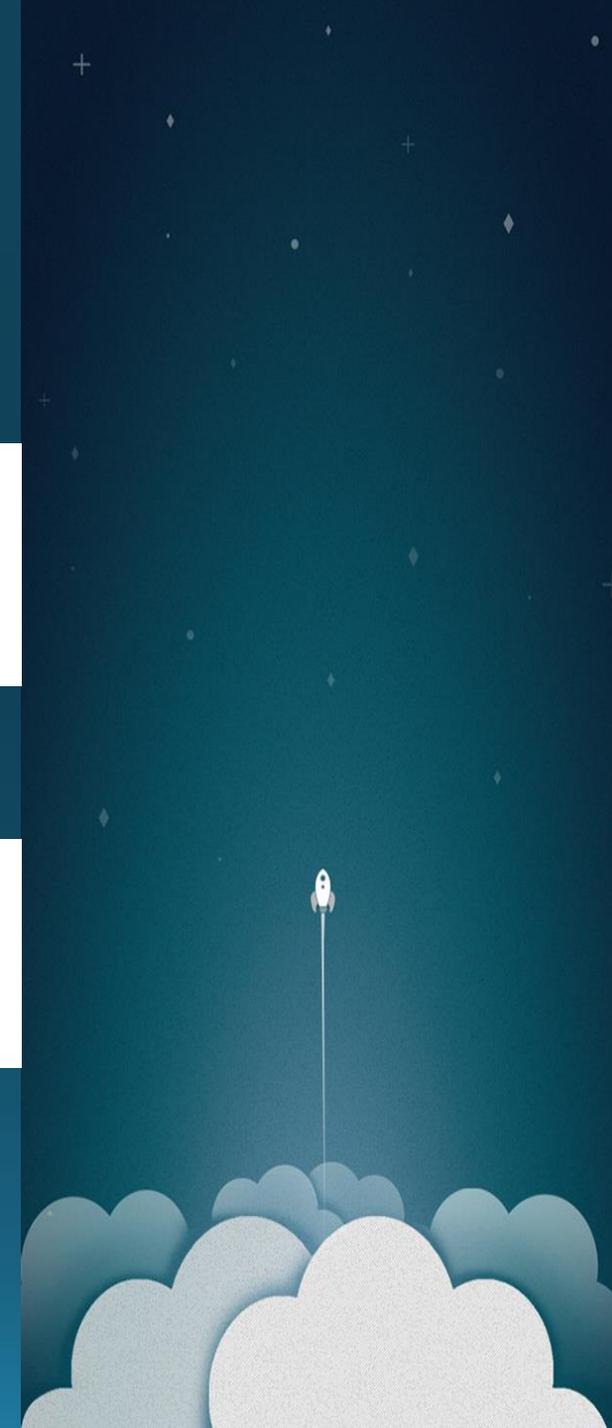
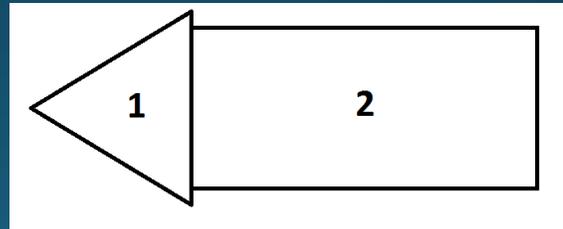


# CD DEVIDO À VARIAÇÃO DE SEÇÃO

$$1. \quad C_{d_{vs}} = \left[ 0.85 \left( 1 + \frac{M^2}{4} + \frac{M^4}{40} \right) \left( \frac{S_2 - S_1}{S_{ref}} \right) \right]$$



$$2. \quad C_{d_{vs}} = C_{d_{base}} \left( \frac{S_1 - S_2}{S_{ref}} \right)$$



# CD DE INTERFERÊNCIA

$$Cd_i = C_{fe} \cdot \frac{D_c R_c N}{S_{ref}} \cdot \left( 1 + 2 \cdot \frac{e}{\bar{c}} \right)$$



# CD PARASITA

$$C_{d_{pa}} = \left[ 0.85 \left( 1 + \frac{M^2}{4} + \frac{M^4}{40} \right) \cdot \max(A, 1) \right] \cdot (St_e - St_i \cdot \max(B, 0))$$

$$A = 1.3 - 0.3 \cdot \left( \frac{Ltb}{Detb} \right); \quad B = 1.0 - \left( \frac{Ltb}{Detb} \right)$$



# CD TOTAL

$$Cd = (Cd_a + Cd_b + Cd_p + Cd_i + Cd_{pa} + Cd_{vs})1.05$$

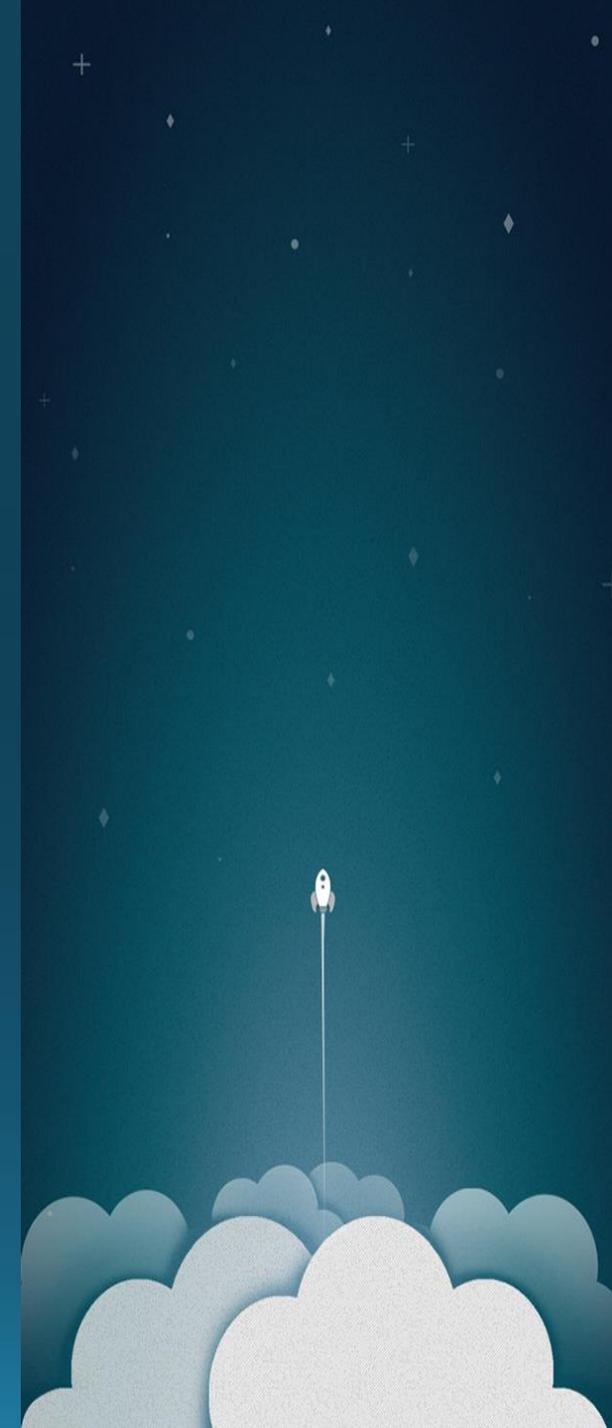
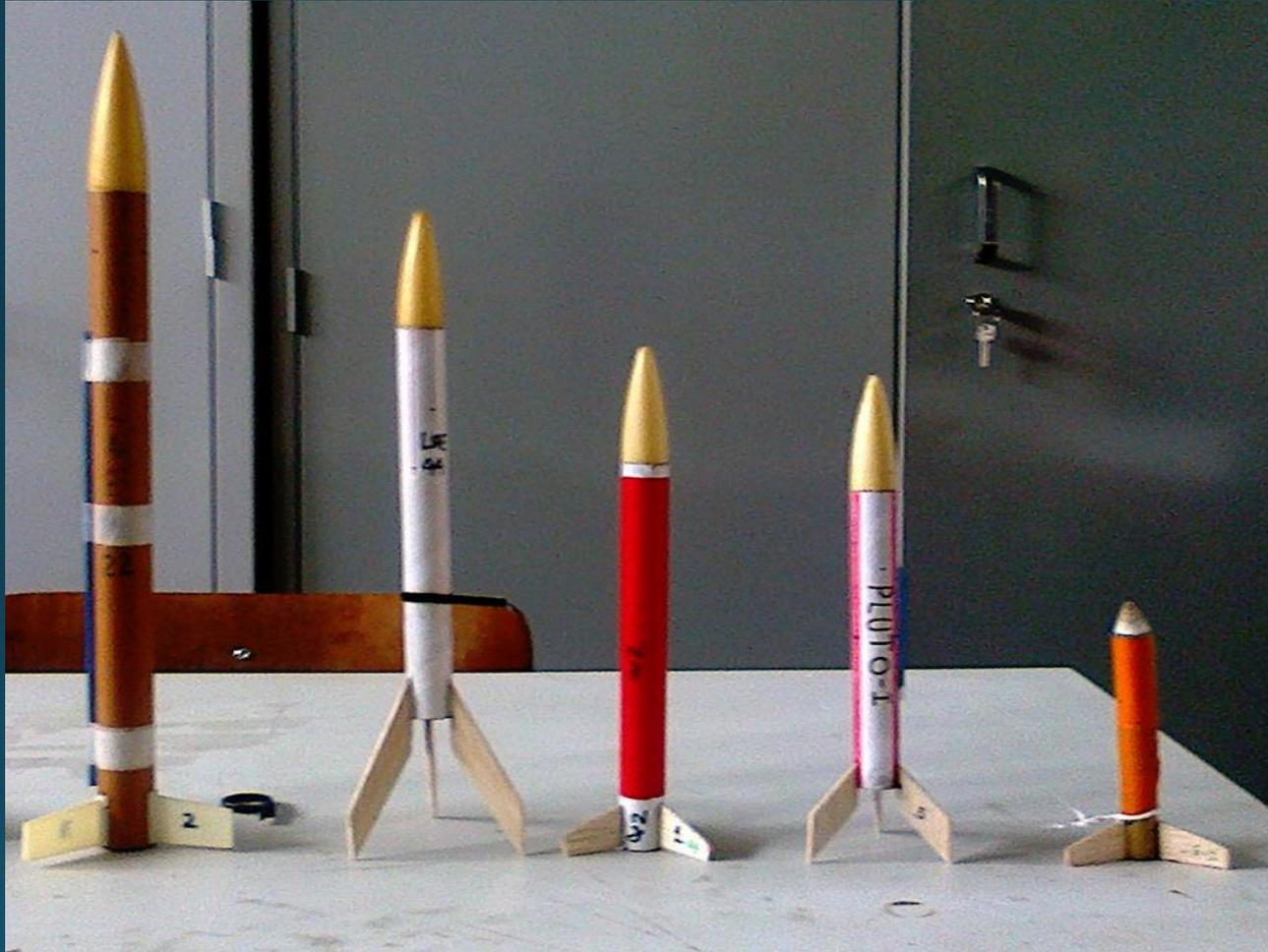


# RESULTADOS

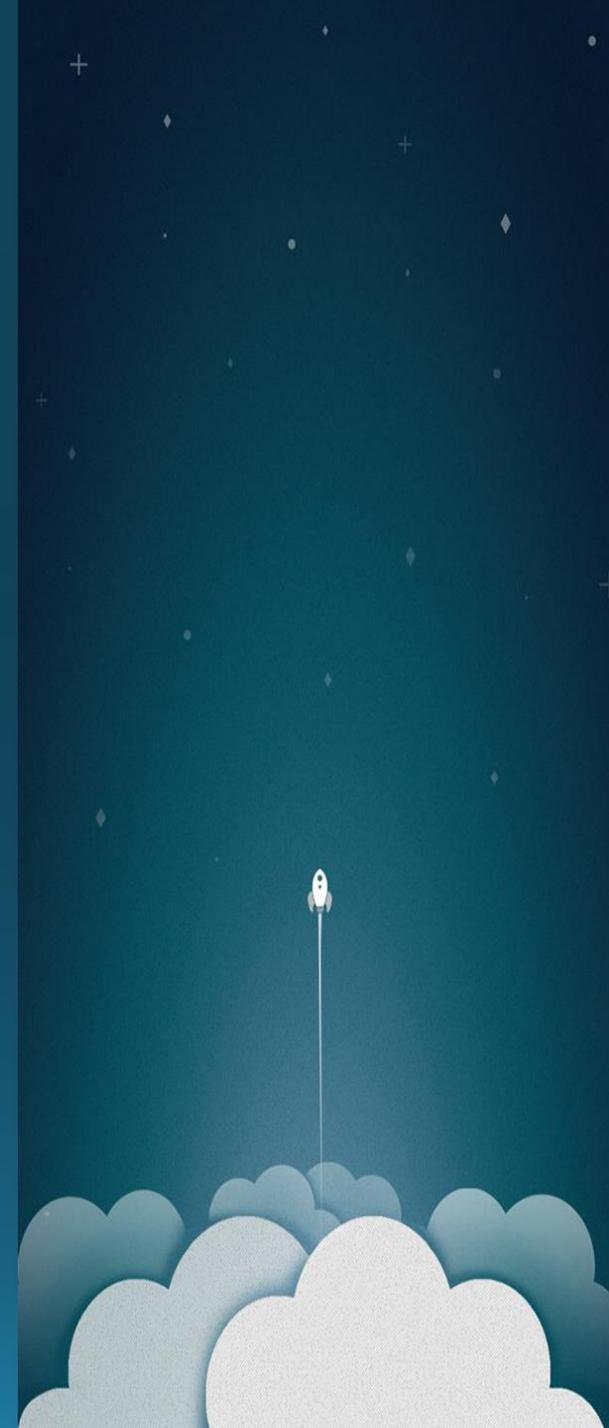
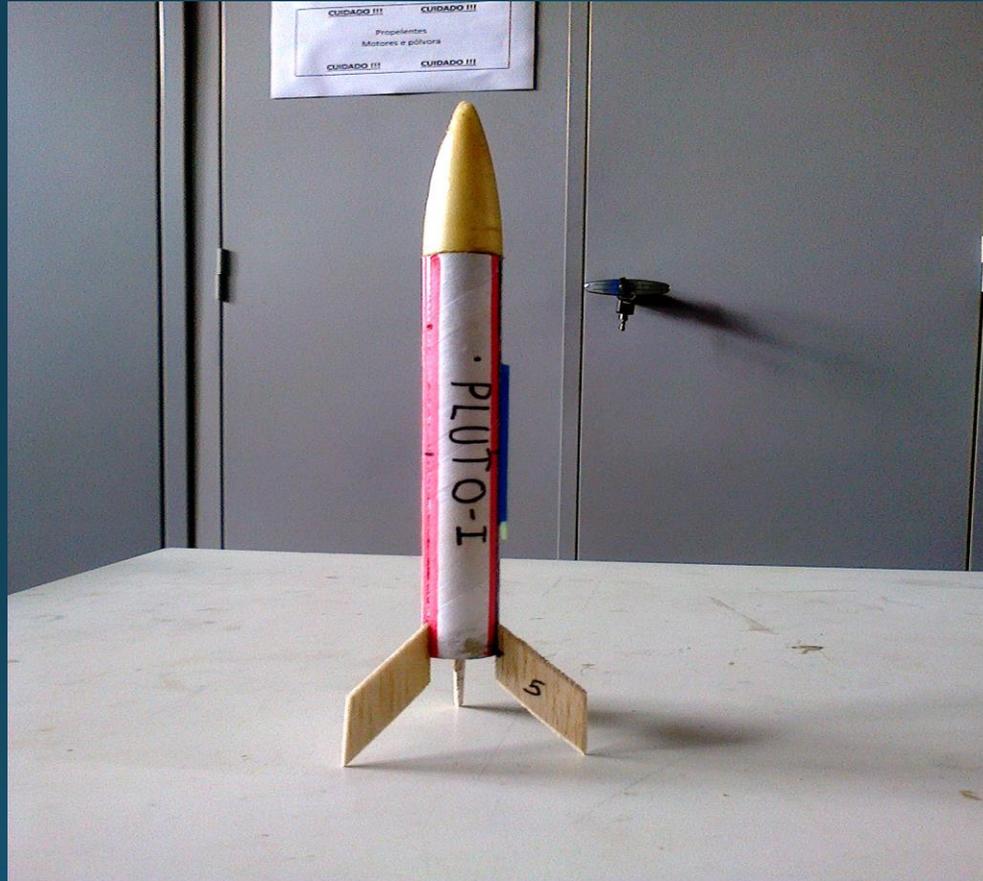
Minifoguete	Apogeu real	Apogeu Rocksim	Apogeu OpenRocket	Apogeu trajetória1p1
LAE - 44	318	502,9	349	272,5
Pluto -1	91,1	107,0	90,8	90,24
Alfa - 2	44,5	55,6	47,8	45,57
Alfa - 6	121,1	161,1	114,0	110,1
LAE - 22	159,1	209,6	178,0	173,1



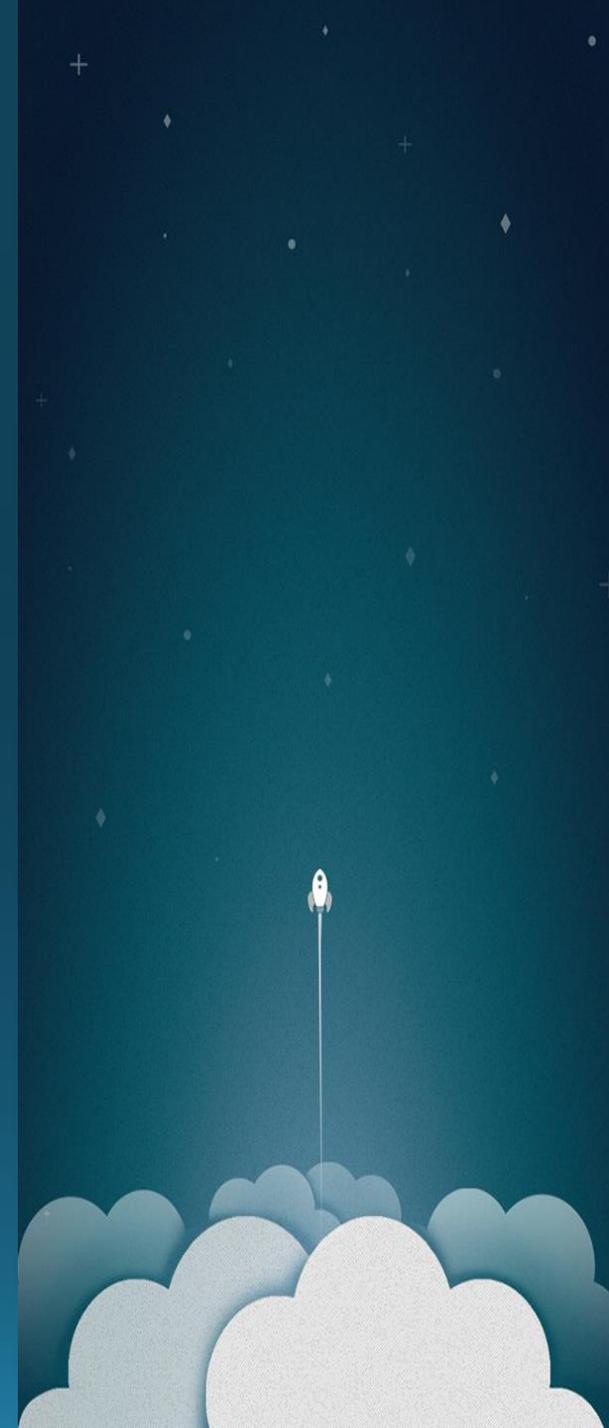
# RESULTADOS



# EXEMPLOS



# EXEMPLOS



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