High-Altitude Balloons on Mars

Aleksander Knutsen

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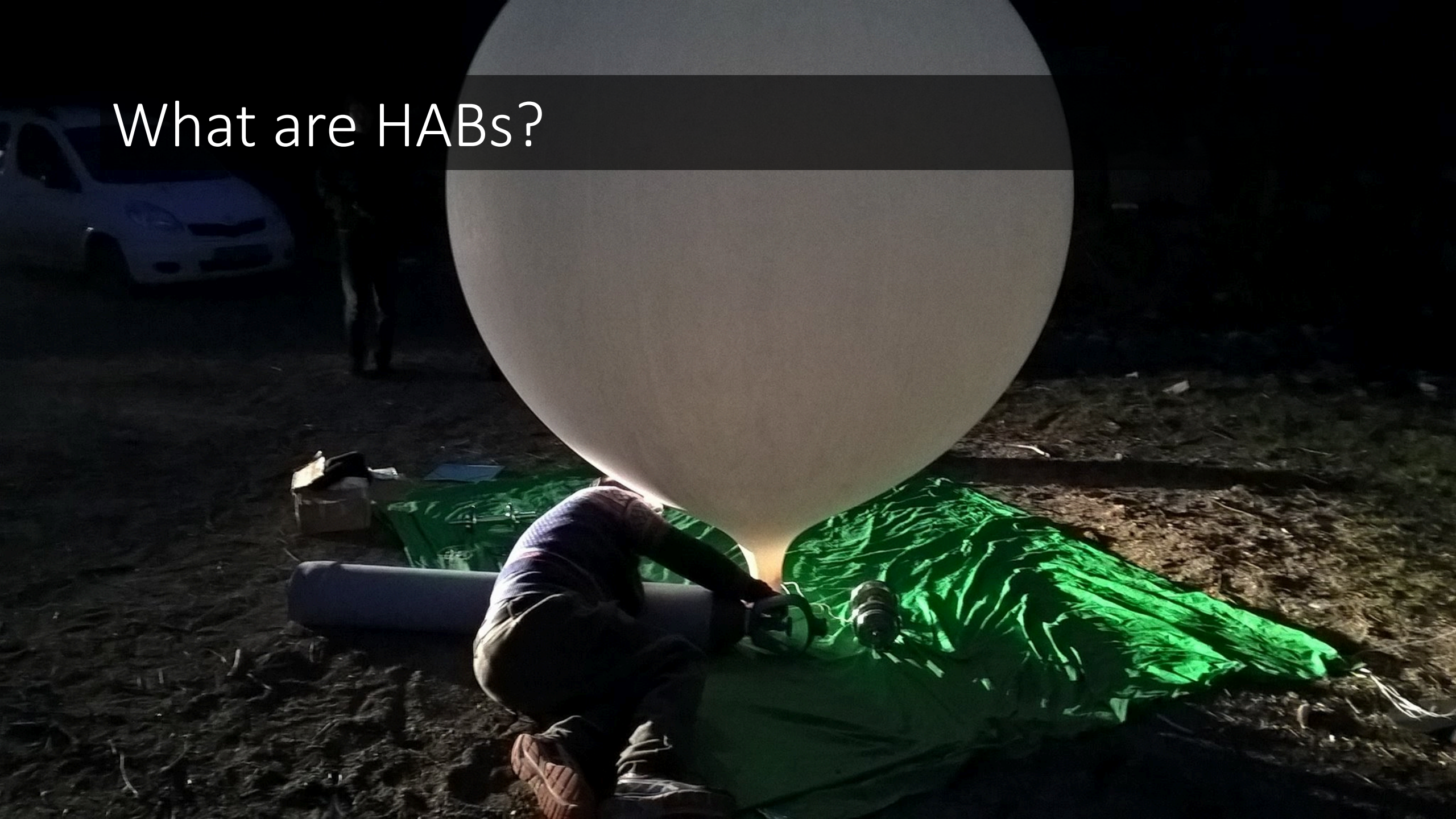
What are HABs?



Using HABs on Mars

- Will it lift?
- Necessary amount of gas
- Altitude
- Duration of flight
- Size of parachute

Will it lift?

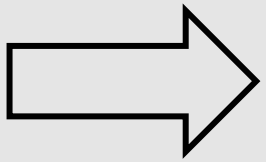
FINDING THE DENSITIES

$$PV = nR_g T$$

Ideal gas law

$$\rho = m/V$$

Definition of density



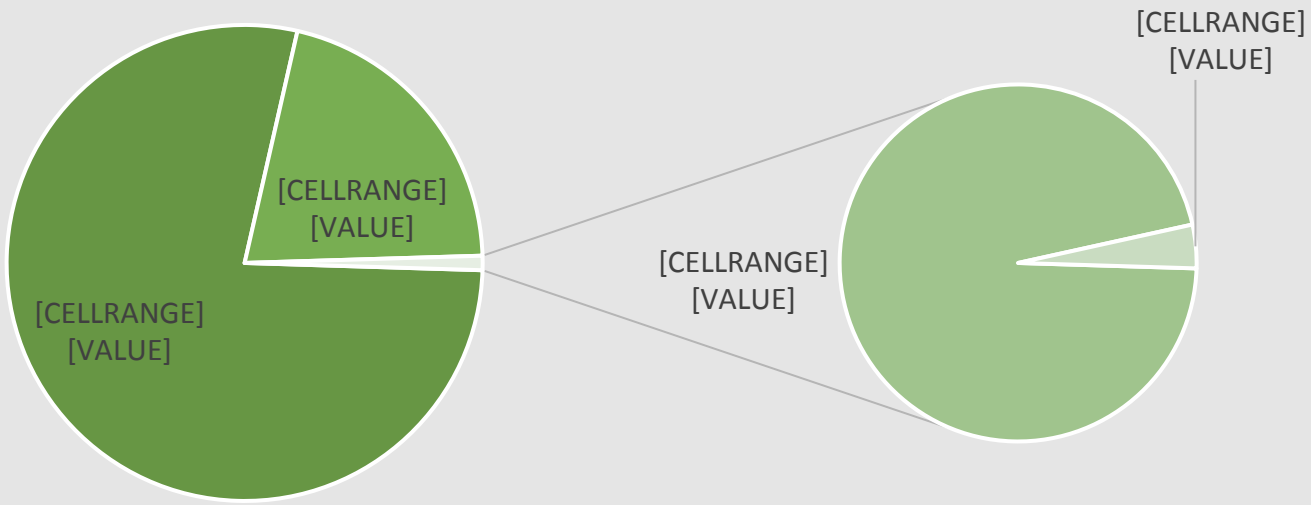
$$\boldsymbol{\rho = P/RT}$$

$$R = R_g / M = R_g n/m$$

Definition of specific gas constant

Will it lift?

FINDING THE DENSITIES

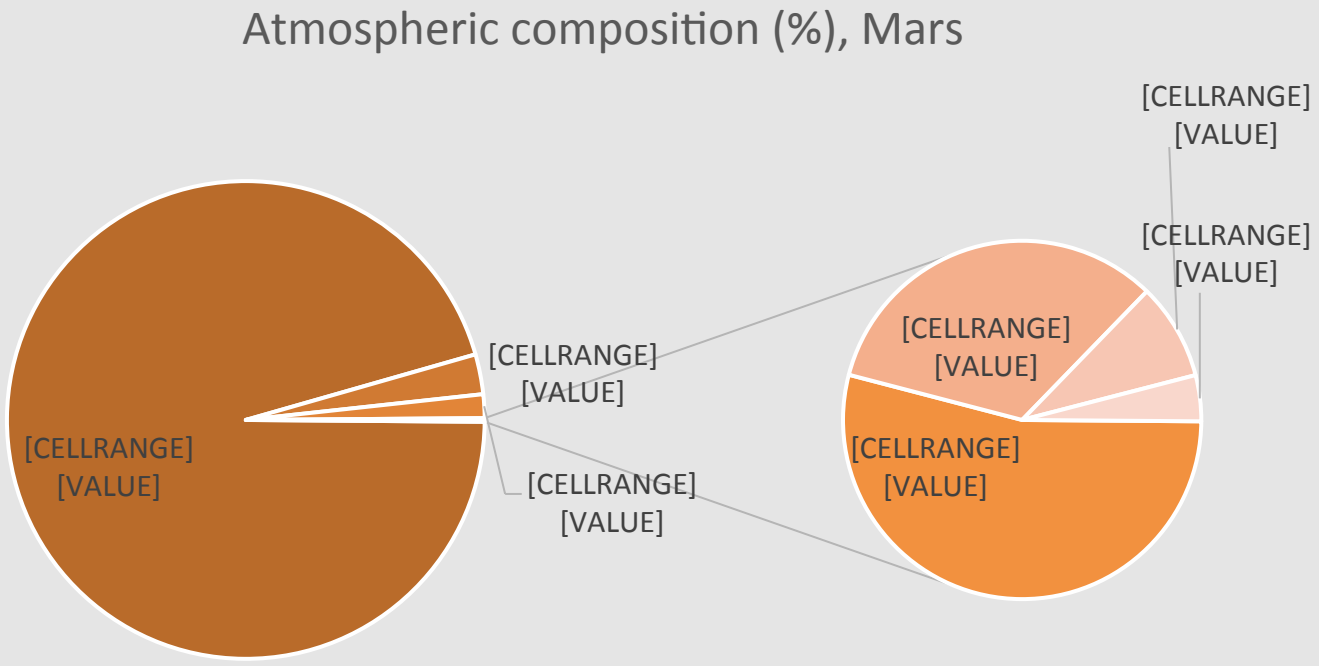


	Molar mass (g/mol)
N_2	28.014
O_2	31.998
Ar	39.948
CO_2	44.009

Source: Grønås, Sigbjørn (2013): *Hvordan klimaet kan endres – en innføring*

Will it lift?

FINDING THE DENSITIES



	Molar mass (g/mol)
CO_2	44.009
N_2	28.014
Ar	39.948
O_2	31.998
CO	28.010
H_2O	24.004
NO	30.006

Source: *https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html*

Will it lift?

FINDING THE DENSITIES

$$M = \sum_{i \in air} p_i M_i \quad \Rightarrow \quad R = R_g / M \quad \Rightarrow \quad \rho = P/RT$$

EARTH

$$\rho_{air} = 1.2251\ kg/m^3$$

$$\rho_{He} = 0.1693\ kg/m^3$$

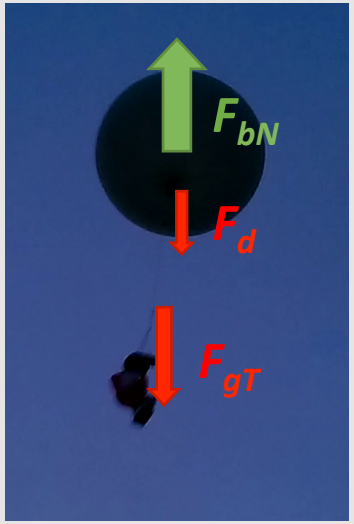
MARS

$$\rho_{air} = 0.0158\ kg/m^3$$

$$\rho_{He} = 0.00146\ kg/m^3$$

Amount of gas

Target ascent rate: ***5 m/s***



$$F_{bN} = Vg(\rho_a - \rho_{He})$$

Net buoyant force

$$F_{gT} = g(m_b + m_p)$$

Gravitational force

$$F_d = 1/2\ C_d\ \rho_a\ v^2\ A$$

Drag force

$$F_{bN} = F_{gT} + F_d$$

Balancing of forces

$$\mathbf{4/3\ \pi r^3\ g(\rho_a - \rho_{He}) = g(m_b + m_p) + 1/2\ C_d\ \rho_a\ v^2\ \pi r^2}$$

Amount of gas

Target ascent rate: ***5 m/s***

EARTH

$r = 0.97\ m$

$V = 3.84\ m^3$

MARS

$r = 3.89\ m$

$V = 246.02\ m^3$

<

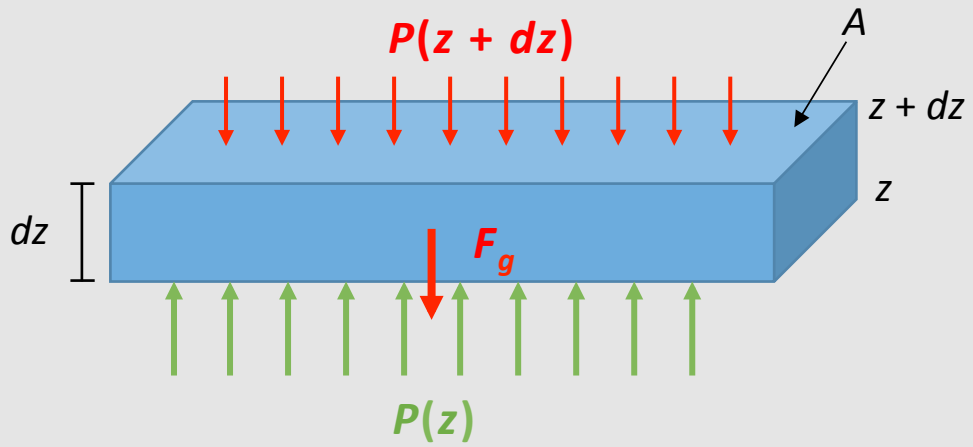
LIMIT

$r = 4.315 m$

$V = 336.54 m$

Maximum altitude

HYDROSTATIC EQUILIBRIUM



$$F\downarrow d + F\downarrow g = F\downarrow u \Rightarrow P(z+dz)A + A\rho\downarrow a\, g dz = P(z)A \Rightarrow P(z+dz) - P(z)/dz = -\rho\downarrow a\, g \Rightarrow dP/dz = -\rho\downarrow a\, g$$

Balance

Write force as area × pressure

Simplify & rearrange

Definition of differentiation

Maximum altitude

HYDROSTATIC EQUILIBRIUM

$$dP/dz = -\rho_a g$$

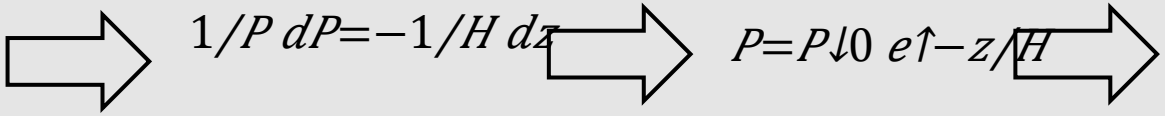
Equation of hydrostatic equilibrium

$$\rho_a = P/RT$$

Air density

$$H = RT/g$$

Scale height



$$1/P\ dP = -1/H\ dz$$

Rearrange & substitute

$$P = P_0\ e^{-z/H}$$

Solve diff.eq.

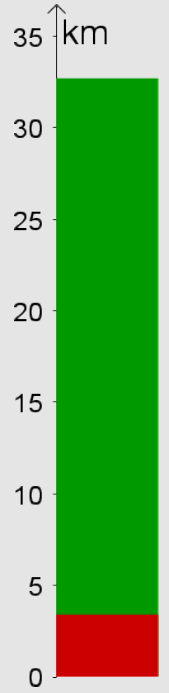
$$\boldsymbol{z = -H \ln(V_0 / V)}$$

Solve for *z* & substitute with ideal gas law

Maximum altitude

$$z{\downarrow}Earth = 32.7\ km$$

$$z{\downarrow}Mars = 3.4\ km$$

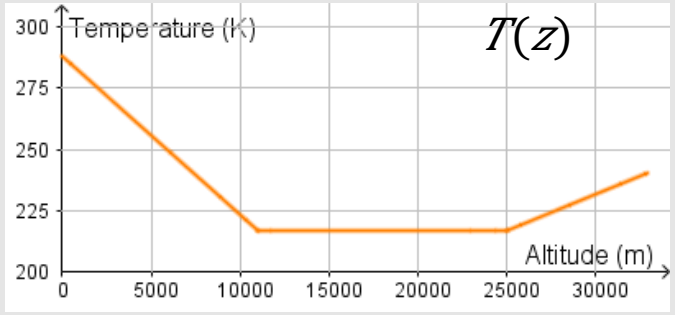


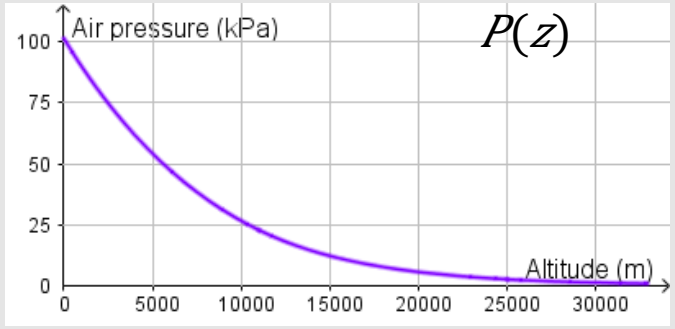
Flight duration

$$t = t_a + t_d = z/v_a + z/v_d$$

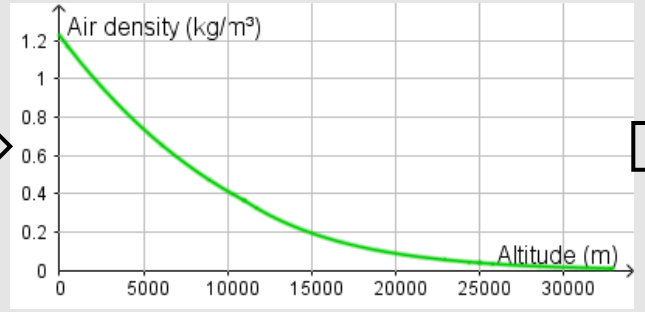
Flight duration

EARTH

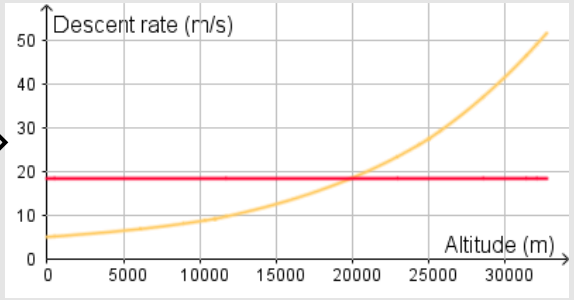




$$\rho_a(z) = P(z)/RT(z)$$



$$v(z) = \sqrt{2mg/C_d A\rho_a(z)}$$



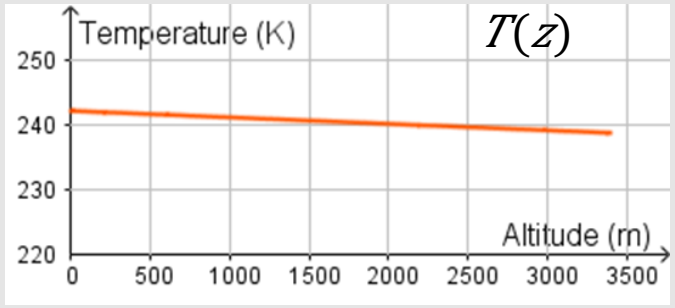
$$v = \int_0^{z_{max}} v(z)dz \,/ z_{max}$$

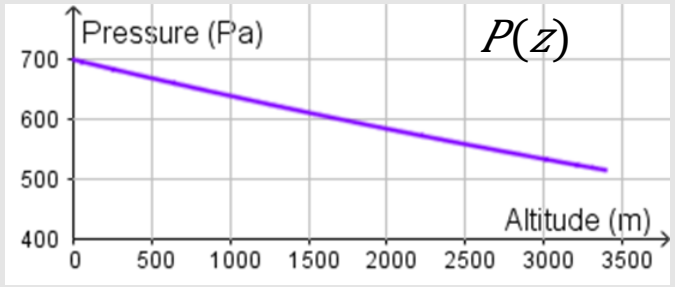
$$\boldsymbol{v = 18.38\ m/s}$$

Source: https://www.grc.nasa.gov/www/k-12/airplane/atmosmet.html

Flight duration

MARS





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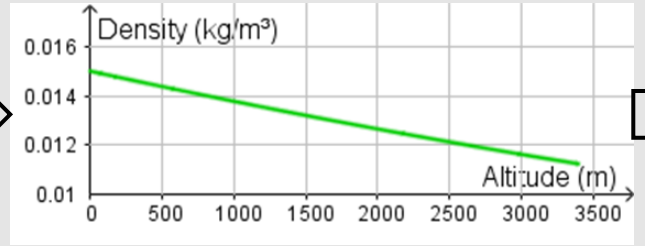

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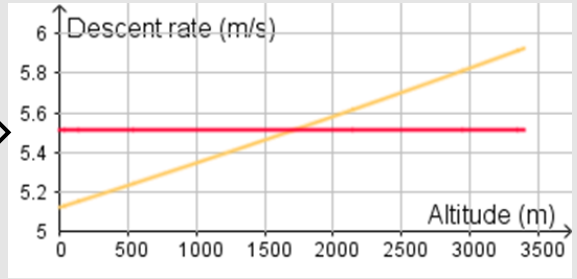
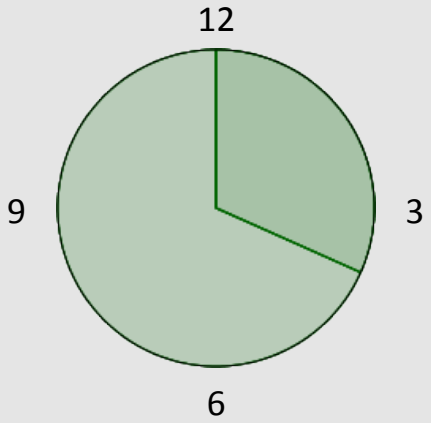


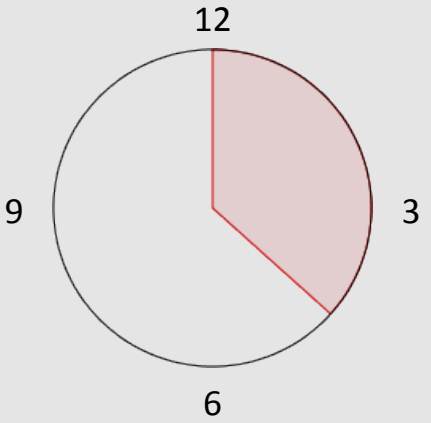
$$v = \int_0^{z_{max}} v(z)dz \,/ z_{max}$$

$$\boldsymbol{v = 5.51\ m/s}$$

Source: https://www.grc.nasa.gov/www/k-12/airplane/atmosmrm.html

Flight duration





	Earth	Mars
Ascent	1h 49min	12min
Descent	30min	10min
TOTAL	***2h 19min***	***22min***

Size of parachute

$$A=2mg/C_d \rho_a v^2$$

$$r_{Earth}=0.58m$$

$$r_{Mars}=3.15m$$

Summary so far

	EARTH	MARS	Difference
Will it lift?	✓	✓	-
Necessary amount of gas	3.84 m^3	246.02 m^3	64x
Altitude	32.7 km	3.4 km	9.6x
Flight duration	2 h 19 min	22 min	6.3x
Size of parachute	1.06 m^2	31.19 m^2	29.4x

Team members (left to right): **Alexander William Brandal**, **Aleksander Knutsen**, **Per Verås** (mentor), **Teodor Larsen Tveit**