The Physics of Freefalling in Freediving

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Don’t panic!

$$F_{total} = F_B + F_G + F_D = mg - C_B \left(V_{diver} + V_{tlc} \frac{10[m]}{d+10[m]} \right) - C_R v|v|$$

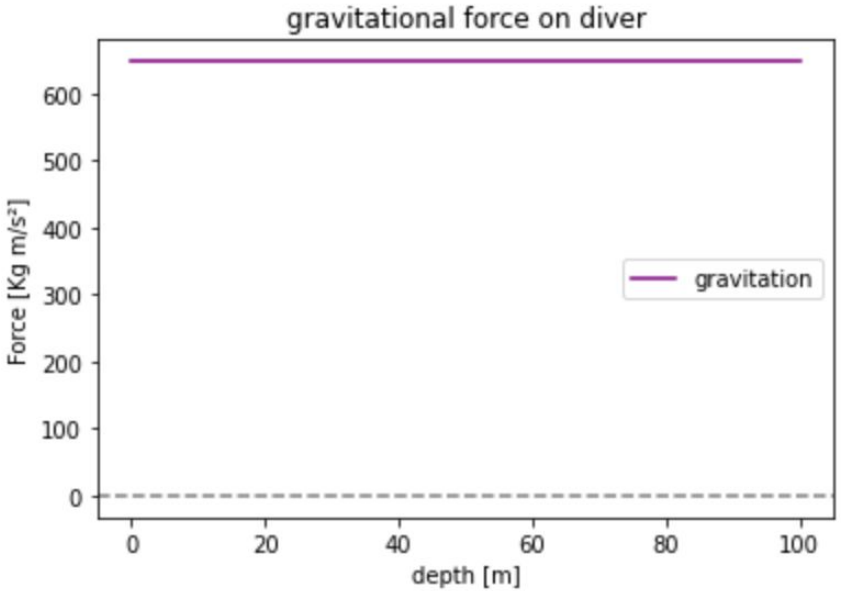
Model diver and physical constants

```
# Physical constants
rho = 1023.6                # kg/m³ density of saline water
g = 9.807                   # m/s²  gravitational acceleration on earth

# Assumptions about diver
V_diver = 0.062             # m³    volume of diver   source [11]
V_tlc = 0.006               # m³    total lung capacity  source [2]
m = 66                      # Kg    weight of diver
A = 0.07                    # m²    crossectional area of diver in diving direction   source: [5]
C_D = 0.3                   # -     Drag coefficient   source: [4]
```

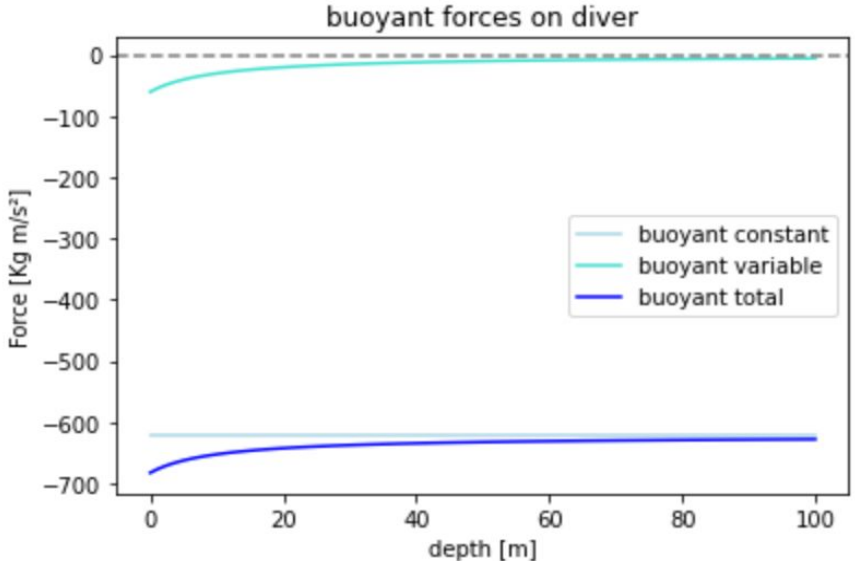
Gravitational force

$$F_G = mg$$



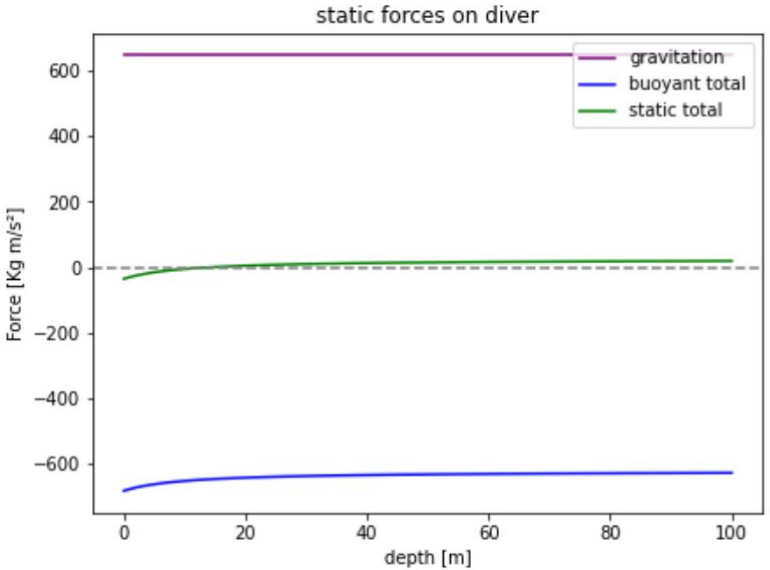
Buoyant force

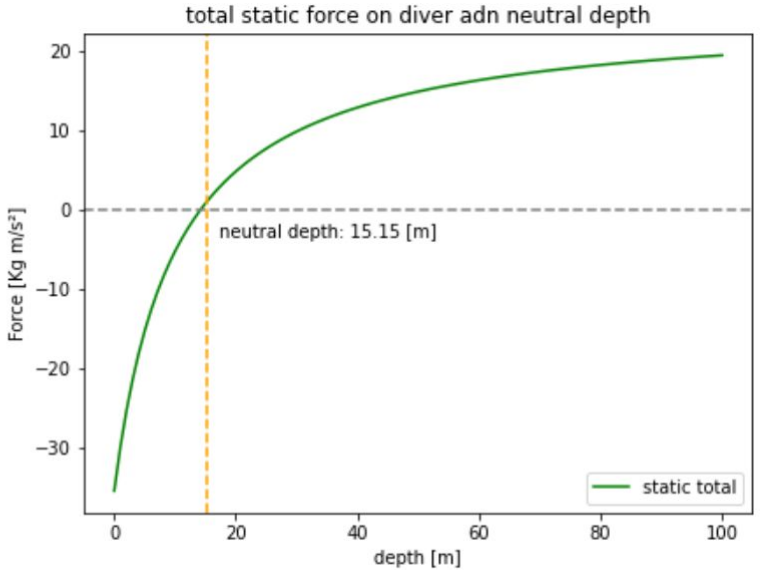
$$F_B = \underbrace{-C_B V_{diver}}_{constant} - \underbrace{C_B V_{tlc} \frac{10[m]}{d+10[m]})}_{variable}$$



Static forces (buoyancy and gravitation)

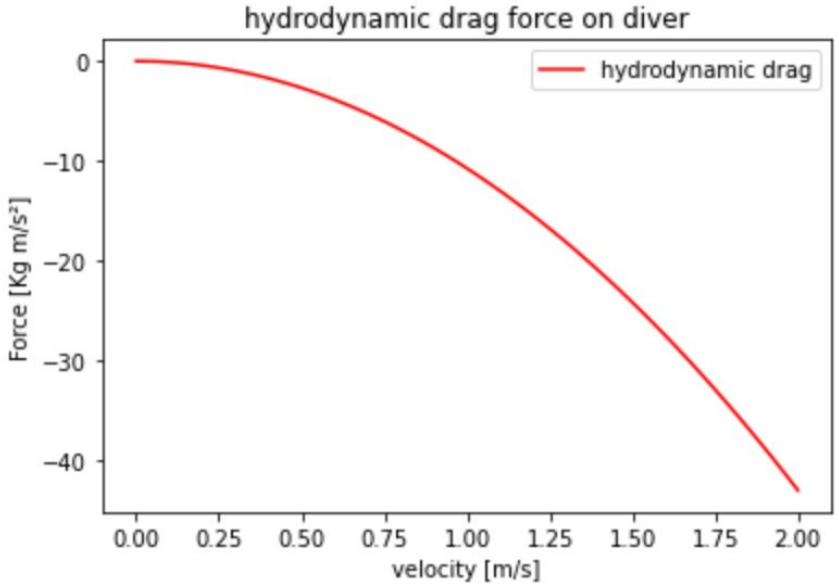
$$F_{static} = F_B + F_G = \underbrace{-C_B \left(V_{diver} + V_{tlc} \frac{d+10[m]}{10[m]} \right)}_{\text{buoyant}} + \underbrace{mg}_{\text{gravitation}}$$





Hydrodynamic drag

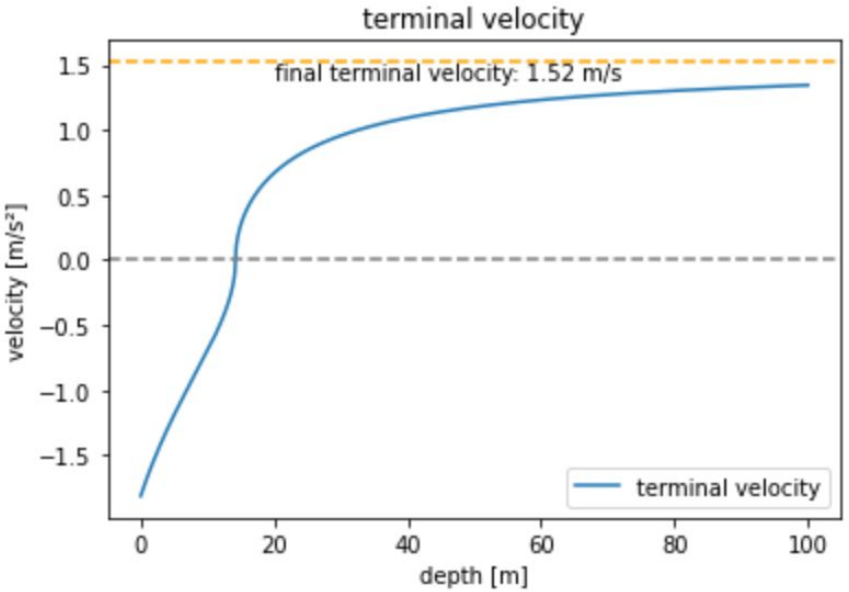
$$F_D = -C_R v|v| \qquad \text{with } C_R = \frac{1}{2}\rho C_D A$$



Terminal velocity

$$v_t = \sqrt{\frac{mg - C_B\left(V_{diver} + V_{tlc}\frac{10[m]}{d+10[m]}\right)}{C_R}}$$

$$v_T = \sqrt{\frac{mg - C_B V_{diver}}{C_R}}$$



Freefall equation

$$F_{total} = F_B + F_G + F_D = mg - C_B \left(V_{diver} + V_{tlc} \frac{10[m]}{d+10[m]} \right) - C_R v|v|$$

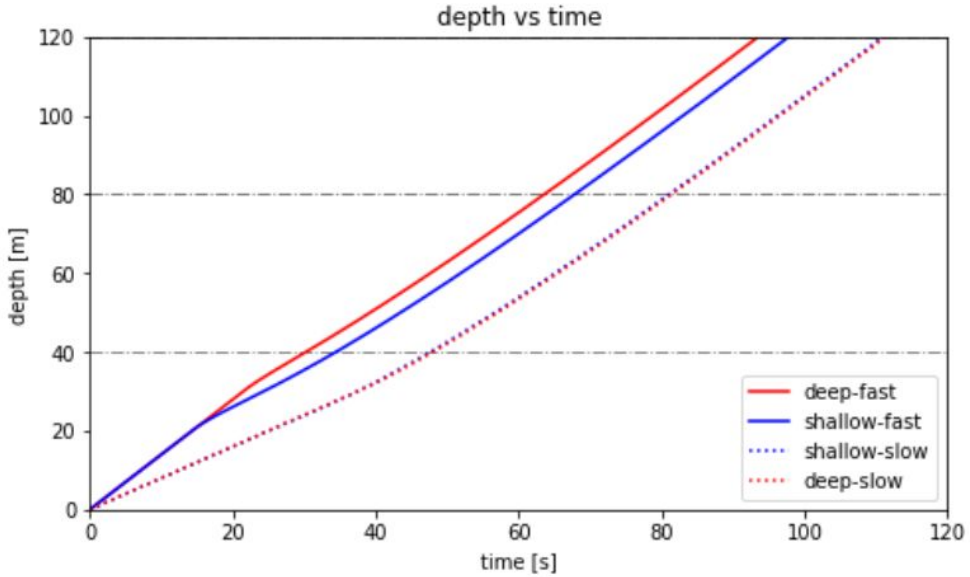
Scenarios

	Start depth [m]	Initial velocity [m/s]
Shallow - fast	20	1.4
Shallow - slow	20	0.8
Deep - fast	30	1.4
Seep - slow	30	0.8

Assumptions:

- Diver swims to start depth with constant speed
- Alignment and body position doesn’t change during freefall

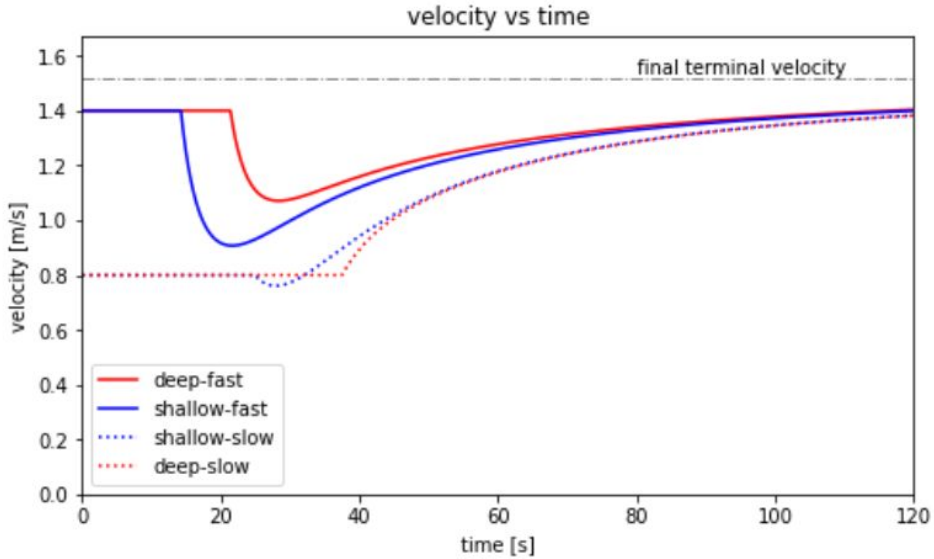
Total dive time



	40	80	120
deep-fast	30	64	94
shallow-fast	34	68	98
shallow-slow	48	81	111
deep-slow	48	81	111
Slowest vs fastest:	18s	17s	17s

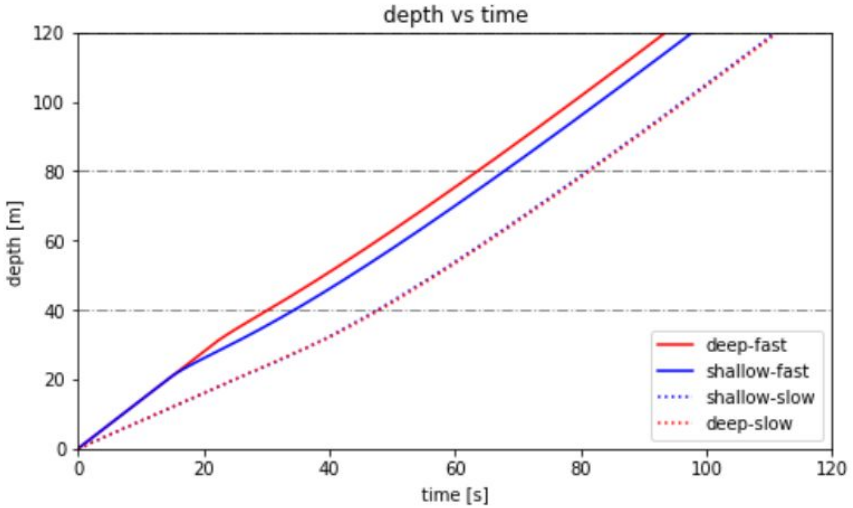
- The difference in dive time is explained only by what happens during the first 40m

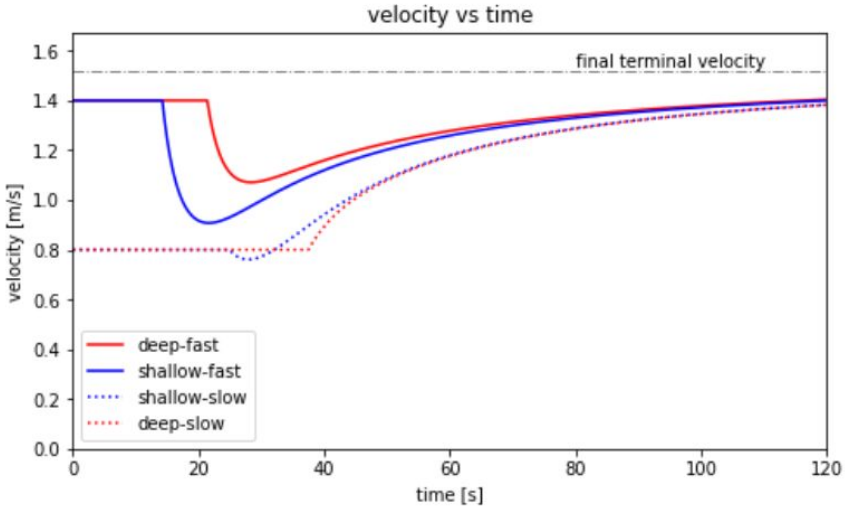
Terminal velocity



- terminal velocity is reached shortly after starting the freefall.
- A diver with a low initial velocity will reach terminal velocity aster than a diver with a high one.
- The higher the difference between the initial and terminal velocity, the faster the diver will slow down after starting the freefall.

Start depth and velocity





- Initial velocity has a much larger impact on the difference between scenarios than starting depth
- Starting depth has more impact at fast initial velocities

Conclusions

- Terminal velocity dominates the freefall
- The phase before freefall determines the time difference between scenarios.
- Initial velocity has a greater impact on time difference than starting depth after a certain point
- For deeper dives (past 40m) alignment, body position, and smoothness become the critical factors

Recommendations

- Define desired velocity
- Calculate/test target depth where terminal velocity reaches desired velocity,
- Swim down not not too slow.
- Start freefalling at target (variation depending on preference)
- Optimize alignment and body position during freefall

Try it yourself

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