Helicopter Engineering Tutorial

Mission calculation

Mission calculation

You have designed a helicopter which has to comply with the following mission profile.

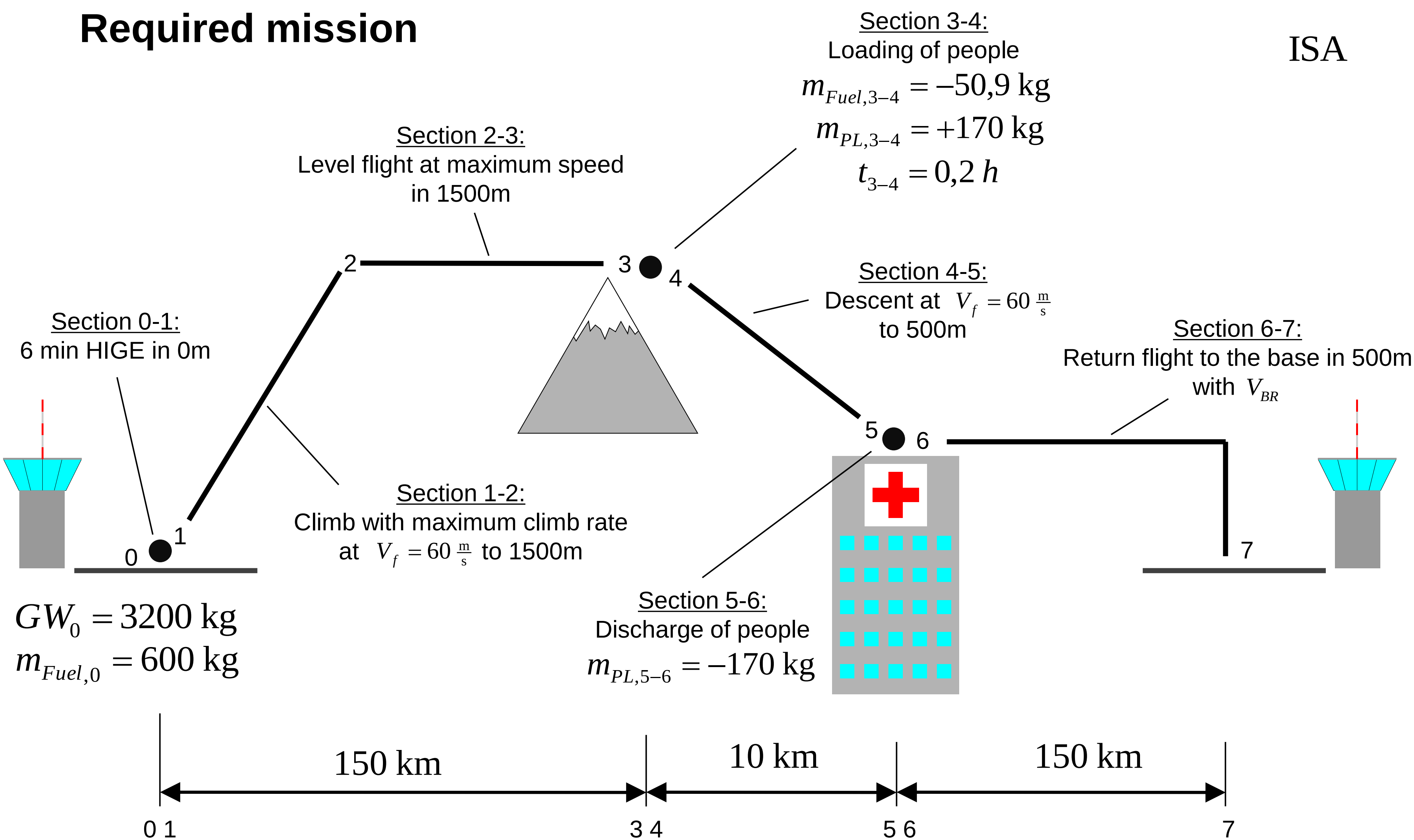
Is this possible if your helicopter starts with full tanks at a maximum take off mass? $m_{Fuel} = 600\ \mathrm{kg}$ $MTOW = 3200\ \mathrm{kg}$

Calculate the single periods of the flight, each with the mass the helicopter features at the begin of the section.

Assume a constant $SFC = 0{,}4\ \frac{\mathrm{kg}}{\mathrm{kWh}}$.

Sketch the progression of flight mass, consumed fuel and covered distance vs the endurance.

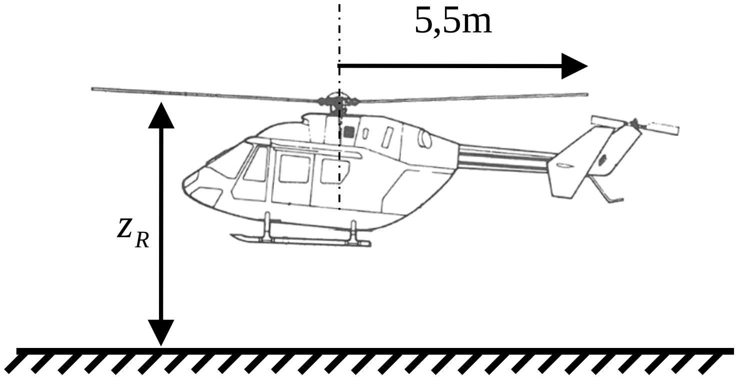
Required mission



1. Section 0-1: 6 min HIGE in 0m ISA

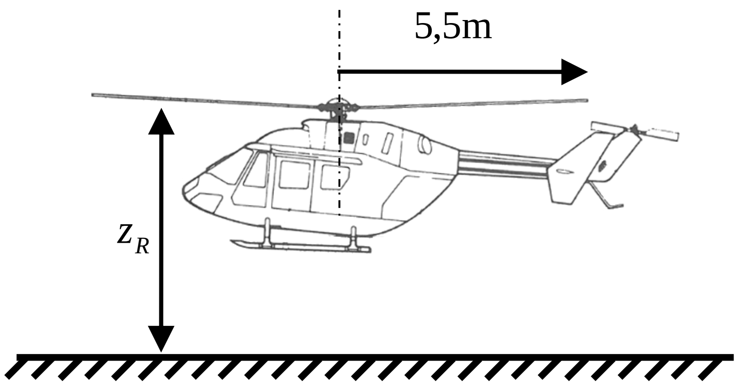
The helicopter hovers with the rotor $z_R = 4{,}5\,\mathrm{m}$ above the ground.
The fuseIage download factor amounts to $k_{DL} = 4\%$, $\kappa = 1{,}15$
Following power components are known:

$$P_0 = 128\,\mathrm{kW}$$
$$P_{TR} = 46\,\mathrm{kW}$$
$$P_{tl} = 10\,\mathrm{kW}$$
$$P_a = 15\,\mathrm{kW}$$



Clue:
Induced Power in ground effect: $P_{i_{ige}} = k_G \cdot P_{i_{oge}}$ $\quad k_G = \dfrac{1}{0{,}9926 + 0{,}0379 \cdot \left(2\frac{R}{z_R}\right)^2}$

Hover in ground effect



Required rotor thrust:

$$T = \frac{GW_0 \cdot g}{1 - k_{DL}} = \frac{3200kg \cdot 9{,}81 \frac{N}{kg}}{1 - 0{,}04} = 32700N$$

Induced power in ground effect:

$$P_{i_{ige}} = k_G \cdot P_{i_{oge}}$$

$$k_G = \frac{1}{0{,}9926 + 0{,}0379 \cdot \left(2 \cdot \frac{5{,}5m}{4{,}5m}\right)^2} = 0{,}82$$

$$P_{i_{ige}} = k_G \cdot \kappa \cdot \frac{T^{\frac{3}{2}}}{\sqrt{2\rho\pi R^2}} = 366\text{kW}$$

Total power requirement:

$$P = P_{i_{ige}} + P_0 + P_{TR} + P_a + P_{tl}$$

$$P = 565\,\text{kW}$$

Fuel mass:

$$m_{Fuel,0-1} = -P \cdot SFC \cdot t_{0-1} = -565\,\text{kW} \cdot 0{,}4 \frac{\text{kg}}{\text{kWh}} \cdot 0{,}1\text{h} = -22{,}6\,\text{kg}$$

Total mass:

$$GW_1 = GW_0 + m_{Fuel,0-1} = 3200\,\text{kg} - 22{,}6\,\text{kg} = 3177{,}4\,\text{kg}$$

2. Section 1-2: Climb to 1500m with maximum climb rate at $V_f = 60\,\frac{\mathrm{m}}{\mathrm{s}}$

Calculate the maximum climb rate for the helicopter at $V_f = 60\,\frac{\mathrm{m}}{\mathrm{s}}$.

The available power is $P_{av} = 670\,\mathrm{kW}$, the rotor radius $R = 5{,}5\,\mathrm{m}$.

The drag areas for the basic helicopter are $(C_D S)_{\mathrm{Basic}} = 1{,}25\,\mathrm{m}^2$,
as well as the mounted rescue hoist $(C_D S)_{\mathrm{RescueHoist}} = 0{,}2\,\mathrm{m}^2$.

Calculate the power in the average altitude ($H = 750\,\mathrm{m}$) $\rho = 1{,}139\,\frac{\mathrm{kg}}{\mathrm{m}^3}$
with the flight mass at the beginning of the Section.

The climb rate is small compared to V_f, the propulsion component of the thrust can be neglected.

Determine also the covered distance d_2.

The following power components are known ($\kappa = 1{,}15$) :

$$P_0 = 160\,\mathrm{kW}$$
$$P_{TR} = 27\,\mathrm{kW}$$
$$P_{tl} = 13\,\mathrm{kW}$$
$$P_a = 15\,\mathrm{kW}$$

Maximum climb rate

Induced power:

$$T = GW_1 \cdot g = 31170\,N$$

$$v_i = \frac{T}{2\rho A V_f} = 2{,}40\,\tfrac{\mathrm{m}}{\mathrm{s}}$$

$$P_i = \kappa \cdot T \cdot v_i$$
$$= 86\,\mathrm{kW}$$

Parasite power:

$$P_p = \frac{1}{2} \cdot \rho \cdot V_f^3 \cdot C_D S$$
$$P_p = 178\,\mathrm{kW}$$

$$C_D S = \left(C_D S\right)_{\mathrm{Basic}} + \left(C_D S\right)_{\mathrm{RescueHoist}} = 1{,}45\,\mathrm{m}^2$$

Available climb power:

$$P_{C_{\max}} = P_{av} - P_i - P_0 - P_p - P_{TR} - P_a - P_{tl}$$
$$P_{C_{\max}} = 192\,\mathrm{kW}$$

Maximum climb rate

Maximum climb rate $GW_1 \cdot g = 31170\,N$ $P_{C_{\max}} = 192\,\text{kW}$

$$V_{C_{\max}} = \frac{P_{C_{\max}}}{GW_1 \cdot g} = 6{,}2\,\tfrac{\text{m}}{\text{s}}$$

Climb duration

$$t_{1-2} = \frac{1500\,\text{m}}{6{,}2\,\frac{\text{m}}{s}} = 4{,}03\,\text{min} = 0{,}067\,\text{h}$$

Fuel mass

$$m_{Fuel,1-2} = -P_{av} \cdot SFC \cdot t_{1-2} = -670\,\text{kW} \cdot 0{,}4\,\tfrac{\text{kg}}{\text{kWh}} \cdot 0{,}067\,\text{h} = -18{,}0\,\text{kg}$$

Total mass

$$GW_2 = GW_1 + m_{Fuel,1-2} = 3177{,}4\,\text{kg} - 18\,\text{kg} = 3159{,}4\,\text{kg}$$

Distance

$$d_2 = t_{1-2} \cdot 60\,\tfrac{\text{m}}{\text{s}} = 14{,}47\,\text{km}$$

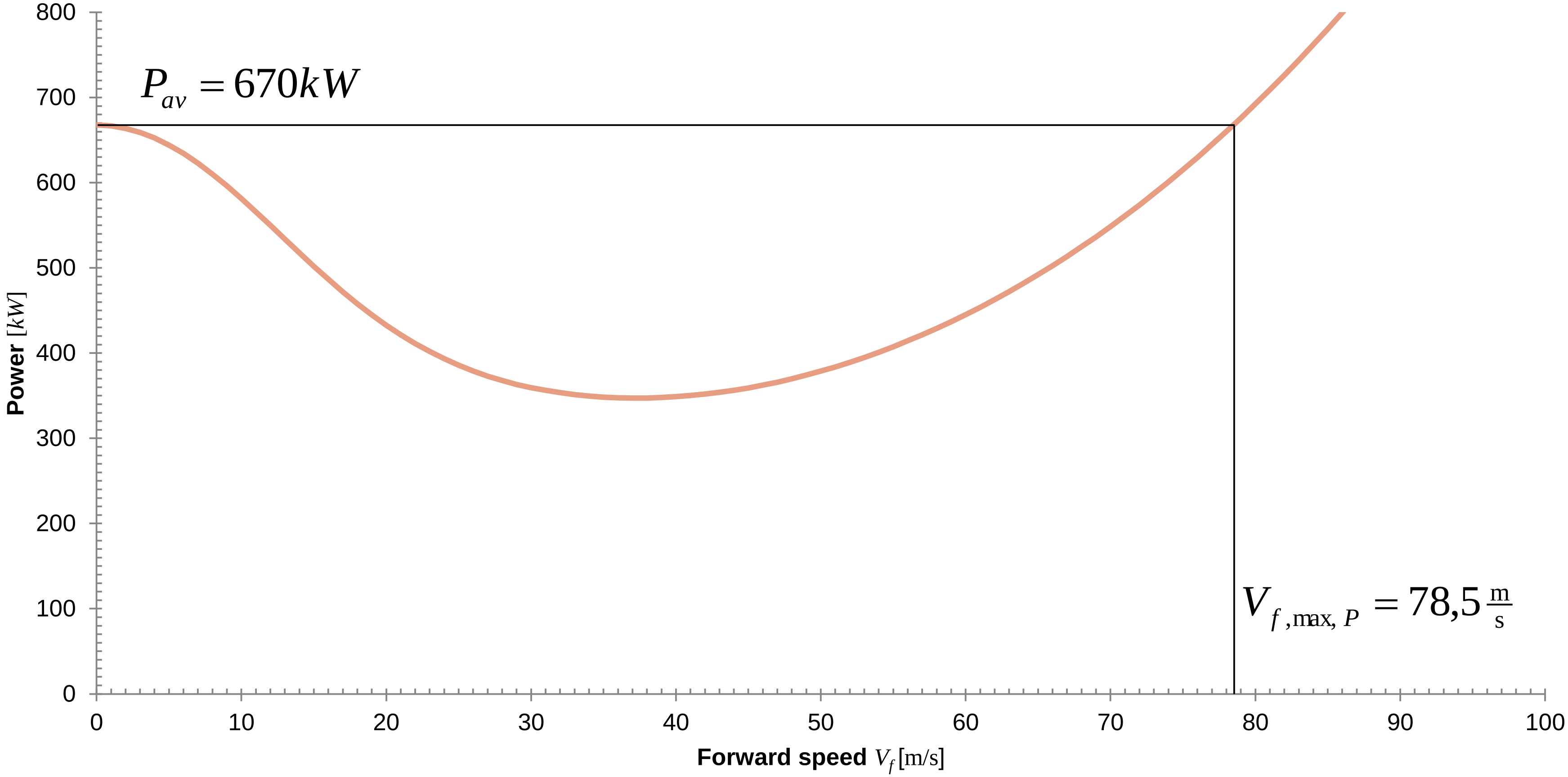
3. Section 2-3: Level flight in 1500m ISA at maximum flight speed

Determine with the help of the given diagrams the maximum forward speed in level flight V_f at an available drive power of $P_{av} = 670\,\mathrm{kW}$.

Provide for the blade loading a speed margin of 15% and disregard the required thrust component for the propulsion .

The air density is $\rho = 1{,}058\,\frac{\mathrm{kg}}{\mathrm{m}^3}$, the rotor radius $R = 5{,}5\,\mathrm{m}$,
the solidity $\sigma = 0{,}074$ and the tip speed $V_{TIP} = 221\,\frac{\mathrm{m}}{\mathrm{s}}$.

Power consumption in level flight



GW_2

1500m ISA

Maximum flight speed in level flight

Maximum flight speed (power limit)

$$V_{f,\max,P} = 78{,}5\,\tfrac{\mathrm{m}}{\mathrm{s}}$$

Blade loading

$$T = GW_2 \cdot g = 30994\,N$$

$$\left(\frac{C_T}{\sigma}\right)_{MR} = \frac{T}{\rho \cdot A \cdot V_{TIP}^2 \cdot \sigma} = 0{,}0853$$

from diagram: $\mu_{\max} = \frac{0{,}394}{1{,}15} = 0{,}34$

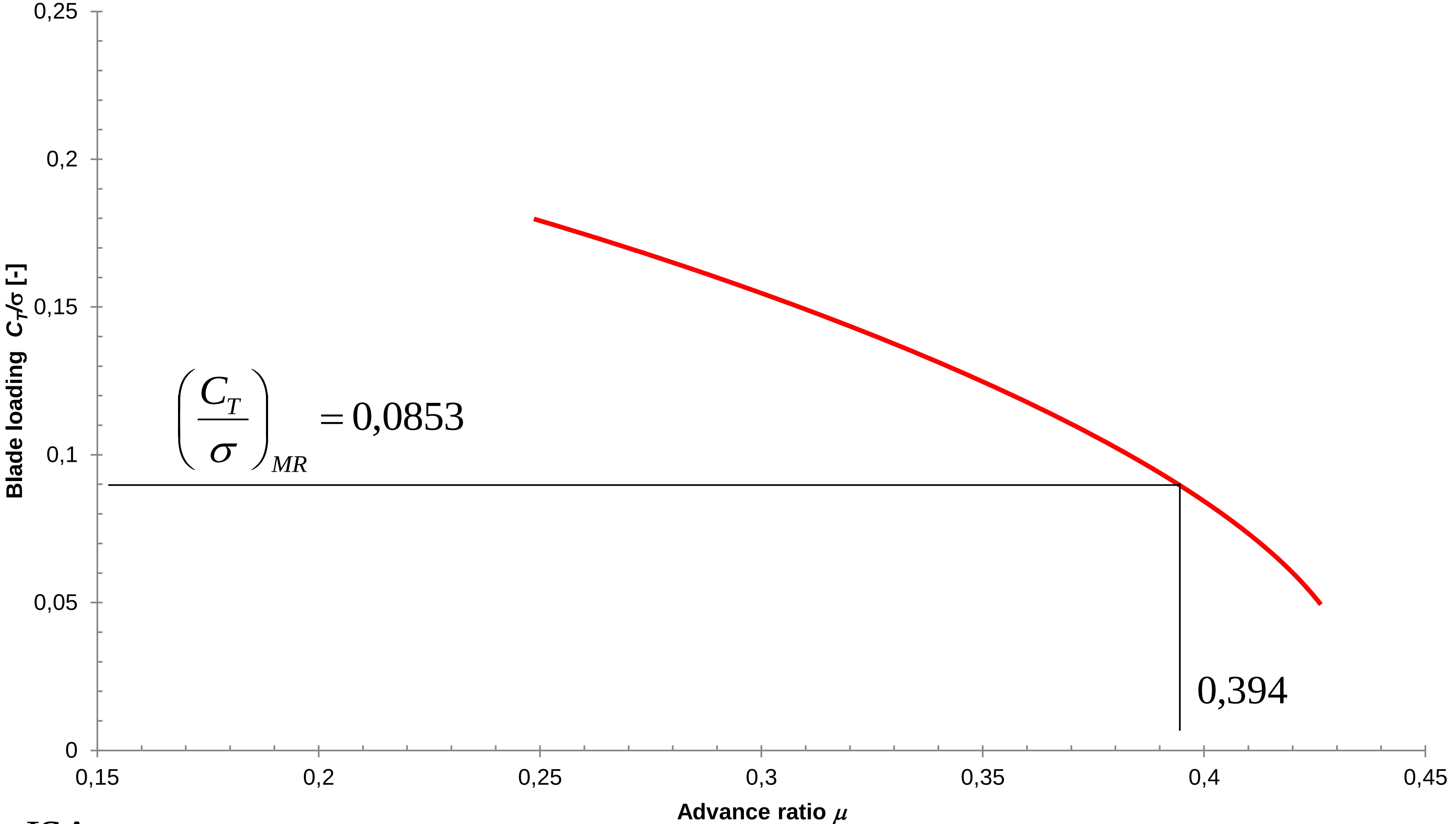
Maximum flight speed (rotor limit):

$$V_{f,\max,BL} = \mu_{\max,BL} \cdot V_{TIP} = 75{,}1\,\tfrac{\mathrm{m}}{\mathrm{s}}$$

$$V_{f,\max,BL} < V_{f,\max,P}$$

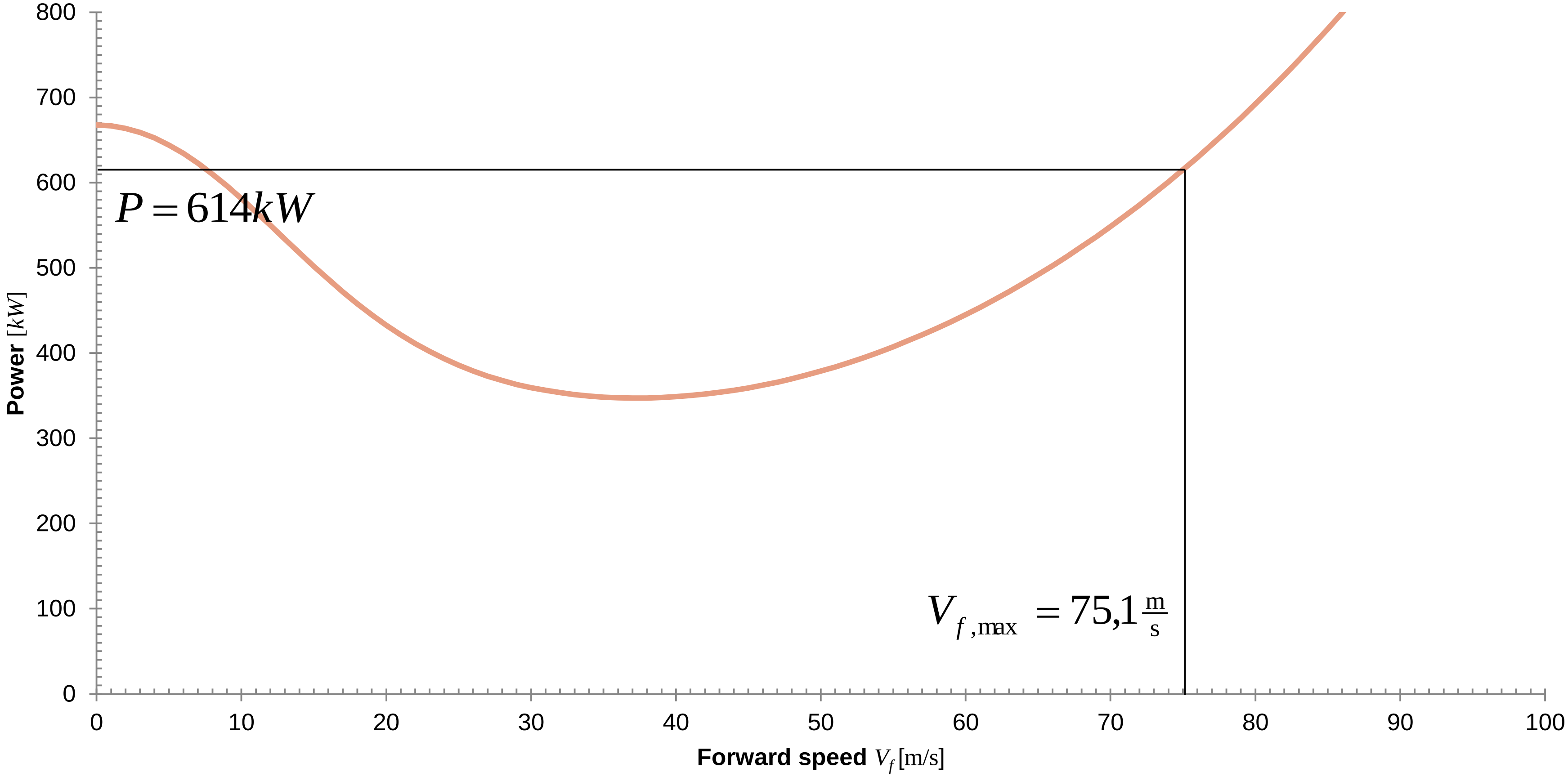
$$V_{f,\max} = 75{,}1\,\tfrac{\mathrm{m}}{\mathrm{s}}$$

Permitted main rotor – blade loading



1500m ISA

Power consumption in level flight



GW_2

$1500\mathrm{m}\ \mathrm{ISA}$

Maximum flight speed in level flight

Power consumption from diagram $V_{f,\max} = 75{,}1\,\frac{\mathrm{m}}{\mathrm{s}}$

$$P = 614\,\mathrm{kW}$$

Endurance in section

$$t_{2-3} = \frac{150\mathrm{km} - d_2}{75{,}1\,\frac{\mathrm{m}}{s}} = 29{,}83\,\mathrm{min} = 0{,}50\,\mathrm{h}$$

Fuel mass

$$m_{Fuel,2-3} = -P \cdot SFC \cdot t_{1-2} = -614\,\mathrm{kW} \cdot 0{,}4\,\frac{\mathrm{kg}}{\mathrm{kWh}} \cdot 0{,}50\,\mathrm{h} = -122{,}8\,\mathrm{kg}$$

Total mass

$$GW_3 = GW_2 + m_{Fuel,2-3} = 3159{,}4\,\mathrm{kg} - 122{,}8\,\mathrm{kg} = 3036{,}6\,\mathrm{kg}$$

5. Section 4-5: Descent to 500m at $V_f = 60\,\frac{\mathrm{m}}{\mathrm{s}}$

Calculate first of all the flight mass after loading the people.

The hospital is located in 500m ISA in a distance of $10\,\mathrm{km}$.
Which flight path angle γ and descent rate V_C does the helicopter need to have at $V_f = 60\,\frac{\mathrm{m}}{\mathrm{s}}$ in order to reach the hospital in a steady descent?

Use the given diagram and assume for the calculation of P that the power components only change insignificantly compared to the level flight.

Descent

Mass after loading of people

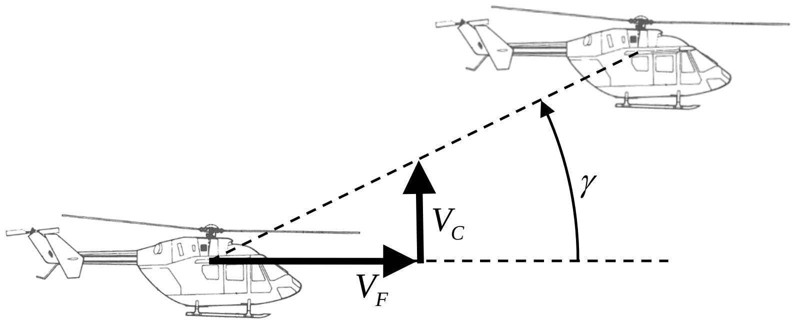
$$GW_4 = GW_3 + m_{Fuel,3-4} + m_{PL,3-4} = 3036{,}6\,\text{kg} - 50{,}9\,\text{kg} + 170\,\text{kg} = 3155{,}7\,\text{kg}$$

Required flight path angle, descent rate

$$d_{4-5} = 10\,\text{km} \qquad H_{4-5} = -1000\,\text{m}$$

$$\gamma = \arctan\left(\frac{H_{4-5}}{d_{4-5}}\right) = -5{,}7°$$

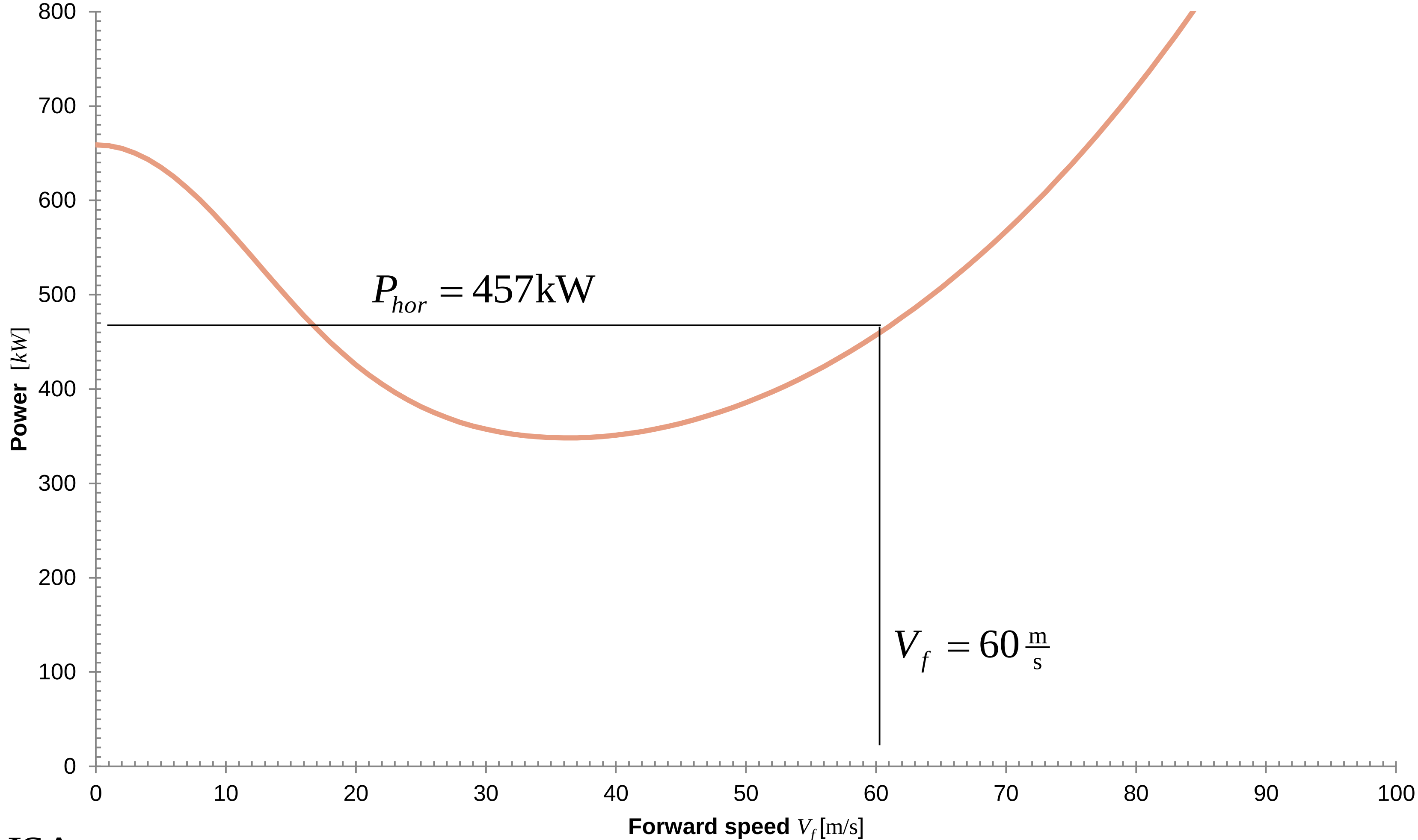
$$V_C = \frac{H_{4-5}}{d_{4-5}} \cdot V_f = \frac{-1000\,\text{m}}{10\,\text{km}} \cdot 60\,\tfrac{\text{m}}{\text{s}} = -6\,\tfrac{\text{m}}{\text{s}}$$



Climb power

$$P_C = V_C \cdot GW_4 \cdot g = -6\,\tfrac{\text{m}}{\text{s}} \cdot 3155{,}7\text{kg} \cdot 9{,}81\,\tfrac{\text{N}}{\text{kg}} = -186\text{kW}$$

Power consumption in level flight



GW_4

1000m ISA

Descent

Power requirement in level flight (from diagram)

$$V_f = 60\,\tfrac{\mathrm{m}}{\mathrm{s}} \qquad P_{hor} = 457\,\mathrm{kW}$$

Power requirement in descent

$$P = P_{hor} + P_C = 271\,\mathrm{kW} \qquad P_C = -186\,\mathrm{kW}$$

Descent duration

$$t_{4-5} = \frac{10\,\mathrm{km}}{60\,\frac{\mathrm{m}}{s}} = 2{,}78\,\mathrm{min} = 0{,}046\,\mathrm{h}$$

Fuel mass

$$m_{Fuel,4-5} = -P \cdot SFC \cdot t_{4-5} = -271\,\mathrm{kW} \cdot 0{,}4\,\tfrac{\mathrm{kg}}{\mathrm{kWh}} \cdot 0{,}046\,\mathrm{h} = -5{,}0\,\mathrm{kg}$$

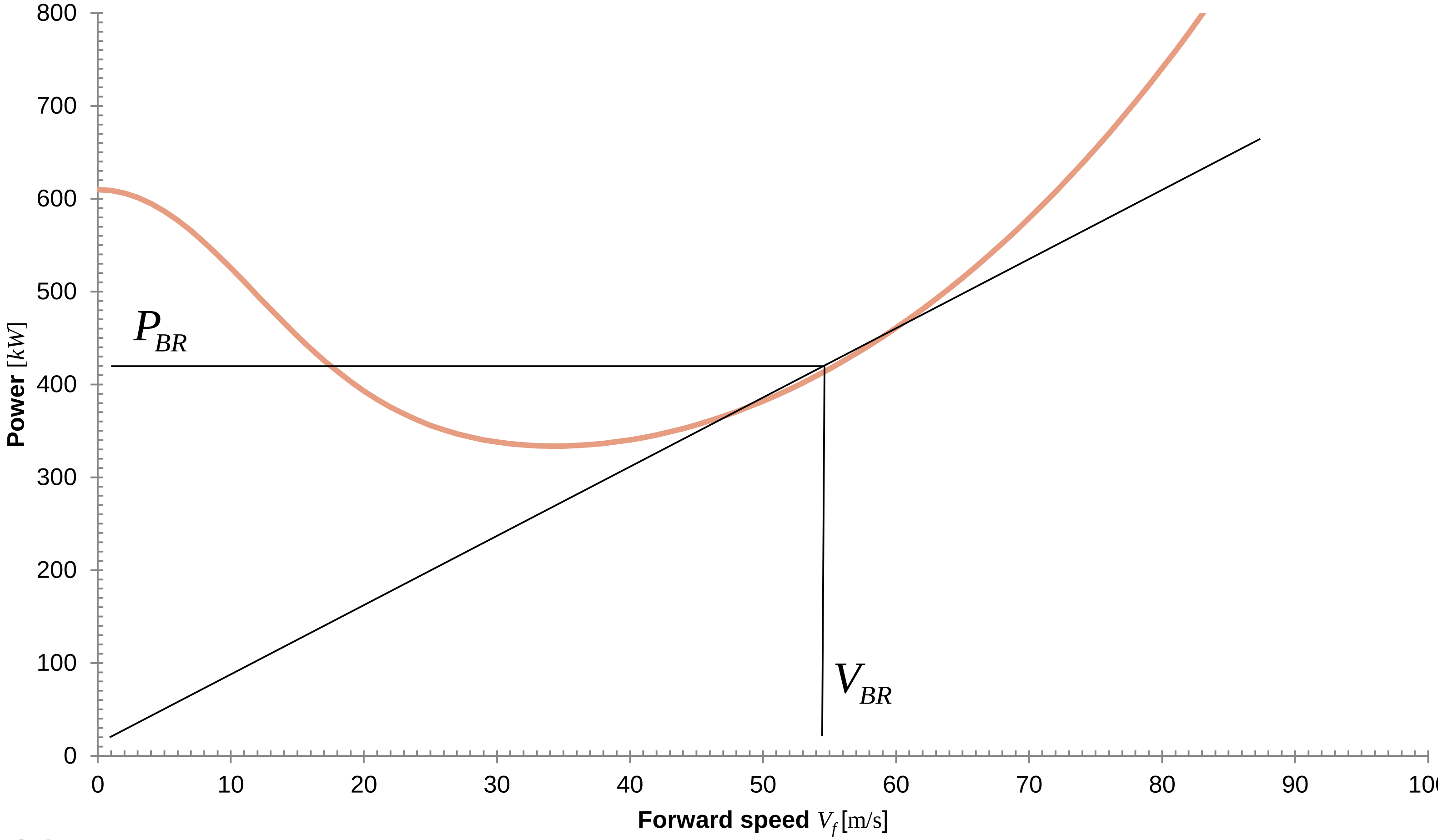
Total mass

$$GW_5 = GW_4 + m_{Fuel,4-5} = 3155{,}7\,\mathrm{kg} - 5{,}0\,\mathrm{kg} = 3150{,}7\,\mathrm{kg}$$

6. Section 6-7: Return flight in 500m with V_{BR}

For the return flight to the base of 150km it should be flown in 500m with the speed for maximum range V_{BR}.
Use the given diagram to determine the power consumption.

Power consumption in level flight



GW_6

500m ISA

Return flight to base

Flight mass after discharge of people

$$GW_6 = GW_5 + m_{PL,5-6} = 3150{,}7\,\mathrm{kg} - 170\,\mathrm{kg} = 2980{,}7\,\mathrm{kg}$$

Speed for highest range (from diagram)

$$V_{BR} = 54\,\tfrac{\mathrm{m}}{\mathrm{s}} \qquad P_{BR} = 410\,\mathrm{kw}$$

Endurance in Section

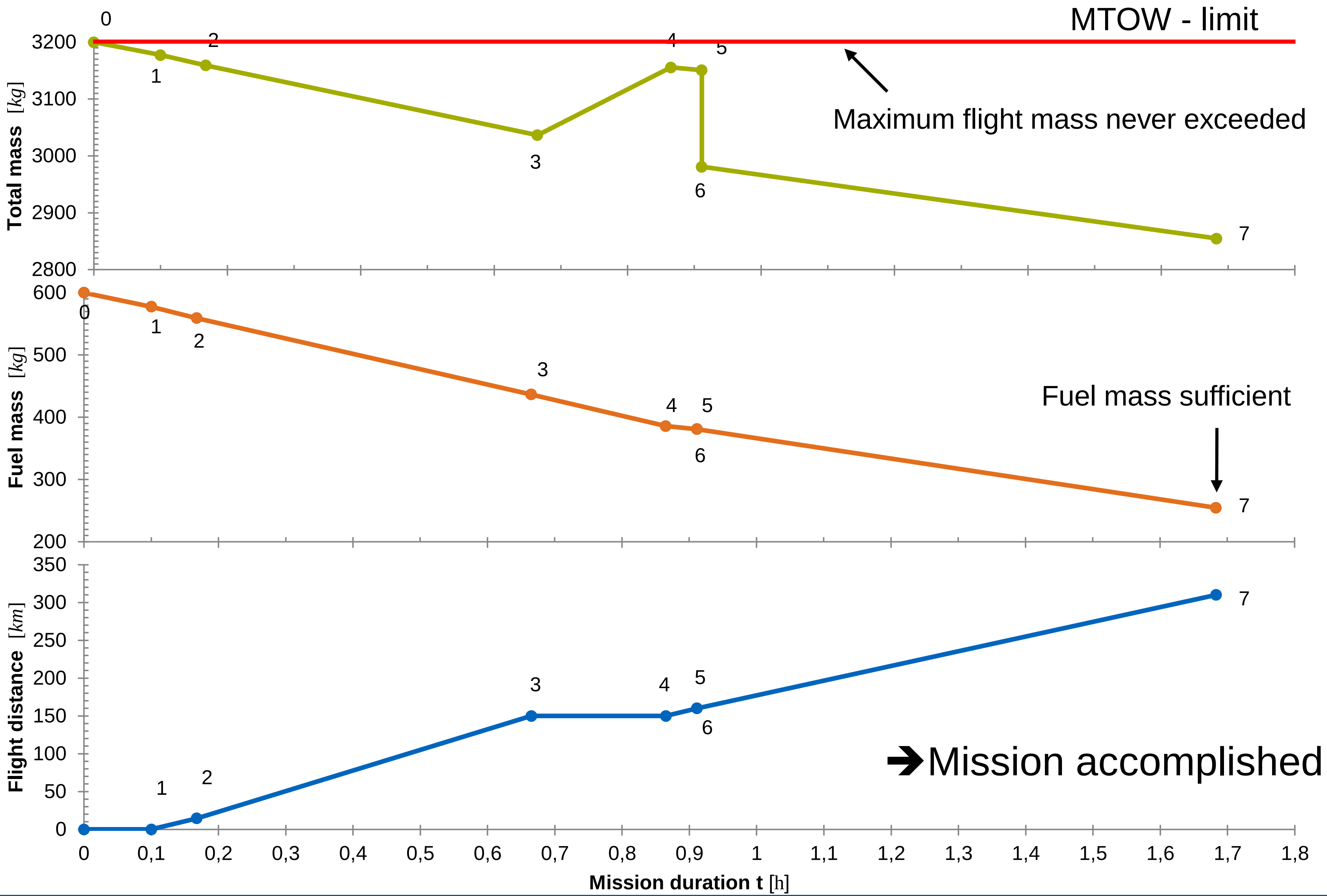
$$t_{6-7} = \frac{150\,\mathrm{km}}{54\,\tfrac{\mathrm{m}}{\mathrm{s}}} = 46{,}29\,\mathrm{min} = 0{,}77\,\mathrm{h}$$

Fuel mass

$$m_{Fuel,6-7} = -P_{BR} \cdot SFC \cdot t_{6-7} = -410\,\mathrm{kW} \cdot 0{,}4\,\tfrac{\mathrm{kg}}{\mathrm{kWh}} \cdot 0{,}77\,\mathrm{h} = -126{,}3\,\mathrm{kg}$$

Total mass

$$GW_7 = GW_6 + m_{Fuel,6-7} = 2980{,}7\,\mathrm{kg} - 126{,}3\,\mathrm{kg} = 2854{,}4\,\mathrm{kg}$$


MTOW - limit
Maximum flight mass never exceeded
Total mass [kg]
3200
3100
3000
2900
2800
Fuel mass sufficient
Fuel mass [kg]
600
500
400
300
200
Flight distance [km]
350
300
250
200
150
100
50
0
➔Mission accomplished
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
1,1
1,2
1,3
1,4
1,5
1,6
1,7
1,8
Mission duration t [h]
0
1
2
3
4
5
6
7