The Iron Man suit: a physics worksheet

Ten problems on the real numbers behind the suit. Free from thesuit.cc, where you can take the suit apart in 3D.

Name _____ Class _____ Date _____

Use g = 9.81 m/s² throughout and round answers to three significant figures. Each problem names the real machine its numbers come from; the guides at thesuit.cc/engineering explain each one in depth.

1. How heavy is a real suit?

A rifle-proof suit with a powered frame and life support would weigh about 200 kg empty (weight guide). Its wearer weighs 80 kg.

- (a) What is the total mass of suit and wearer?
- (b) What is their weight, in newtons, on Earth?

2. Hovering on jet engines

Fueled for a short flight, suit and wearer come to about 360 kg at takeoff. A JetCat P400-PRO microturbine, the class of engine real jet suits fly on, makes 425 N of thrust and weighs 4.01 kg (flight guide).

- (a) What thrust does the suit need just to hover?
- (b) How many P400-PRO engines does that take? (Engines come whole.)
- (c) What is one engine's thrust-to-weight ratio?

3. How long can it fly?

Gravity Industries' jet suit turbines burn about 4 litres of jet fuel a minute, and the suit typically carries 40 litres. Jet fuel has a density of about 0.8 kg per litre.

- (a) How long can it fly on a full load at that rate?
- (b) What is the mass of a full fuel load?
- (c) How many kilograms of fuel would one hour of flight burn?

4. Could repulsors be plasma thrusters?

NASA's record X3 Hall-effect thruster makes 5.4 N of thrust from 99 kW of electrical power (repulsors guide).

- (a) How many newtons does it make per kilowatt?
- (b) How many X3 thrusters would it take to hover the 360 kg suit from problem 2?
- (c) How much electrical power would they draw together, in megawatts?

5. The arc reactor's power

In the films, the arc reactor puts out 3 gigawatts (arc reactor guide). An average US home uses about 10,500 kWh of electricity a year.

- (a) How much energy, in joules, does the reactor release in one minute?
- (b) What is the average power a home draws, in kilowatts? (A year has 8,760 hours.)
- (c) How many homes could the reactor supply at that average?

6. How much does the armor weigh?

Real rifle-rated armor weighs about 43 kg for every square meter it covers (materials guide). Assume the suit's outer surface is 2.3 m^2.

- (a) What mass of armor does it take to cover the whole suit?
- (b) What share of a 200 kg suit is that?

7. Titanium or steel?

A chest plate is 50 cm by 40 cm and 6 mm thick. Titanium alloy Ti-6Al-4V has a density of 4.43 g/cm^3; steel has 7.85 g/cm^3.

- (a) What is the plate's volume in cm^3?
- (b) What is its mass in titanium, and in steel?
- (c) What percentage of the mass does titanium save?

8. Keeping the wearer cool

A person working hard gives off about 500 W of heat. A spacesuit's liquid cooling garment carries it away in water that warms as it flows (cooling guide). Water's specific heat capacity is 4,186 J/(kg·°C).

- (a) How much heat, in joules, does the wearer give off in one hour?
- (b) If the cooling water warms by 10 °C, what mass of water must flow through the garment each hour?
- (c) What flow is that per minute?

9. Stopping hurts

The suit flies at 100 m/s (360 km/h) and stops in 10 m, as in the films' landings (life support guide).

- (a) What is its average deceleration, in m/s²?
- (b) How many g is that?
- (c) Untrained people black out at about 5 g. Over what distance would the suit have to stop from 100 m/s to stay at 5 g?

10. Batteries for a real exoskeleton

The Sarcos Guardian XO, a real full-body powered exoskeleton, draws about 500 W (exoskeleton guide). Good lithium-ion cells store about 250 Wh per kilogram.

- (a) How much energy, in kWh, does an 8-hour shift take?
- (b) What mass of batteries is that?

Bonus. Too much power?

A real suit needs about 5 MW to fly. How many times more power than that does a 3 GW arc reactor make, and where would all the unused power have to go?

Answer key

1. How heavy is a real suit?

- (a) 200 kg + 80 kg = **280 kg**
- (b) W = mg = 280 × 9.81 = **2,750 N** (2,746.8 N)

2. Hovering on jet engines

- (a) To hover, thrust equals weight: 360 × 9.81 = **3,530 N** (3,531.6 N)
- (b) 3,531.6 ÷ 425 = 8.31, so **9 engines**
- (c) Weight of one engine: 4.01 × 9.81 = 39.3 N, so 425 ÷ 39.3 = **10.8**

3. How long can it fly?

- (a) 40 L ÷ 4 L per minute = **10 minutes**
- (b) 40 × 0.8 = **32 kg**
- (c) 4 L × 60 = 240 L an hour, × 0.8 = **192 kg**. That is why real jet suits fly for minutes, not hours.

4. Could repulsors be plasma thrusters?

- (a) 5.4 ÷ 99 = **0.0545 N per kW**
- (b) 3,531.6 ÷ 5.4 = 654.0, so **654 thrusters**
- (c) 654 × 99 kW = 64,746 kW = **64.7 MW**, more than many small power stations produce

5. The arc reactor's power

- (a) $E = Pt = 3 \times 10^9$ W × 60 s = **1.80×10^{11} J** (180 GJ)
- (b) 10,500 kWh ÷ 8,760 h = **1.20 kW**
- (c) 3×10^9 W ÷ 1,200 W = **2.50 million homes**

6. How much does the armor weigh?

- (a) 43 × 2.3 = **98.9 kg**, about 100 kg
- (b) 98.9 ÷ 200 = **49.5%**, about half the suit

7. Titanium or steel?

- (a) 50 × 40 × 0.6 = **1,200 cm^3**
- (b) Titanium: 1,200 × 4.43 = 5,316 g = **5.32 kg**. Steel: 1,200 × 7.85 = 9,420 g = **9.42 kg**
- (c) (9.42 – 5.32) ÷ 9.42 = **43.6%** lighter

8. Keeping the wearer cool

- (a) Q = Pt = 500 × 3,600 = **1.80×10^6 J** (1.8 MJ)
- (b) $m = Q \div (c\Delta T) = 1.8 \times 10^6 \div (4{,}186 \times 10)$ = **43.0 kg** of water an hour
- (c) 43.0 ÷ 60 = **0.717 kg per minute**, about 0.7 litres a minute

9. Stopping hurts

- (a) $a = v^2 \div 2d = 100^2 \div (2 \times 10)$ = **500 m/s^2**
- (b) 500 ÷ 9.81 = **51.0 g**, about ten times what a person can take
- (c) 5 g = 49.05 m/s^2, so $d = v^2 \div 2a$ = 10,000 ÷ 98.1 = **102 m**

10. Batteries for a real exoskeleton

- (a) 0.5 kW × 8 h = **4 kWh**
- (b) 4,000 Wh ÷ 250 Wh/kg = **16 kg** of batteries

Bonus. Too much power?

$(3 \times 10^9) \div (5 \times 10^6)$ = **600 times** more than the suit needs. No machine turns all of its power into useful work, and whatever is not used ends up as heat. Even a small fraction of 3 GW, released inside a suit the size of a person, would cook the wearer: the cooling guide shows why heat, not power, is the suit's hardest limit.