Space Jump Energy

On 14 October 2012, Felix Baumgartner spent 2½ hours reaching the heights of the upper stratosphere with the aid of a Red Bull sponsored weather balloon, then spent the next 10 minutes getting back down.

1. One of the aims of the Red Bull Stratos project was for Felix to break the sound barrier by falling at more than $300ms^{-1}$ (the speed of sound at 30km altitude – it varies depending, primarily, on temperature). Felix, his suit and his parachute rig weighed 118kg in total. Calculate the energy required for him to be moving at $300ms^{-1}$.

2. If there were no resistive forces involved, what is the minimum height he would need to jump from to reach this speed?

3. Felix in fact jumped from a height of $39045m$. Calculate his initial Gravitational Potential Energy.

4. Air resistance at this altitude could be considered negligible, but since Felix's velocity is very high for much of the drop, it becomes an important factor. Given that he reached $300ms^{-1}$ at an altitude of $33945m$, calculate the work done against resistive forces during this first phase of motion, and hence the average resistive force.

5. Felix reaches his top speed of $373ms^{-1}$ at an altitude of $28563m$. Assuming that air resistance is constant for this second phase of motion, calculate the force of air resistance.

6. His parachute was opened at an altitude of 1600m. We can assume that at this point his speed has dropped to a safe $60ms^{-1}$ (terminal velocity for skydivers at normal altitude). Assuming air resistance is constant from this point on, what must the force of air resistance be in order to slow him down to a speed of $10ms^{-1}$ by the time he lands?

Extension: If Felix had performed his little stunt on the moon, assuming he still dropped from $39045m$ and still pulled his parachute at an altitude of 1600m as he did on Earth, and taking acceleration due to gravity on the moon as $1.6ms^{-2}$, what would his top speed be?

Space Jump Energy Solutions

On 14 October 2012, Felix Baumgartner spent 2½ hours reaching the heights of the upper stratosphere with the aid of a Red Bull sponsored weather balloon, then spent the next 10 minutes getting back down.

1. One of the aims of the Red Bull Stratos project was for Felix to break the sound barrier by falling at more than $300ms^{-1}$ (the speed of sound at 30km altitude – it varies depending, primarily, on temperature). Felix, his suit and his parachute rig weighed 118kg in total. Calculate the energy required for him to be moving at $300ms^{-1}$.

$$KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 118 \times 300^2 = 5310000J = \mathbf{5.31MJ}$$

2. If there were no resistive forces involved, what is the minimum height he would need to jump from to reach this speed?

$$GPE = mgh \quad \Longrightarrow \quad 5310000 = 118 \times 9.8h \quad \Longrightarrow \quad \boldsymbol{h = 4590m\ to\ 3\ s.f.}$$

3. Felix in fact jumped from a height of $39045m$. Calculate his initial Gravitational Potential Energy.

$$GPE = mgh = 118 \times 9.8 \times 39045 = 45151638J = \boldsymbol{45.2MJ\ to\ 3\ s.f.}$$

4. Air resistance at this altitude could be considered negligible, but since Felix's velocity is very high for much of the drop, it becomes an important factor. Given that he reached $300ms^{-1}$ at an altitude of $33945m$, calculate the work done against resistive forces during this first phase of motion, and hence the average resistive force.

$$Initial\ GPE + Initial\ KE = 45151638 + 0 = 45151638J$$

$$Final\ GPE + Final\ KE = 118 \times 9.8 \times 33945 + \frac{1}{2} \times 118 \times 300^2 = 44563998J$$

$$Work\ done\ against\ resistive\ forces = 45151638 - 44563998 = 587640J = \boldsymbol{588kJ\ to\ 3\ s.f.}$$

$$Average\ resistive\ force = \frac{Work\ Done}{Distance} = \frac{587640}{39045 - 33945} = \boldsymbol{115N\ to\ 3\ s.f.}$$

5. Felix reaches his top speed of $373ms^{-1}$ at an altitude of $28563m$. Assuming that air resistance is constant for this second phase of motion, calculate the force of air resistance.

$$Initial\ KE + Initial\ GPE = 44563998J$$

$$Final\ KE + Final\ GPE = \frac{1}{2} \times 118 \times 373^2 + 118 \times 9.8 \times 28563 = 41238864.2J$$

$$Work\ done\ against\ air\ resistance = 44563998 - 41238864.2 = 3325133.8J$$

$$Work\ Done = Force \times Distance \quad \Longrightarrow \quad 3325133.8 = F \times 5382 \quad \Longrightarrow \quad F = \boldsymbol{618N\ to\ 3\ s.f.}$$

6. His parachute was opened at an altitude of 1600m. We can assume that at this point his speed has dropped to a safe $60ms^{-1}$ (terminal velocity for skydivers at normal altitude). Assuming air resistance is constant from this point on, what must the force of air resistance be in order to slow him down to a comfortable speed of $5ms^{-1}$ by the time he lands?

$$Initial\ KE + Initial\ GPE = \frac{1}{2} \times 118 \times 60^2 + 118 \times 9.8 \times 1600 = 2062640J$$

$$Final\ KE + Final\ GPE = \frac{1}{2} \times 118 \times 5^2 + 0 = 1475J$$

$$Work\ done\ against\ air\ resistance = 2062640 - 1475 = 2061165J$$

$$Work\ Done = Force \times Distance \quad \Longrightarrow \quad 2061165 = F \times 1600 \quad \Longrightarrow \quad F = \boldsymbol{1290N\ to\ 3\ s.f.}$$

Extension: If Felix had performed his little stunt on the moon, assuming he still dropped from $39045m$ and still pulled his parachute at an altitude of 1600m as he did on Earth, and taking acceleration due to gravity on the moon as $1.6ms^{-2}$, what would his top speed be?

$$Initial\ KE + Initial\ GPE = 0 + 118 \times 1.6 \times 39045 = 7371696J \qquad Final\ KE + Final\ GPE = \frac{1}{2}mv^2 + 0$$

$$Since\ no\ resistive\ forces\ act: \ \frac{1}{2}mv^2 = 7371696 \quad \Longrightarrow \quad \frac{1}{2} \times 118 \times v^2 = 7371696 \quad \Longrightarrow \quad \boldsymbol{v = 353ms^{-1}\ to\ 3\ s.f.}$$

Note: parachute deployment is irrelevant; no air resistance means the parachute wouldn't slow him down at all, and he would hit the surface at almost $800mph$.