<table>
<tr><th>Question</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>(a)</td><td>Gravitational energy transferred = $mgh + mgb$
Energy transferred to body (elastic, heat) = Fb
(Average force × resulting movement of the C of M.)
If these two are the same (ie if there is no "give" in the ground) then

$Fb = mgh + mgb$ or $f = mg(1 + \frac{h}{b})$

Can also be done by calculating the deceleration ($a = \frac{gh}{b}$) and summing forces in the vertical plane.</td><td rowspan="5">Partially correct mathematical solution to the given problems.

AND / OR

Partial discussion of the underlying physics of this application.</td><td rowspan="5">(Partially) correct mathematical solution to the given problems.

AND

Reasonably thorough discussion of the underlying physics of this application.</td><td rowspan="5">Thorough discussion of the underlying physics of this application.

AND

Correct mathematical solution to the given problems.</td></tr>
<tr><td>(b)</td><td>$Fd = \Delta E$ $\quad F = mg\frac{h+b}{b}$
$h = 3$ m , $b = 0.5$ m gives $F = 7mg$

And its only the average force - we are assuming constant acceleration for the duration of the stop and since the acceleration has to begin and end at zero and take some time to reach its maximum value, the maximum value must be larger than the $7mg$ calculated.</td></tr>
<tr><td>(c)</td><td>$b = v_{av} \times t = \frac{vt}{2}$
$v = (2gh)^{0.5}$ (due to conservation of energy)
$t = \frac{2b}{(2gh)^{0.5}} = b\left(\frac{2}{gh}\right)^{0.5}$
Effectively the distance b is increased as the snow sinks a bit on landing. Assuming b increases by 10 cm this will make $F = 6mg$. This is a significant reduction.</td></tr>
<tr><td>(d)</td><td>The force normal to the surface will reduce as θ gets larger and $\cos\theta$ gets closer to zero. As the slope gets steeper the force normal to the surface will reduce.</td></tr>
<tr><td>(e)</td><td>The answer wanted is a diagram showing the slope to be a parabola – the slope will match the freefall path of the snowboarder and so no force will be exerted at the time of (grazing) contact. However it should be noted that forces will have to be exerted at some time when the slope changes its profile (or else the projectile keeps going down forever).</td></tr>
</table>

<table>
<tr><th>Question</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>2(a)</td><td>GPE goes to KE – specify that the arm must be massless, otherwise there is rotational KE in the rotating beam.</td><td rowspan="4">Thorough understanding of this application of physics.

OR

Partially correct mathematical solution to the given problems

AND / OR

Partial understanding of this application of physics.</td><td rowspan="4">(Partially) correct mathematical solution to the given problems.

AND / OR

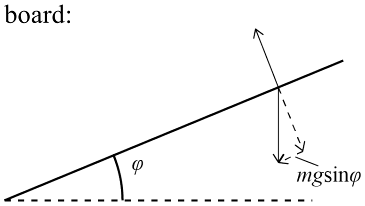
Reasonably thorough understanding of this application of physics.</td><td rowspan="4">Correct mathematical solution to the given problems.

AND

Thorough understanding of this application of physics.</td></tr>
<tr><td>(b)</td><td>$R = \frac{2v^2 \sin\alpha \cos\alpha}{g}$
v = velocity of projectile at release
α = angle of v to the horizontal (at release)

At max range $\alpha = 45^{\circ}$ so $\sin\alpha \cos\alpha = 0.5$
And $\frac{1}{2} mv^2 = \text{M}gh$ (All of the GPE is converted to KE)

So $v^2 = \frac{2\text{M}gh}{\text{m}}$
and $R = \frac{2 \times 2\text{M}gh \times 0.5}{\text{m}g}$
$R = \frac{2\text{M}h}{m}$</td></tr>
<tr><td>(c)</td><td>When the falling weight is dropped it swings BACKWARDS, so the trebuchet frame "wants" to go forward – centre of mass tries to stay in the same position; or conservation of momentum in a closed system. So yes, put it on wheels so it can roll forward and give the projectile some additional KE.</td></tr>
<tr><td>(d)</td><td>It would be the same (100 m).
• Equation for maximum range is independent of g.
• Force supplied by the falling counterweight is only 1/6 that supplied on the Earth but once launched the projectile is only subject to 1/6 of the force returning it to the ground. These two factors exactly cancel each other.</td></tr>
</table>

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
3 (a)i)	By considering the force due to gravity acting down the board:  So the vertical acceleration component is $g\sin\varphi$. At top the vertical velocity is zero. Setting $a = g\sin\varphi$ And showing that the initial vertical velocity is $v_0\sin\theta$. Then using the kinematic equation $v_f^2 = v_i^2 + 2ad$ Rearranging provides the result.	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(ii)	The horizontal component of velocity is $v_0\cos\theta$. The distance, d will be travelled in time Δt – given no forces are acting this is a constant velocity situation – $\Delta t = \frac{d}{v}$			
(iii)	$v + at = 0$ at top so $\Delta t = \frac{v_0 \sin\theta}{g\sin\varphi}$			
(b)	Using the results to the two previous questions it can be shown that $\frac{d}{v_0\cos\theta} = \frac{2v_0\sin\theta}{g\sin\varphi}$ Using the trig identity provided gives $v_0^2 \sin 2\theta = gd\sin\varphi$ Simple rearrangement gives $\theta = \frac{1}{2}\sin^{-1}\left(\frac{gd\sin\varphi}{v_0^2}\right)$			
(c)	Initial energy $\frac{1}{2}I\omega_0^2 + \frac{1}{2}mv_0^2 = \frac{7}{10}mv_0^2$ Final energy at the top where v_f is the horizontal velocity (since it is unchanged) is $\frac{7}{10}mv_f^2 + mg\Delta y\sin\varphi$ $v_f = v_0\cos\theta$ Equate energies and rearrange gives $\frac{7}{10}mv_0^2(1-\cos^2\theta) = mg\Delta y\sin\varphi$ using trig identity gives $\frac{7}{10}mv_0^2(\sin^2\theta) = mg\Delta y\sin\varphi$ Therefore $\Delta y = \frac{7}{10}\frac{(v_0\sin\theta)^2}{g\sin\varphi}$			
(d)(i)	This will result in Δy tending to infinity – a simple consequence of Newton's first law.			
(d)(ii)	More energy input due to additional rotational component.			

<table>
<tr><th>Q</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>4 (a)</td><td>Vertical velocity component = $V\sin\phi$
Time to highest point = $\dfrac{v\sin\phi}{g}$ Total time of flight = $\dfrac{2v\sin\phi}{g}$
Range = Total time of flight × Horizontal component of velocity
$R = \dfrac{2v\sin\phi}{g} \times v\cos\phi = \dfrac{2v^2\sin\phi\cos\phi}{g}$
$= \dfrac{v^2\sin 2\phi}{g}$</td><td rowspan="4">Thorough understanding of these applications of physics.

OR

Partially correct mathematical solution to the given problems.

AND / OR

Partial understanding of these applications of physics.</td><td rowspan="4">(Partially) correct mathematical solution to the given problems.

AND / OR

Reasonably thorough understanding of these applications of physics.</td><td rowspan="4">Correct mathematical solution to the given problems.

AND

Thorough understanding of these applications of physics.</td></tr>
<tr><td>(b)</td><td>$\sin 2\phi = R\dfrac{g}{v^2} = 80 \times \dfrac{9.81}{28^2} = 1$
$\phi = 45°$
Time of flight $= \dfrac{\text{Range}}{\text{Horizontal velocity}} = \dfrac{80}{28\cos 45°}$
$T = 4.0406\text{ s} = 4.04\text{ s}$</td></tr>
<tr><td>(c)(i)</td><td>$R = 80 = R_1 + R_2 = \dfrac{28^2\sin 2\phi}{g} + \dfrac{14^2\sin 2\phi}{g}$
$\sin 2\phi = 0.8 \quad \phi = 26.56°$
$R_1 = \dfrac{28^2\sin 53.2°}{9.81} = 64\text{ m} \quad R_2 = 16\text{ m}$
Time to first bounce $= \dfrac{64}{28\cos 26.6°} = 2.556\text{ s}$
Time from first to second $\dfrac{16}{14\cos 26.6°} = 1.278\text{ s}$
Total time of flight $= 3.83\text{ s}$</td></tr>
<tr><td>(ii)</td><td>The second throw, with its lower elevation has a greater horizontal component velocity, and this allows for a shorter total flight time, despite the loss of speed caused by the bounce.</td></tr>
</table>

Q	Evidence	1-4 marks	5-6 marks	7-8 marks
(d)	$\text{Time up} = \dfrac{v\sin\phi}{\text{g}}$ $\text{Distance gained up} = \dfrac{v^2\sin^2\phi}{2\text{g}}$ $\text{Distance fallen} = \dfrac{v^2\sin^2\phi}{2\text{g}} + 2$ $\text{Time down} = \sqrt{\dfrac{2d}{\text{g}}} = \sqrt{\dfrac{2\left(\dfrac{v^2\sin^2\phi}{2\text{g}}+2\right)}{\text{g}}}$ $\text{Total time of flight} = \dfrac{v\sin\phi + \sqrt{v^2\sin^2\phi + 4\text{g}}}{\text{g}}$ $\text{Range} = \text{Horizontal speed} \times \text{time}$ $\text{Range} = v\cos\phi\dfrac{v\sin\phi + \sqrt{v^2\sin^2\phi + 4\text{g}}}{\text{g}}$			

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
5(a)	When the puck is 4 m in front of Nicole the centre of mass is 4 / 101 m in front of her and the puck is 3.9604 m in front of the CoM. Space Vehicle 2 takes 32.69 s to go 85 m (85 / 2.6). The CoM of Nicole and the puck will travel 196.154 m in this time (32.69 × 6). With the puck being 3.9604 m in front of the CoM, 200.114 m is the greatest reach of the puck and enough to reach the craft in time.	Some understanding of at least two important aspects of the physics of the situation outlined.	Clear understanding of two important aspects of the physics of the situation outlined.	Clear understanding of all important aspects of the physics of the situation outlined.
(b)(i)	From above: At 6.0 m s^{-1} it takes 200 / 6 s for Nicole to reach Space Vehicle 2 (SV2) = 33.33 seconds. Nicole only has the time that SP2 has to move 85 m to make contact – that time is 85 / 2.6 s = 32.69 s. It takes 196 / 6 s (32.67 s) to get within 4 m of SP2. In 32.69 s Nicole only travels 196.154 m (32.69 × 6). Puck has 32.69 – 32.67 seconds (0.02564 s) to move the 4m. This is equivalent to an average velocity of 156 m s^{-1}. Any speed lower than this will result in failure of the mission. Using conservation of momentum: When Nicole fires the puck forwards she will recoil backwards (the CoM will continue at 6 m s^{-1} forwards regardless). Looking at the extreme case: Results in a velocity of Nicole of 7.44 m s^{-1} backwards since she was already going at 6 m s^{-1} forwards she will now go 1.44 m s^{-1} backwards (from conservation of momentum). At this speed it is still possible for a successful mission. As long as the puck and Nicole come to a dead stop at the end of the explosion – the CoM will 0.15384 m further on from the 4 m point at the end of the explosion. This will mean that if the puck can travel greater than 3.84616 m during the explosion then the mission will be a success. The time of the explosion will be 4 / (v_p+ v_n) so the distance travelled by the puck in relation to the CoM will be $4v_p$ / (v_p+ v_n) if this is greater than 3.84616 m then the puck will make it. This will always be the case for velocities greater than about 150 m s^{-1}. Consideration will also be given to answers that show particular physical insight – such as discussion involving the enormous accelerations that would be experienced. The fact that the above model assumes that the puck and Nicole do not recoil when they reach the 4m extension. The fact that energy losses will result in the explosions.			
(ii)	At low velocity the puck does not collide so has no effect. At a speed of 750 m s^{-1} by considering conservation of momentum it can be shown that $4 \times 10^{-5} \times M \times 750$ (downwards) + $M \times 2.6$ (across) = Mv_{new} The acquired momentum will have little effect. (0.03 compared to 2.6). It will result in a torque on SP2. In terms of energy at say 300 m s^{-1} the energy of impact is similar to the kinetic energy of SP2 – there will be considerable damage caused. At higher velocities this effect will obviously be greater.			