(d) Clearly $s(t_c) = 0$ & $s(t) > 0$ for $t < t_c$

So $\lim_{t \to t_c} \dfrac{s(t) - s(t_c)}{t - t_c} \leq 0$ or

$$\dot{s}(t_c) \leq 0.$$

$\ddot{s} = 2W - U \rightarrow \ddot{s} > 0$ just before coll.

$$\dot{s}(t_c) - \dot{s}(t_c - \varepsilon) = \int_{t_c - \varepsilon}^{t_c} \ddot{s}(\tau)\,d\tau$$

or $$\dot{s}(t_c - \varepsilon) = \dot{s}(t_c) - \int_{t_c - \varepsilon}^{t_c} \ddot{s}(\tau)\,d\tau$$

Both terms on RHS are ≤ 0 so $\dot{s}(t_c - \varepsilon) \leq 0$.

(e) $-\dot{s}/s \geq 0$ clearly so

$$-\frac{\dot{s}\,\vec{L}_{cm}^{\,2}}{s} \leq -4\dot{s}(\ddot{s} - W)$$

$$\vec{L}_{cm}^{\,2} \int_{t_1}^{t_2} \left(-\frac{\dot{s}}{s}\right) dt' \leq 4\int_{t_1}^{t_2} \dot{s}(W - \ddot{s})\,dt'$$

$$-\vec{L}_{cm}^{\,2} \log\left[\frac{s(t_2)}{s(t_1)}\right] \leq 4\int_{t_1}^{t_2} \dot{s}(W - \ddot{s})\,dt'$$