The Gymnastics Research Institute

GRI's Physics of a Gymnastics Skill
The Math Breakdown

Skill: Simone Biles' Yurchenko Double Pike from Warm-up at US Classics 2023

Question: Roughly, how many G's does Simone experience when she lands her Yurchenko Double Pike Vault?

Key Equations:

$$Rotation\ Kinetic\ Energy\ (KE_r) = \frac{1}{2} * I_{pike} * \omega^2$$

$Moment\ of\ Inertia\ (I_{pike}) - calculated\ using\ the\ equations\ in\ Krishnan\ et\ al.$ [1]

$$Translational\ Kinetic\ Energy\ (KE_t) = \frac{1}{2} * m * {v_{impact}}^2$$

$$Gravitational\ Potential\ Energy\ (PE_g) = m * g * \Delta h$$

$$\Delta h = h_{COM\ @\ peak} - h_{COM\ @\ impact}$$

$$Average\ Acceleration = \frac{\Delta v}{\Delta t} = \frac{v_{impact} - v_{still}}{t_{impact} - t_{still}}$$

ω - angular velocity [=] rad/sec
m - mass [=] kg
l - height of the gymnast [=] m

v - velocity [=] m/s
g - acceleration due to gravity [=] m/s^2

h - height of center of mass at peak and at impact [=] m
t - time of impact and when movement downward stops [=] s

Math Breakdown:

$$PE_{g\ @\ peak} + KE_{r\ @\ peak} = KE_{t\ @\ impact}$$

$$m * g * \Delta h + \frac{1}{2} * I_{pike} * \omega^2 = \frac{1}{2} * m * {v_{impact}}^2$$

$$m * g * (h_{COM\ @\ peak} - h_{COM\ @\ impact}) + \frac{1}{2} * I_{pike} * \omega^2 = \frac{1}{2} * m * {v_{impact}}^2$$

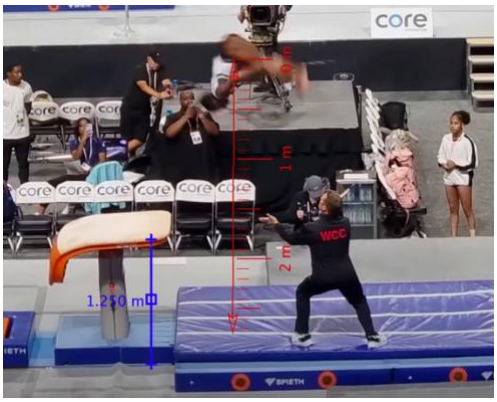
$$m * g * (h_{COM\ @\ peak} - h_{COM\ @\ impact}) + \frac{1}{2} * I_{pike} * \omega^2 = \frac{1}{2} * m * {v_{impact}}^2$$

$$g * (h_{COM\ @\ peak} - h_{COM\ @\ impact}) + \frac{1}{2} * I_{pike} * \omega^2/m = \frac{1}{2} * {v_{impact}}^2$$

$$2g * (h_{COM\ @\ peak} - h_{COM\ @\ impact}) + I_{pike} * \omega^2/m = {v_{impact}}^2$$

$$v_{impact} = \sqrt{2g * (h_{COM\ @\ peak} - h_{COM\ @\ impact}) + I_{pike} * \omega^2/m}$$

Adding In the Numbers:



$I_{pike} = 2.51\ kg * m^2$

$g = 9.8\frac{m}{s^2}$

$h_{COM\ @\ peak} = 2.743\ m$

$h_{COM\ @\ impact} = 0.564\ m$

$m = 47.17\ kg$

$l = 4'8" = 56\ in = 1.4224\ m$

$$\omega = \left(\frac{1\ rotation}{0.4\ sec}\right) * \left(\frac{60\ sec}{1\ min}\right) = 150\ rpm * \frac{2\pi}{60} = 15.71\ rad/sec$$

$$v_{impact} = \sqrt{2 * 9.8 * (2.743 - 0.564) + 2.51/47.17 * 15.71^2}$$
$$v_{impact} = \sqrt{55.841}$$
$$v_{impact} = 7.473\ m/s$$

$$Average\ Acceleration = \frac{\Delta v}{\Delta t} = \frac{v_{impact} - v_{still}}{t_{impact} - t_{still}}$$

$v_{impact} = 7.473\ m/s$
$v_{still} = 0\ m/s$
$t_{impact} = 1.14\ s$
$t_{still} = 1.25\ s$

Acceleration is negative because she is decelerating.

$$Average\ Acceleration = \frac{\Delta v}{\Delta t} = \frac{v_{impact} - v_{still}}{t_{impact} - t_{still}} = \frac{7.473 - 0}{1.14 - 1.25} = -67.9\ \frac{m}{s^2}$$

$$Average\ Acceleration = \frac{-67.9\ \frac{m}{s^2}}{9.8\frac{m}{s^2}} \approx -6.9\ Gs$$

Results: Simone experienced roughly 7 G's of force when she landed her Yurchenko Double Pike at the US Classic during warm-ups.

Works Cited

[1] R. H. Krishnan, V. Devanandh, A. K. Brahma and S. Pugazhenthi, "ESTIMATION OF MASS MOMENT OF INERTIA OF HUMAN BODY, WHEN BENDING FORWARD, FOR THE DESIGN OF A SELF-TRANSFER ROBOTIC FACILITY," *Journal of Engineering Science and Technology,* vol. 11, no. 2, pp. 166-176, 2016.