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Additional Problems: Estimating force in rugby tackles

I. INTRODUCTION

When All-Black Jonah Lomu burst onto the international rugby scene in the 1995 world cup, he caused a sensation. He was bigger and faster than anyone else, and shocked England in the semi-final by scoring four tries against them, including one where he ran straight over their fullback Mike Catt. He was also a terrifying proposition in defense, making huge tackles against a number of players. The aim here is to estimate how much force Jonah Lomu tackled with, and to understand how much more forceful his tackles were than those of lighter slower players.

II. ESSENTIAL PHYSICS

a) The momentum of a moving body is the product of its mass m and its velocity v:

$$p = mv. \tag{2.1}$$

b) To change the momentum of a body, we must apply a force, F, to it. Newton's second law of motion tells us force is equal to the rate of change of momentum:

$$F = \frac{dp}{dt}. \tag{2.2}$$

c) If a body changes its momentum by an amount Δp in a time Δt the rate of change of its momentum is approximately

$$F = \frac{dp}{dt} \approx \frac{\Delta p}{\Delta t}. \tag{2.3}$$

d) Newon's third law: if A applies a force F to B, then B must simultaneously apply a force of $-F$ to A.

FIG. 1: Jonah Lomu. Photo credit: Bjorn Bednarek. CC BY-SA 2.0 License.

Our strategy is to estimate Jonah's change of momentum during a tackle, Δp, estimate how long the tackle takes, Δt, and hence estimate the force exerted on Jonah by his opponent during the tackle. By Newton's third law, this is equal to the force Jonah exerts on the player he is tackling.

III. JONAH LOMU'S SPEED

In figure 2 we show two frames from a video showing Jonah Lomu, circled in red, running into a tackle. The stills are ten frames apart and the video was filmed at 30fps. On the right we show the two frames superposed. Jonah has moved the distance between the red crosses.

Exercise 1. *Given that Jonah is 2m tall, estimate v, the speed he enters the tackle with.*

IV. FORCE OF A TACKLE 1: TIME

Exercise 2. *Jonah Lomu has a mass of 120kg. How much momentum, p_i, does he have going into the tackle?*

Exercise 3. *During the tackle, Jonah is brought to a complete halt. How big an impulse, Δp, has he had?*

FIG. 2: Left and centre: two frames separated by 1/3s showing Jonah (circled) approaching a tackle. Right: Frames superposed. Jonah has moved the distance between the red crosses.

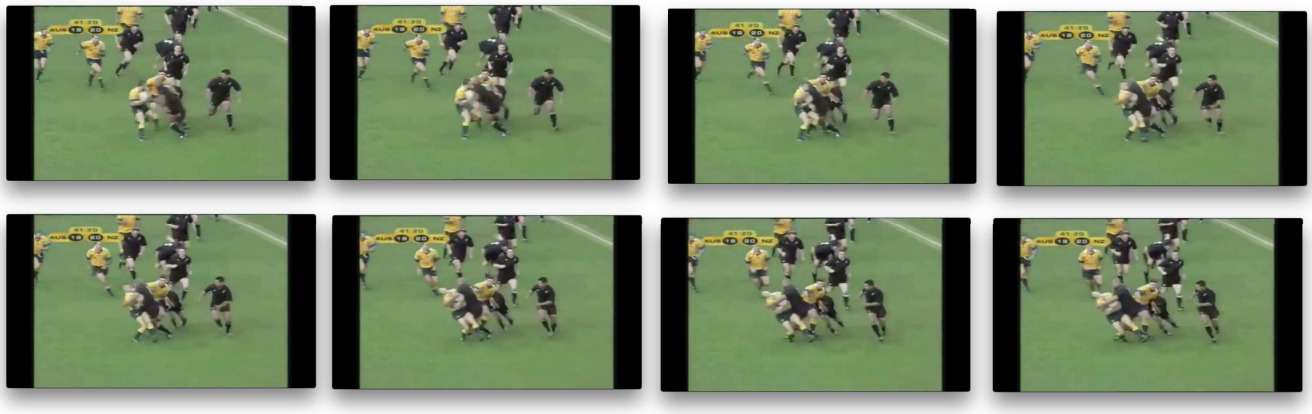

FIG. 3: 8 frames showing Jonah collide in the same tackle as fig. 2. The video is at 30fps.

Figure 3 shows 8 video frames spanning the tackle. In the first three frames Jonah is still approaching the player with the ball. In the last three frames both players are simply falling over without horizontal motion. We thus assume the collision in the tackle starts at frame four, and finishes at frame 6.

Exercise 4. *Assuming that the force Jonah applies to the other player is constant during the collision, what force does Jonah tackle with?*

Exercise 5. *What is the mass, M, of an object whose weight is equal to Jonah's tackling force?*

V. FORCE OF A TACKLE 2: DISTANCE

Rugby players typically tackle shoulder first, bent over as shown in fig. 4. We can model the tackle by assuming that the player with the ball remains stationary, while the tackling player straightens up during the tackle, effectively moving forward a distance $s = 1m$ while coming to a halt.

Exercise 6. *Assuming Jonah approaches the tackle at his top speed of $v = 10\text{ms}^{-1}$ and decelerates at a constant rate during the tackle, how long, Δt, does the tackle last?*

Exercise 7. *What is the force of the tackle, remembering that Jonah Lomu has a mass of* 120kg.

In a bad tackle the player may fail to bend over, leading to the players' chests colliding. In this case the player's chests must compress during the collision, leading to a much shorter stopping distance.

Exercise 8. *If in this case Jonah stops in a distance $s = 10\text{cm}$ what is the force of the tackle?*

A more usual player might weigh 80kg and move only 80% as fast as Jonah.

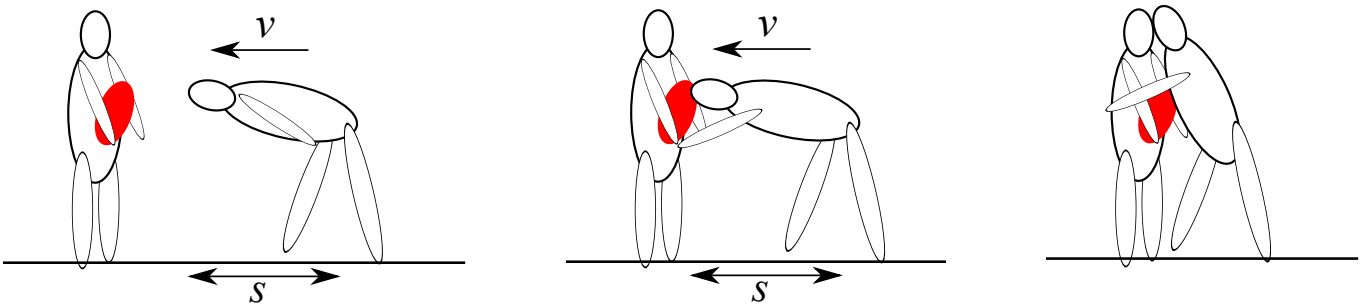

FIG. 4: Approximation of a rugby tackle. Left: The tackling player runs in with a velocity v bent over into an L shape. Middle: the tackling player collides. Right: During the collision the tackling player comes to a halt at straightens up, moving a distance s during the tackle.

Exercise 9. *What percentage of Jonah's force does a normal player tackle with?*

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