Lab #4 - Linear Impulse and Momentum

Purpose:

The objective of this lab is to understand the linear and angular impulse/momentum relationship. Upon completion of this lab you will:

- Understand and know how to calculate positive and negative impulse using both the trapezoidal rule in Excel and the grid block method.
- Understand and know how to calculate moment arms, moments of horizontal and vertical forces, and angular momentum.
- Be able to plot moment-time curves from a data set.

Introduction:

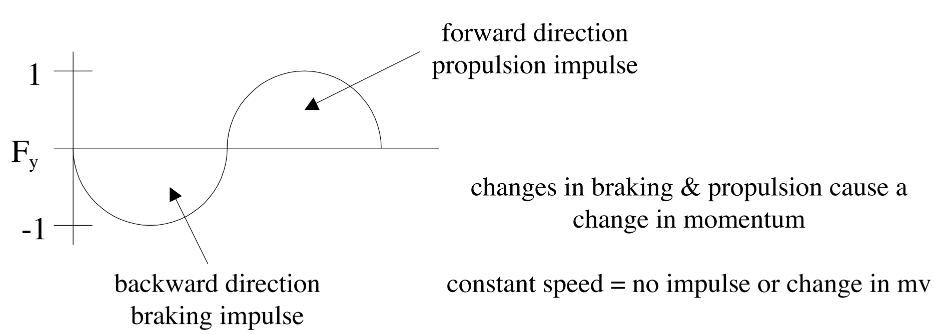
Many athletic movements, such as the takeoff of a dive, require athletes to generate both linear and angular impulse. The linear impulse will translate the total body center of mass (TBCM) in the direction of the net linear impulse relative to the TBCM. Similarly, the angular impulse will rotate the TBCM in the direction of the net angular impulse relative to the TBCM.

I. IMPULSE

Linear impulse represents the effect of a force on a system. It is defined as the net force acting over a specified time period.

Linear Impulse = $\Sigma F \Delta t$ = area under force-time curve

Figure 1. An example of horizontal reaction force.



Propulsive Impulse > Braking Impulse => Increase in velocity
Propulsive Impulse < Braking Impulse => Decrease in velocity

II. MOMENTUM

Linear momentum represents the quantity of motion that a body possesses. It is defined as the product of the mass of an object and its velocity.

L = m * v

Where L = linear momentum
m = mass
v = linear velocity

III. PRINCIPLE OF IMPULSE AND MOMENTUM

The principle of impulse and momentum is a useful concept for understanding the cause-effect relationship between kinetics (forces) and kinematics (motion). Newton's Second Law illustrates the basic relationship that **ΣF = ma** (cause = effect). From this relationship we are able to substitute and rearrange terms to come up with other useful relationships.

$$\Sigma F = ma$$

$$\text{substitute:} \quad a = (v_f - v_i)/\Delta t$$

$$\Sigma F = m((v_f - v_i)/\Delta t)$$

$$\Sigma F\Delta t = m(v_f - v_i)$$

$$\mathbf{\Sigma F\Delta t = mv_f - mv_i}$$

Here, we see that the linear impulse created by forces acting on an object is equal to the change in momentum of the object.

Rearranging the terms a different way,

$$\boxed{\mathbf{mv_f = mv_i + \Sigma F\Delta t}}$$

Here, the final momentum of an object is equal to an object's initial momentum and the impulse created by the forces acting on the object over a specified time period.

Pre Lab:

The ground reaction forces generated during a back and reverse rotating dive are shown on the following pages. ONLY DO THIS FOR Subject 1. (Subject 2 IS PRACTICE.)

1. Label the Load, Tip and Push phases on the force curves. Please see the handout on the webpage that defines "Load, Tip and Push."
2. For both dives, draw a complete free body diagram (including all forces) and mass acceleration diagram for a time point in each phase using the information given in the graph. Define your coordinate system and the system of interest (person). Load: t = -0.35s, Tip: t = -0.275s, Push: t = -0.1s, Flight: t = 0.1s
3. For both dives, draw the free body diagrams (using the forces APPLIED to the force plate) during the load, tip, push, and flight phases of each trial**.**
4. In each force curve, estimate the impulse due to vertical reaction force (Rv) using the "box counting method", by counting boxes formed by the positive portion of each force-time curve. Multiply the number of boxes counted by the area of one box (units: Ns) to estimate the total area under the curve (impulse).
5. In each force curve, estimate the impulse due to body weight (BW) using the box counting method.
6. Using what you calculated from steps 4 and 5, please calculate the NET vertical impulse (impulse due to Rv- impulse due to BW).
7. In each force curve, estimate the positive (+) impulse (above zero) due to horizontal reaction force (Rh) using the box counting method.
8. In each force curve, calculate the negative (-) vertical and negative horizontal impulse (below zero) by counting the boxes formed by the negative portion of the force-time curve. Again, multiply the number of boxes counted by the area of one box to estimate the total area under the curve (impulse). Start from t=0.
9. In both graphs, calculate the net horizontal impulse as the sum of positive and negative horizontal impulse.

10. Assuming that the velocity at the beginning of the graph is zero, what are the horizontal and vertical velocities at takeoff ($t = 0, v_f$) of each dive? Remember what the full form of the impulse-momentum relationship states.

Force Based Definitions of Diving Events

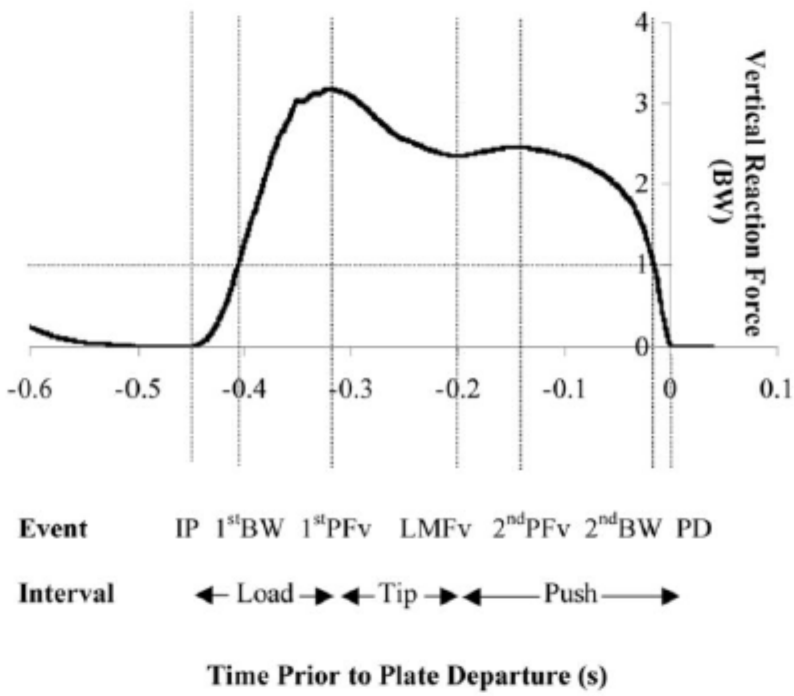
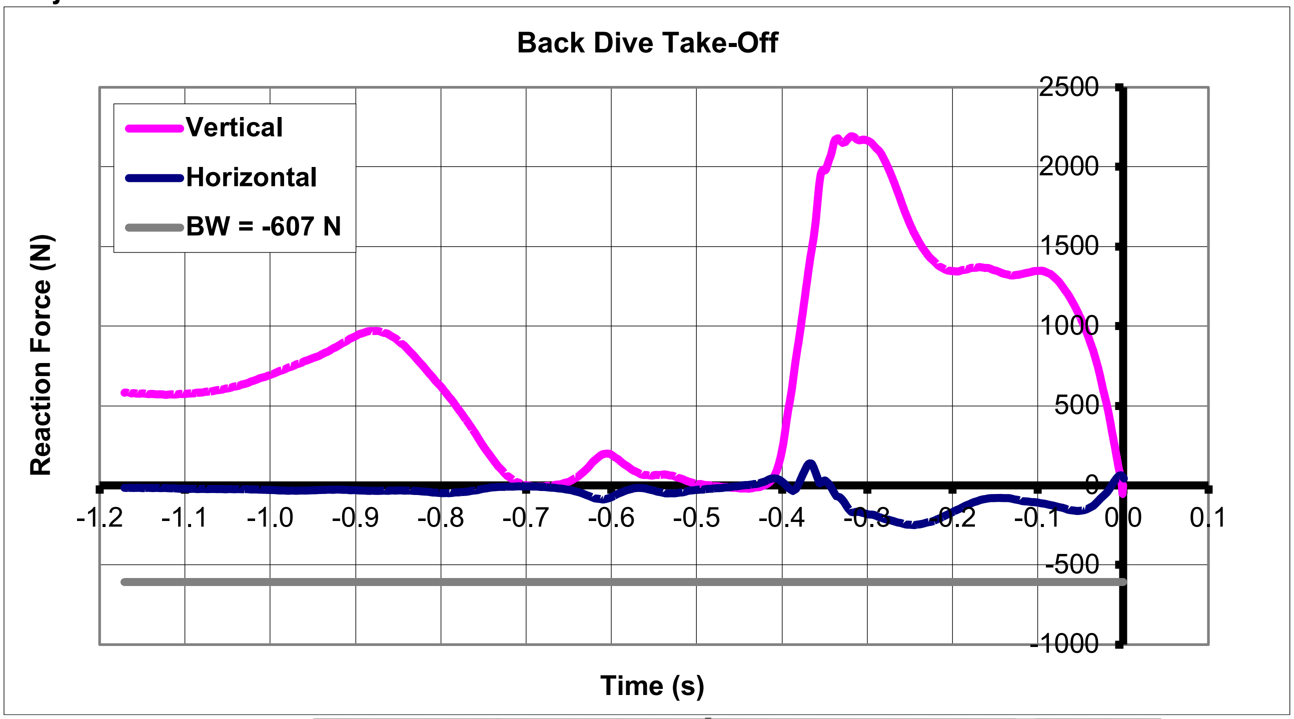


Figure 2 — A series of events and intervals within the take-off phase of the experimental tasks. The load interval is defined as the interval from initial increase of ground reaction force (initial position [IP]) to the time of first peak vertical ground reaction force (1stPFv). The Tip interval is identified as the time from the peak to the local minimum vertical ground reaction force (LMFv). The Push interval lasts from the local minimum vertical ground reaction force to plate departure (PD). Note that 1stBW and 2ndBW indicated the time of vertical ground reaction force equals to the body weight prior to the 1stPFv and PD, respectively. In addition, 2ndPFv signified the time of second peak vertical ground reaction force.

For the Pre-Lab:

'Load' starts at first rise in force and ends at the top of the first peak (-0.45s to -0.32s here)
'Tip' starts at first peak and end at the first minimum (-0.32s to -0.20s here)
'Push' starts at the first minimum and ends at departure (-0.20s to 0.00s in this image)

Subject 1



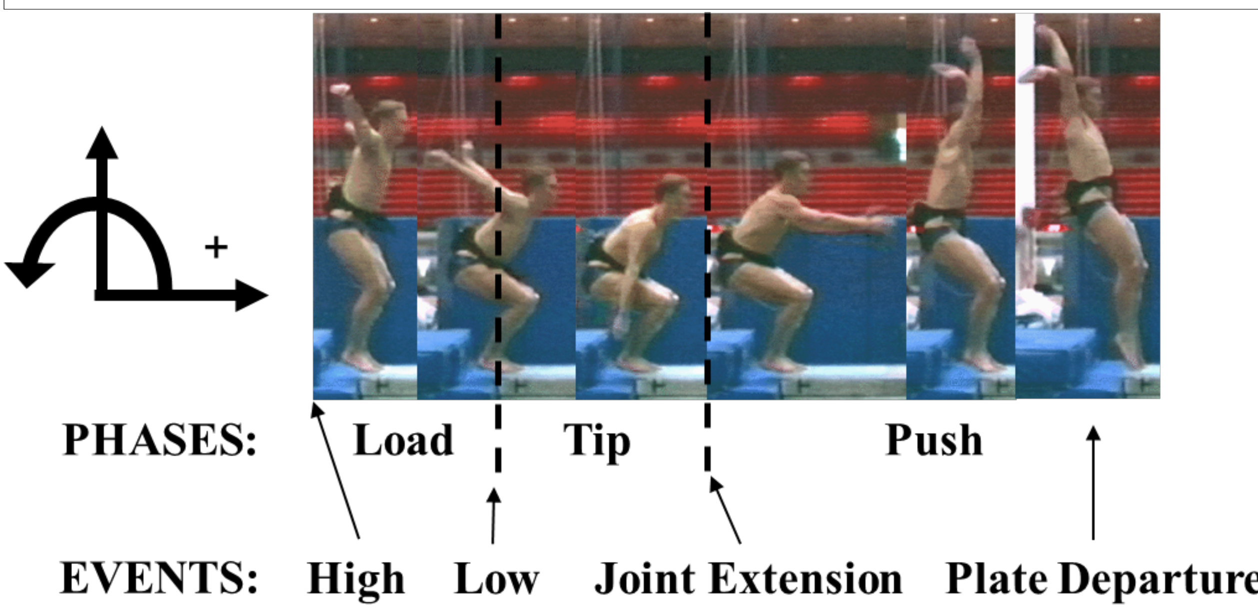
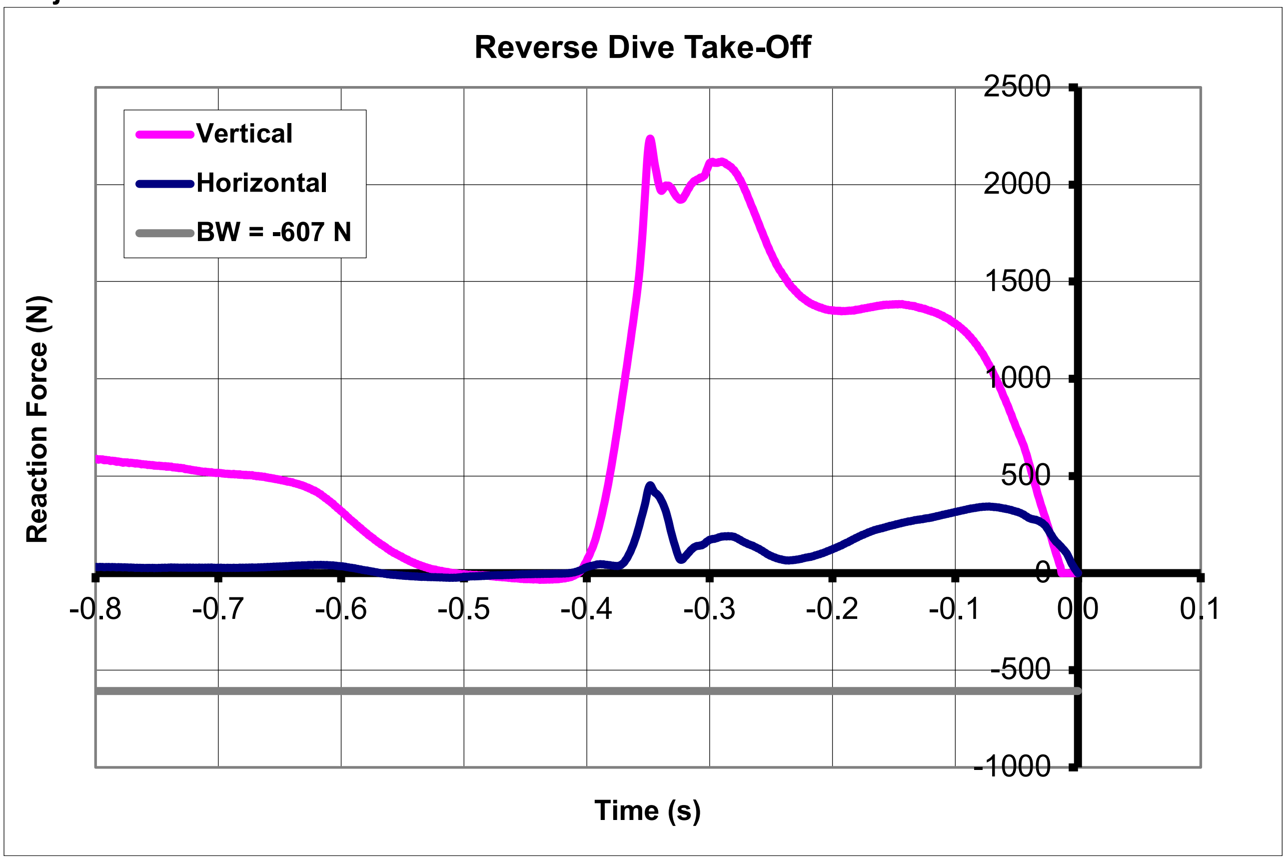


Figure 3. Reaction force during the takeoff phase of a back rotating dive. The reference system of the reaction force and direction of movement is given on the left. The representative body position of each phase is shown.

Subject 1



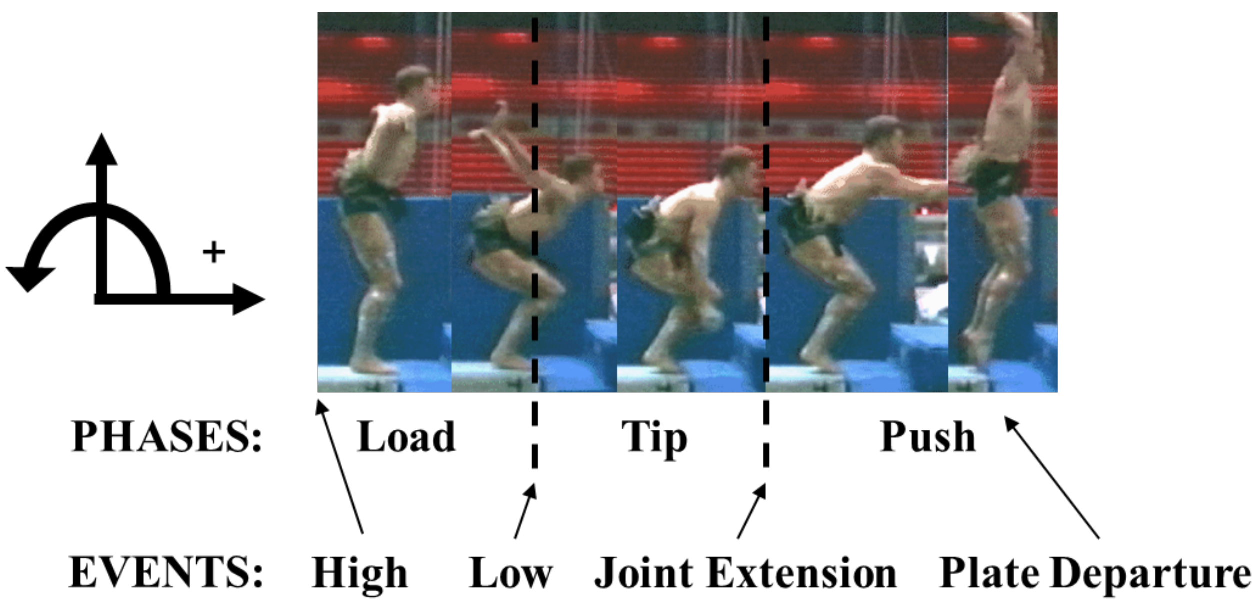


Figure 4. Reaction force during the takeoff phase of a reverse rotating dive. The reference system of the reaction force and direction of movement is given on the left. The representative body position of each phase is shown. Please note the difference in direction of the horizontal reaction force between the back and reverse rotating dive.

Subject 2

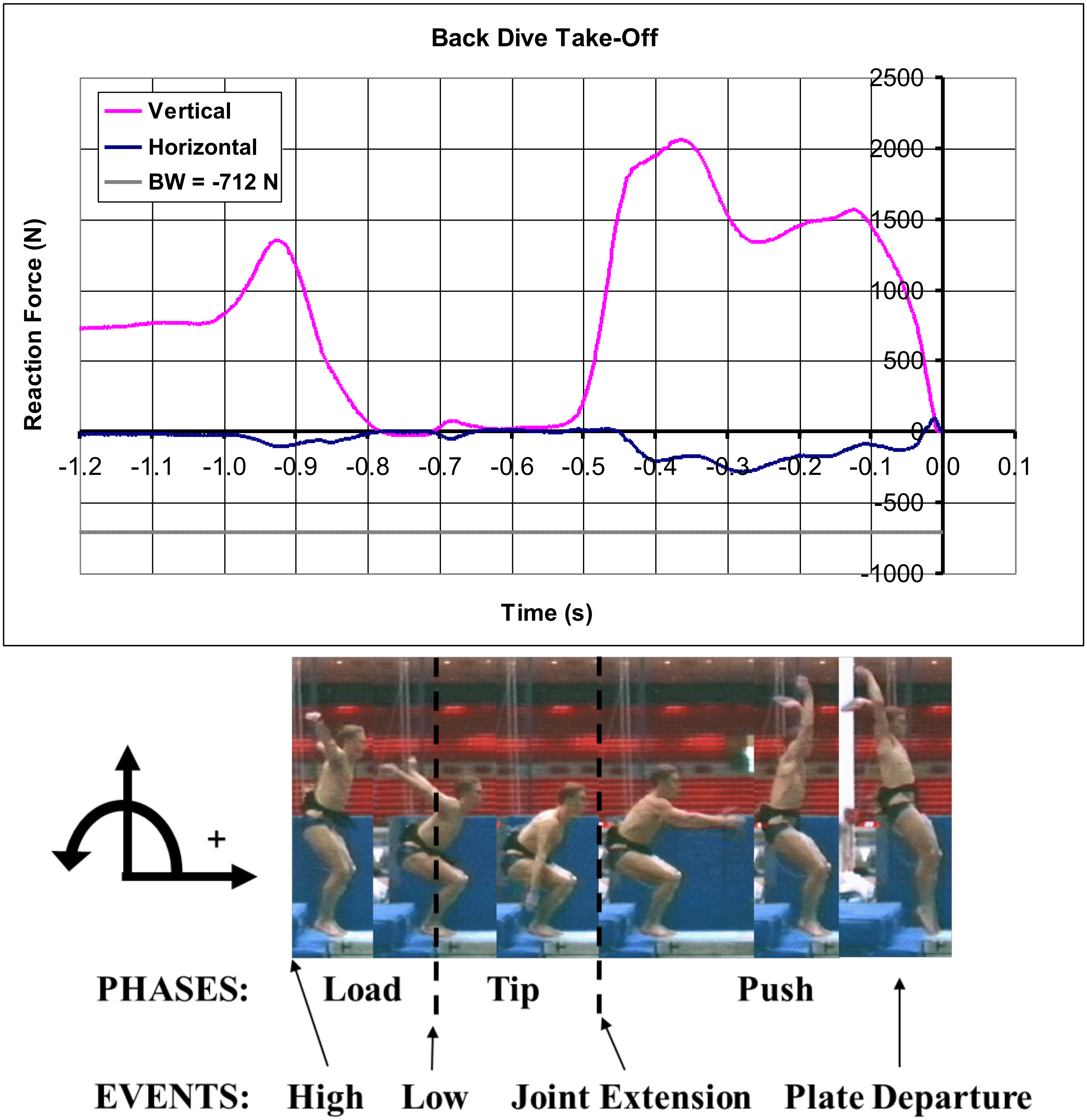
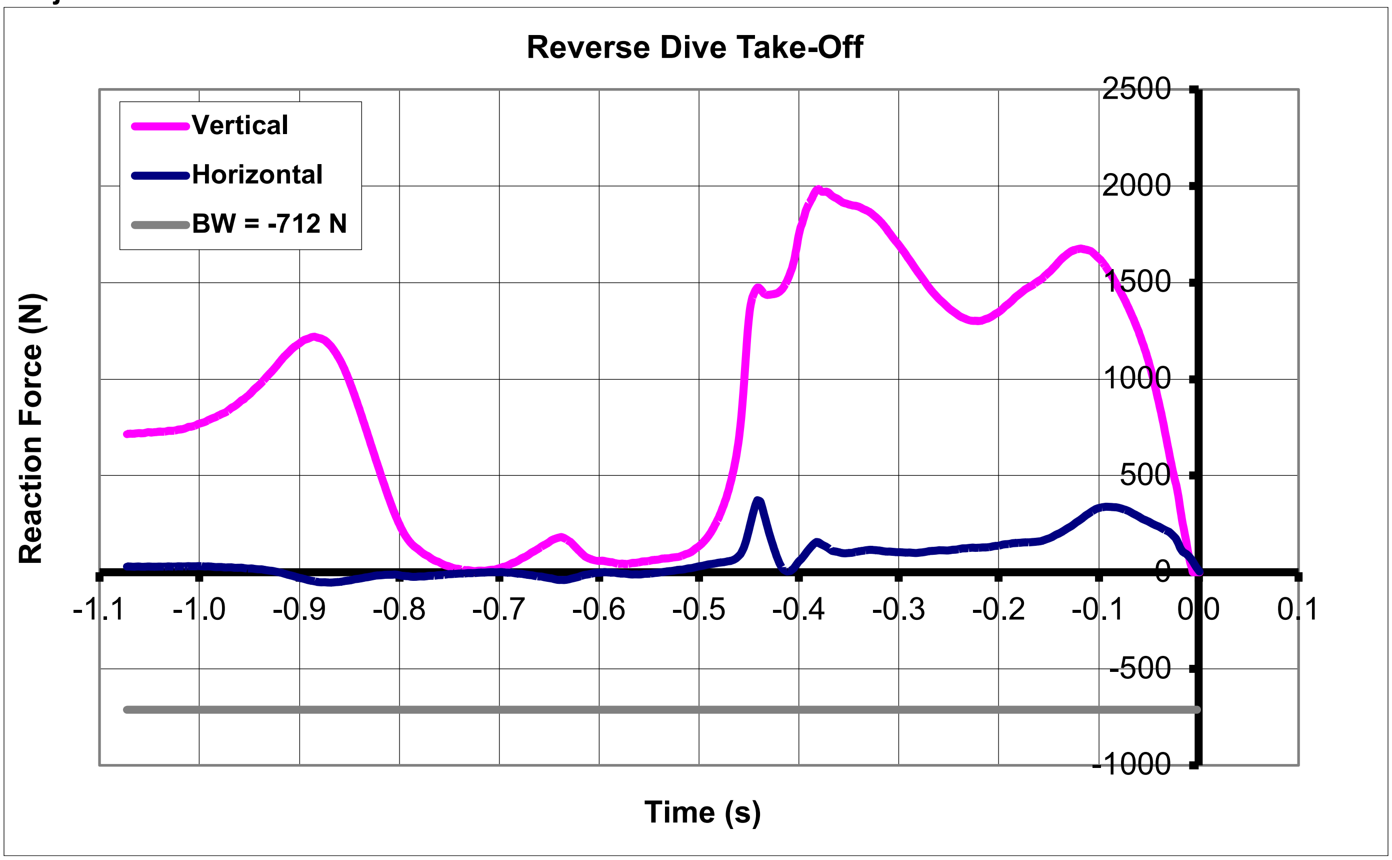


Figure 5. Reaction force during the takeoff phase of a back rotating dive. The reference system of the reaction force and direction of movement is given on the left. The representative body position of each phase is shown.

Subject 2



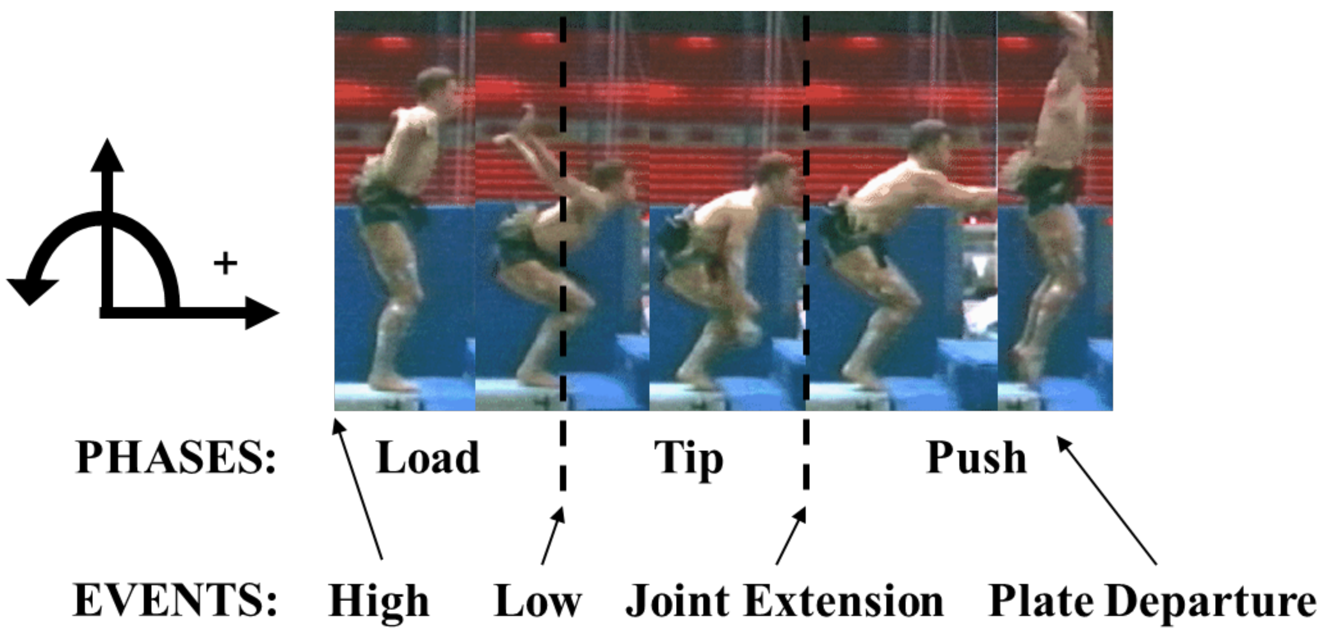


Figure 6. Reaction force during the takeoff phase of a reverse rotating dive. The reference system of the reaction force and direction of movement is given on the left. The representative body position of each phase is shown. Please note the difference in direction of the horizontal reaction force between the back and reverse rotating dive.

Lab #4 - Laboratory Procedure:

In this lab, you will use force data of a diver performing a back timer, back, and reverse rotating dive takeoff to generate and analyze three force-time curves.

RULES: Delete excel cells that refer to empty cells.

1. Save the Excel file named “Linear Impulse” for your subject to the desktop. Open the file from within Excel and save it as a new file.
2. In this file, locate the following data: Frame, Time, Horizontal, Vertical, BW. Horizontal and Vertical are the ground reaction forces acting on the subject.
3. For each dive, calculate the vertical impulse due to vertical reaction force by integrating the Rv force curve.
    a. Use the **trapezoidal rule** to compute the integral in Excel. You may need to increase the number of decimal points you display in order to see the values.
    b. Start at the first frame (quiet standing).
    c. End when the diver leaves the force plate (end of plate contact; t=0s).
    d. Calculate the total positive vertical impulse (due to Rv) by summing this column of data.
4. For each dive, calculate the negative vertical impulse by integrating the BW curve.
    a. Use the trapezoidal rule to compute the integral in Excel.
    b. Start at the first frame (quiet standing).
    c. End when the diver leaves the force plate (end of plate contact; t=0s).
    d. Calculate the total negative vertical impulse (due to BW) by summing this column of data.
5. For each dive, calculate the total positive and negative horizontal impulse.
    a. Integrate the horizontal force curve from the first frame to when the diver leaves the force plate.
    b. Start at the first frame (quiet standing).
    c. End when the diver leaves the force plate (end of plate contact; t=0s).
    d. Calculate the total positive and total negative horizontal impulse by summing this column of data. Note that there will be positive and negative values in this column that correspond to when the horizontal force is positive or negative.
6. For each dive, calculate the net vertical impulse (sum of positive and negative vertical impulse).
7. For each dive, calculate the net horizontal impulse (sum of positive and negative horizontal impulse).
8. For each dive, calculate the change in horizontal and vertical velocities due to the impulse generated during the takeoff phase. Use the impulse/momentum relationship.

Lab #4 - Analysis and Questions:

1. In your own words, define linear impulse and explain what information it provides. Do *not* use equations.
2. Describe the contributions of horizontal and vertical impulse to jump height and jump distance. Should you increase net horizontal and/or net vertical impulse to increase jump height? Should you increase net horizontal and/or net vertical impulse to increase jump distance?
3. Provide a table with the positive, negative and net horizontal and vertical impulse values that you calculated for all three dives.
4. For the back and reverse dives, compare the positive, negative and net horizontal and vertical impulse values you obtained using the trapezoidal integration method with that of the grid block addition method used in the Pre Lab section. Do your values agree with what you expected? Explain any differences.
5. During the back timer, in what direction will the diver translate relative to the body (forward or backward) as a result of the net horizontal impulse observed? **Just choose forward or backward as an answer.**
6. During the back, in what direction will the diver translate relative to the body (forward or backward) as a result of the net horizontal impulse observed? **Just choose forward or backward as an answer.**
7. During the reverse, in what direction will the diver translate relative to the body (forward or backward) as a result of the net horizontal impulse observed? **Just choose forward or backward as an answer.**
8. Compare the net horizontal and vertical impulses of the back timer and the back. How do you think these differences would be reflected in terms of the diver’s performance?

9. Compare the net horizontal and vertical impulses of the back and the reverse. How do you think these differences would be reflected in terms of the diver's performance?
10. Is the velocity you calculated in step 8 the take-off velocity? Why or why not?