



Jordan University of Science and Technology
Faculty of Engineering
Biomedical Engineering Department

BioMechanics and BioMaterials Lab

BME 541

Part I: Biomechanics

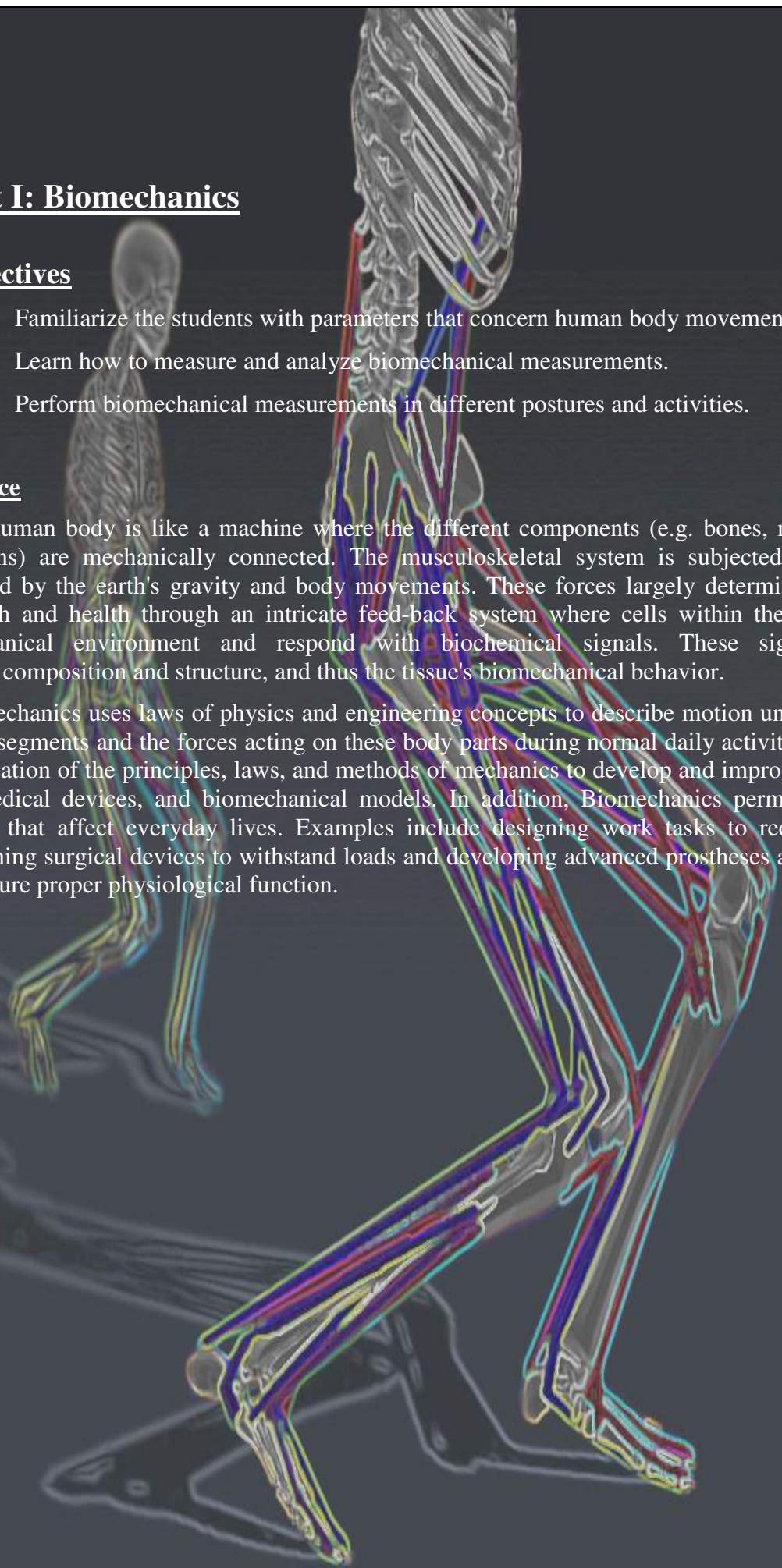
Objectives

- Familiarize the students with parameters that concern human body movements.
- Learn how to measure and analyze biomechanical measurements.
- Perform biomechanical measurements in different postures and activities.

Preface

The human body is like a machine where the different components (e.g. bones, muscles, ligaments and tendons) are mechanically connected. The musculoskeletal system is subjected to mechanical forces created by the earth's gravity and body movements. These forces largely determine tissue development, growth and health through an intricate feed-back system where cells within the tissue can sense their mechanical environment and respond with biochemical signals. These signals in turn alter the tissue composition and structure, and thus the tissue's biomechanical behavior.

Biomechanics uses laws of physics and engineering concepts to describe motion undergone by the various body segments and the forces acting on these body parts during normal daily activities. It also involves the application of the principles, laws, and methods of mechanics to develop and improve medical diagnostics, biomedical devices, and biomechanical models. In addition, Biomechanics permeates a wide range of fields that affect everyday lives. Examples include designing work tasks to reduce physical stresses, designing surgical devices to withstand loads and developing advanced prostheses and surgical procedures to ensure proper physiological function.



Experiment #1

Biomechanical Analysis

Anthropometry and Goniometry

Objectives

1. To learn how to use the measuring instruments.
2. To learn how to perform and describe reference points to take anthropometric and range of motion measurements.
3. To express anthropometric measures in percentiles of any similar population for the measured data.
4. To become familiar with goniometry system.
5. To study the range of motion for selected body joints.

Theory

Anatomical Body Planes

An anatomical plane is a hypothetical plane used to transect the human body, in order to describe the location of structures or the direction of movements. In human anatomy, three principal planes are used:

- The sagittal plane or median plane (longitudinal, anteroposterior) is a plane parallel to the sagittal suture. It divides the body into left and right.
- The coronal plane or frontal plane (vertical) divides the body into dorsal and ventral (back and front, or posterior and anterior) portions.
- The transverse plane or axial plane (lateral, horizontal) divides the body into cranial and caudal (head and tail) portions.

There are two primary types of dimensions:

1. Static dimension: taken when the body is in fixed (static) positions (Shoulder height).
2. Dynamic dimensions: taken under conditions in which the body is engaged in some physical activity, such as practical limit of arm reach.

Anthropometry

Anthropometry simply means "measurement of people". The word is derived from the Greek 'Anthropos' meaning human, and 'metrein' meaning measure. It is the science that deals with the measurement of size, mass, shape and inertial properties of the human body. Anthropometry is empirical in nature and has developed quantitative methods to measure various physical dimensions and other properties of specific populations. The results are statistical data describing human size, mass, and form. Anthropometric data are fundamental to occupational biomechanics and without such data biomechanical models that predict human reach, force and space requirements cannot be developed.

When performing a biomechanical analysis of a person, the human body is considered to be a system of mechanical links with each link of known physical size and form. Anthropometry defines these size and form properties as the followings:

- Body-Segment Link Length
- Body-Segment Volume and Weight
- Body-Segment Link Locations of Center of Mass
- Body-Segment Inertial Property

Standard anthropometric postures for standing and sitting:

For the seated person measurements are taken relative to the horizontal and vertical reference planes that represent the seat surface and back of the seat. The point where these two planes and the median plane of the body intersect is called the seat reference point (SRP) (Fig. 1a).

In the standard standing posture, the person must be in a free standing position, erect at full height with eyes looking straight ahead, with relaxed shoulders and arms down to the sides (Fig. 1b).

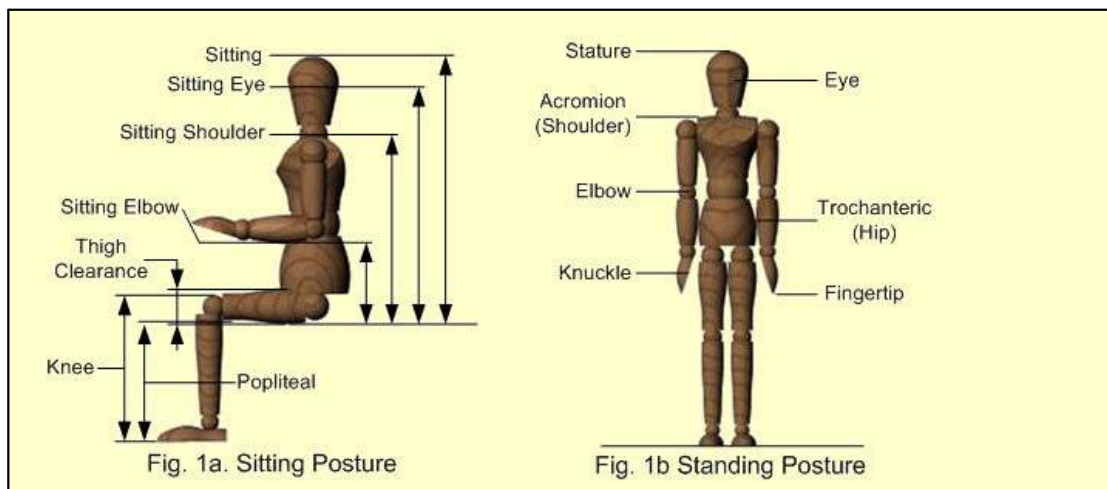


Fig.1: Various Heights for Standard Anthropometric Postures

Goniometry

Joint motion is often referred to as joint mobility or joint flexibility. Although joint motion could be defined relative to a specific absolute posture, it is generally conceded that body segments rotate about a joint; thus the range of motion (maximum angular deviation) available at the joint is the best means to express joint mobility. This measure is quite acceptable for primarily simple joint rotation found when one flexes or extends the elbow or knee. For more complex joints, such as those at the hips and shoulders, motion must be expressed with reference to a particular plane of motion—that is in the sagittal, frontal (coronal) or horizontal (transverse) planes. Because of this complication, a set of definitions has been developed for all major joints which assume that motion is measured with the person beginning in the standard anatomical position.

Various systems have been developed to measure joint motion which seek to satisfy accuracy, repeatability, ease of use, low cost and flexibility one of these systems is "Goniometry". The term goniometry is derived from two Greek words "gōnia" meaning angle, and "metron" meaning measure. Goniometry refers to the measurement of angles created at human joints by the bones of the body.

A goniometer is a special name given to the sensor that can be attached to measure a joint angle. One arm of the goniometer is attached to one limb segment, the other to the adjacent limb segment, and the axis of the goniometer is aligned to the joint axis.

Materials and Methods

1. Anthropometric calipers (The Large Anthropometer has a range of 0 to 60 cm in 0.1 cm increments. Popular uses include measuring shoulder width, long bone length and chest depth for tracking growth and development of children or for use in motion analysis studies. Aluminum in

construction, it uses a spring-loaded ball bearing in a sliding C-shaped arm to provide accurate and precise measurement. The Small Anthropometer has a range of 0 to 30 cm in 0.1 cm increments. Popular uses include measuring wrist, elbow, knee and ankle widths, as well as measuring smaller muscle masses like the bicep and calf. Aluminum in construction, it uses a spring-loaded ball bearing in a sliding C-shaped arm to provide accurate and precise measurement).

2. Twin axis goniometers (SG65 (wrist joint) and SG110 (elbow, ankle and neck joints): "SG" series twin axis goniometers (Figure 2) permit the simultaneous measurement of angles in two planes, e.g. wrist flexion/extension and radial/ulnar deviation. Referring to Figure 3 below rotation of one end block relative to the other about axis X-X is measured using the grey plug and the green plug measures the rotation of one end block relative to the other about axis Y-Y.

The working principle of the lab used goniometer is that between the two end blocks inside the protective spring there is a composite wire that has a series of strain gages mounted around the circumference. As the angle between the two ends changes, the change in strain along the length of the wire is measured and this is equated to angle.

When mounting the goniometer across the joint, the center of rotation of the sensor does not coincide with the center of rotation of the joint. As the joint moves through a determined angle the relative linear distance between the two mounting positions will change.

3. Measuring tape
4. Metric scale



Figure 2: SG series twin axis goniometers

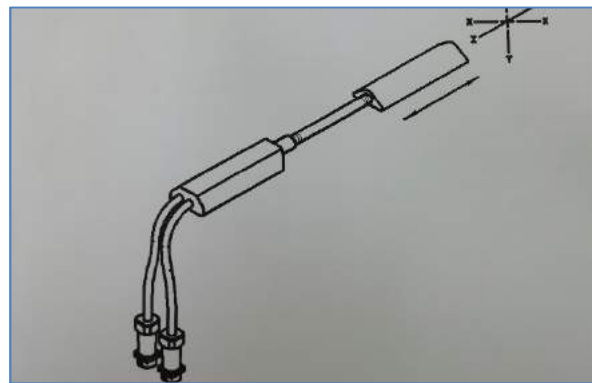


Figure 3: Twin axis goniometer SG series

Procedure

Part one- Anthropometry

Practical guidelines for lab:

1. Each member of the lab group will be assigned to a measurement group and will provide that measurement to all other members.
2. Be as accurate as possible in your measurements and follow the procedures as described.
3. Perform each measurement 3 times and compute the mean of the three performances.
4. Avoid any kind of bent or unnatural posture.
5. Avoid keeping an arm outstretched either forwards or sideways.

Height and Length Measurements

1. All heights and lengths should be measured along the Longitudinal axis for the total body or the segment.
2. The measuring tape or anthropometer should be placed at the appropriate anatomical location.

Stature Measurement

The vertical distance from the standing floor to the vertex (the highest point on the head and it is dependent on the orientation of the head).

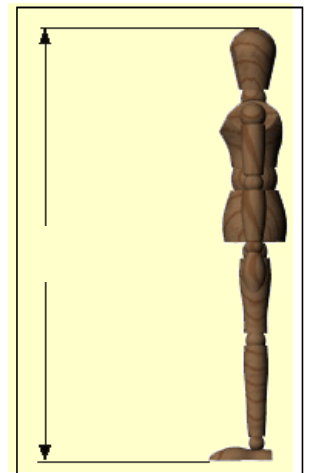
Stature

Reading 1 -----cm
Reading 2 -----cm
Reading 3 -----cm

Mean ----- cm

Method:

- Ask the subject to stand erect stretching upwards to the fullest extent, barefoot on a level floor against the wall with her/his back touching the wall and as straight as possible.
- Mark the required landmarks.
- Stand on the right side of the subject with measuring tape placed in the median sagittal plane of the subject and pulled it taut.
- Record your reading.

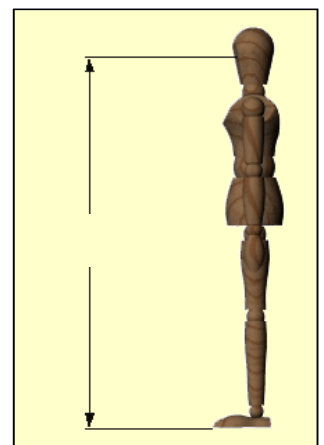


Eye height

Vertical distance from the floor to the inner canthus (corner) of the eye.

Method:

- Ask the subject to stand erect stretching upwards to the fullest extent, barefoot on a level floor against the wall with her/his back touching the wall and as straight as possible.
- Mark the required landmarks.



- Stand on the right side of the subject with measuring tape placed in the median sagittal plane of the subject and pulled it taut.
- Record your reading.

Eye height

Reading 1 -----cm
 Reading 2 -----cm
 Reading 3 -----cm

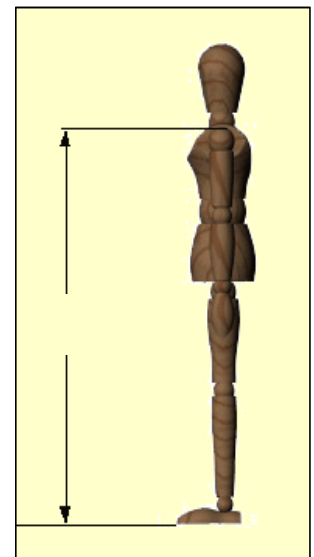
Mean ----- cm

Shoulder height

Vertical distance from the floor to the acromion (the bony tip of the shoulder).

Method:

- Ask the subject to stand erect stretching upwards to the fullest extent, barefoot on a level floor against the wall with her/his back touching the wall and as straight as possible.
- Mark the required landmarks.
- Stand on the right side of the subject with measuring tape placed in the median sagittal plane of the subject and pulled it taut.
- Record your reading.



Shoulder height

Reading 1 -----cm
 Reading 2 -----cm
 Reading 3 -----cm

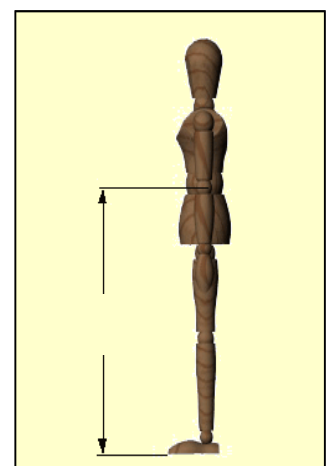
Mean ----- cm

Elbow height

Vertical distance from the floor to the radiale (The radiale is the bony landmark formed by the upper end of the radius bone)

Method:

- Ask the subject to stand erect stretching upwards to the fullest extent, barefoot on a level floor against the wall with her/his back touching the wall and as straight as possible.
- Mark the required landmarks.



- Stand on the right side of the subject with measuring tape placed in the median sagittal plane of the subject and pulled it taut.
- Record your reading.

Elbow height

Reading 1	-----cm	
Reading 2	-----cm	Mean ----- cm
Reading 3	-----cm	

Upper limb length

- **Total upper extremity Length**
Distance from the acromion to the fingertip.

Method:

- Ask the subject to stand in a standard arm hanging position.
- Mark the required landmarks.
- Stand on the right side of the subject with measuring tape/anthropometer.
- Record your reading.

Total upper extremity length

Reading 1	-----cm	
Reading 2	-----cm	Mean ----- cm
Reading 3	-----cm	

- **Segmental measurements**
 - a. **Shoulder-elbow length (Upper arm length):** Distance from the acromion to underside of the elbow.

Method:

- The subject may stand or sit. His upper arm hangs vertical at his side, making a right angle with the forearm.
- The fixed cross-bar of the anthropometer is placed on the acromion process (the uppermost bony point on the lateral aspect of the shoulder), and the movable cross-bar is raised until it makes firm contact with the olecranon process (bottom of elbow).
- The main anthropometer bar is held vertical.

Shoulder-elbow length

Reading 1	-----cm	
Reading 2	-----cm	Mean ----- cm
Reading 3	-----cm	

- b. **Elbow-wrist length (Forearm length):** Distance from the back of the elbow to the tip of the wrist.

Method:

- The subject may stand or sit, holding his upper arm and forearm as for (a) above.
- With the main anthropometer bar parallel to the forearm, the fixed cross-bar touches the olecranon process (behind the elbow) and the movable arm makes light contact with the tip of the wrist.

Elbow-wrist length

Reading 1	-----cm	
Reading 2	-----cm	Mean ----- cm
Reading 3	-----cm	

- c. **Hand Length:** Distance from the crease of the wrist to the tip of the middle finger with the hand held straight and stiff.

Method:

- The subject holds his right hand straight, fingers open stiffly.
- With the shaft of the small sliding anthropometer parallel to the long axis of the subject's hand, the fixed cross-bar is hooked behind the proximal border (away from the fingertips towards the wrist) of the navicular bone at the base of the thumb. The movable bar of the anthropometer makes light contact with the distal end of the middle fingertip.

Hand length

Reading 1	-----cm	
Reading 2	-----cm	Mean ----- cm
Reading 3	-----cm	

Lower limb measurement

• **Total lower extremity Length**

It is the vertical distance from standing floor of the subject to iliospinale (It is the most forward point on the anterior superior iliac spine) in erect position of the subject.

Method:

- With subject standing erect.
- Place the anthropometer/measuring tape vertical on the landmarks
- Record your reading.

Total lower extremity length

Reading 1	-----cm	
Reading 2	-----cm	Mean ----- cm
Reading 3	-----cm	

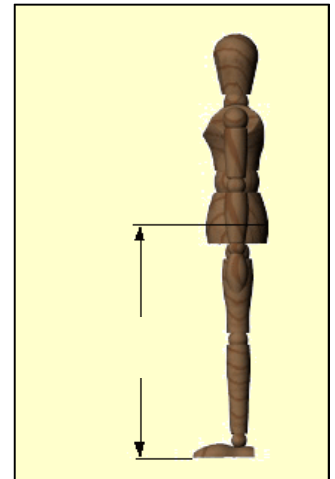
• **Segmental measurements**

a. **Hip height**

Vertical distance from the floor to the greater trochanter (a bony prominence at the upper end of the thigh bone).

Method:

- Ask the subject to stand erect stretching upwards to the fullest extent, barefoot on a level floor against the wall with her/his back touching the wall and as straight as possible.
- Mark the required landmarks.
- Stand on the right side of the subject with measuring tape placed in the median sagittal plane of the subject and pulled it taut.
- Record your reading



Hip height

Reading 1 -----cm
Reading 2 -----cm
Reading 3 -----cm

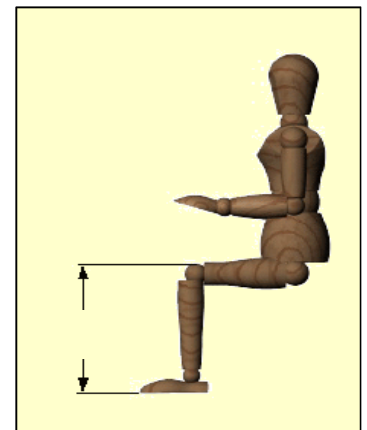
Mean ----- cm

b. Knee height

Vertical distance from the floor to the upper surface of the knee (usually measured to the quadriceps muscle rather than the kneecap).

Method:

- Ask the subject to sit erect with legs hanging freely at an angle of 90°.
- The body stretched to the maximum.
- The thighs should be almost horizontal with back of the knee touching the vertical surface of the chair and also don't allow the knees to bend.
- The hands should rest on the thighs with palms facing down.
- Mark the required landmarks.
- Anthropometer should be held at the front of the subject.
- Record the reading.



Knee length

Reading 1 -----cm
Reading 2 -----cm
Reading 3 -----cm

Mean ----- cm

c. Foot length

Distance, parallel to the long axis of the foot, from the back of the heel to the tip of the longest toe.

Method:

- Ask the subject to sit erect with legs hanging freely at an angle of 90°.
- The body stretched to the maximum.

- The thighs should be almost horizontal with back of the knee touching the vertical surface of the chair and also don't allow the knees to bend.
- The hands should rest on the thighs with palms facing down.
- Mark the required landmarks.
- Anthropometer should be held parallel to the long axis of the foot.
- Record the reading.

Foot length

Reading 1	-----cm	
Reading 2	-----cm	Mean ----- cm
Reading 3	-----cm	

Weight Measurement

Weight should be taken by means of standard weighing machine with fine accuracy. The weight should be taken barefoot. Body weight is measured in kilograms, which gives an idea of body mass.

Method:

- Ask the subject to stand with equal weight on both the feet.
- Ask the subject to remove his/her shoes and stand erect at the center of machine platform, with arm hanging by the sides of the body.
- The head of the subject should be forward.
- Take care that the subject does not move while the measurement is being recorded.
- Note the reading on the weighing scale.

Weight (Total body)

Reading -----Kg

Part two- Goniometry

Practical guidelines for lab:

1. Each member of the lab group will be assigned to a measurement group and will provide that measurement to all other members.
2. Locate the required bony landmarks.
3. Each joint range of motion (ROM) targeted below will describe the starting position, where to place the goniometer, the direction in which the joint should be moved, and hints for accurate ROM measurements.
4. Goniometers should be handled and manipulated as instructed since mishandling may result in inaccurate data.

System set up

1. Make certain that an appropriate Bluetooth adaptor is installed and activated.
2. Power the desired Bluetooth Data LOG ON and have any other Bluetooth Data LOG units powered OFF.

3. Launch the Data LOG software application, the unit should automatically communicate using Bluetooth. (This may take up to one minute).
4. Open the Detected Units window, if not already open. Go to >View menu>Detected Units. All Data LOG units detected and recognized by the application will be displayed.

Note: If a particular Data LOG was not used the previous time with the PC, then perform the Bluetooth

Scan. Switch on all the desired Data LOG units. Go to >Set up menu >Port and click on >Bluetooth Scan. The program will take several seconds to scan for the Data LOG(s) and then will communicate using Bluetooth. All the desired Data LOG Units should appear in the Detected Units window. The default name for each Data LOG is the Serial Number.

If there are any problems connecting a Bluetooth Data LOG, quit the Data LOG PC Application, turn off the Data LOG unit(s), and then try starting both again.

Connecting Biometrics' Goniometers

Wrist flexion and extension

- For each channel connect the black socket of the J series lead to the black plug of the sensor ensuring that the polarization marks are aligned before insertion. (Figure 4)



Figure 4: J type interconnect leads

- Connect the plug of the J series cable to one of the Analogue Input sockets of the Data LOG. Lightly rotate the plug in the socket to align and push to engage with a click. (To remove, hold the outer case and pull until it disengages).
- Start with the subject's shoulder in abduction at 90 degrees and elbow flexed at 90 degrees, such that the forearm is close to full pronation. This position is defined as the neutral position. (Figure 5)

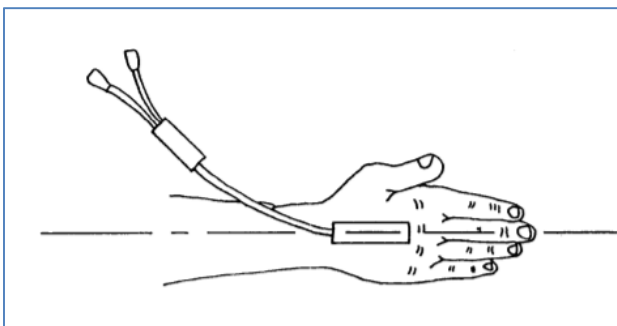


Figure 5: Neutral position

- Attach the distal end block (SG 65) to the dorsal surface over the third metacarpal with the center axis of the hand and end block coincident.
- While fully flexing the wrist, extend the goniometer and attach the proximal end block to the forearm so that the axes of the forearm and end block are coincident. (Figure 6)

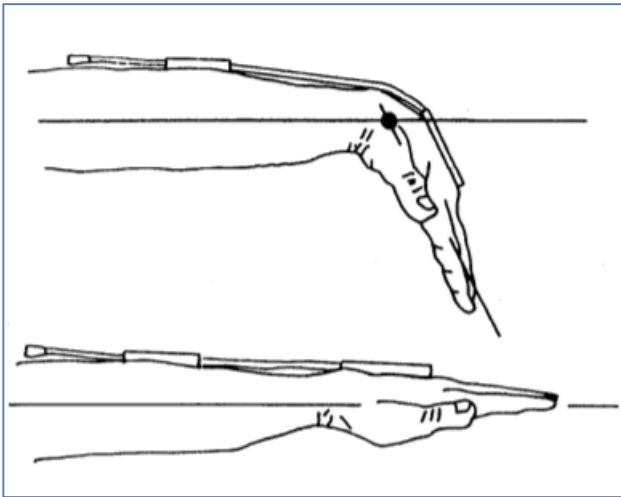


Figure 6: Goniometer's position

- Flex and extend the wrist with the goniometry freely sliding
- Measurement of flexion/extension is obtained from the grey plug
- Configure the analog channel: from Set up menu > Analogue Inputs, the Data LOG Analogue Inputs dialogue box will be shown. (Enable the checkbox for the active channels, press Zero All before recording to perform a zero operation on analogue channels and select the sampling rate as instructed), then press Apply and OK.
- Instruct the subject that the followings will be done during the experiment:
 1. Start from the neutral position (as figure 5).
 2. Keep the hand open and the fingers extended during recording.
 3. Move hand upward (wrist dorsiflexion) from the neutral position as far as possible and hold it for five seconds.
 4. Return the hand to the neutral position for five seconds.
 5. Move hand downward (wrist palmar flexion) from the neutral position as far as possible and hold it for five seconds.
 6. Return the hand to the neutral position for five seconds.
 7. Continue recording the flexion and extension cycle for two more times
- Press the Start data transfer / Recording button from the Biometrics Data LOG software or from the Data LOG itself and follow the previous recording instructions.
- After recording the required cycles, press Stop data transfer button.
- After data collection, a graph of the data automatically displayed.

Data Analysis

- Scroll through the recording graph and press the “Show All” button from the toolbar, so the three extension-flexion cycles are shown.
- Determine the maximum angle for wrist flexion (palmar flexion) and extension (dorsiflexion), time to maximum flexion and extension and time period of wrist flexion (palmar flexion) and extension (dorsiflexion) for the three cycles as the table below by press the “Mark Time axis” and the “Mark Value axis” from the toolbar and placing the cursors in the correct positions.

- Export the collected data into a specified file by choosing "Export" from File menu.
- Determine the exported trace and file type from the Export Data File format dialogue box. Then press "OK" button.

Wrist Angles (degrees)				
Action	1 st	2 nd	3 rd	Mean
Extension (dorsiflexion)				
Flexion (palmar flexion)				
Time to maximum flexion				
Time to maximum extension				
Time span for flexion				
Time span for extension				
Maximum flexion velocity				
Maximum extension velocity				

Experiment #2

Muscle Biomechanics

Objectives

1. To Understand muscle contraction.
2. To understand muscle's force generation mechanism.
3. To Understand and test factors affecting muscular force generations
4. To measure maximum weight that can be held at various joint angles
5. Investigate the relationship between EMG and elbow angle

Theory

Skeletal muscles are composed of numerous fibers ranging in size from 10 to 80 micrometers. Each of these fibers is composed of even smaller subunits called myofibrils. A typical muscle fiber contains anywhere from several hundred to several thousand myofibrils, which are composed of approximately 1500 myosin and 3000 actin filaments. Myosin and actin filaments are large polymerized protein molecules that are responsible for muscle contraction.

Muscle contraction occurs in the following steps:

1. An action potential travels along a motor nerve, arriving at muscle fibers.
2. Acetylcholine is released at the nerve ending, which then acts on a local area of the muscle fiber membrane to open acetylcholine-gated channels.
3. Large quantities of sodium ions flow to the interior of the muscle fiber membrane through the opened acetylcholine-gated channels.
4. An action potential is produced by the influx of sodium ions. The action potential travels along the length of the muscle fiber.
5. The action potential depolarizes the muscle fiber membrane and travels deep inside the muscle fiber, causing the release of stored calcium ions into the myofibrils.
6. Calcium ions induce attractive forces between actin and myosin filaments, causing them to slide over one another. This is the contractile process.
7. Almost instantaneously, calcium ions are pumped back out of the myofibril to be stored for the next action potential. Once the calcium ions are pumped out of the myofibril, muscle contraction is ceased.

Types of Muscle contractions:

1. There are two types of isotonic contractions: (1) concentric and (2) eccentric. In a concentric contraction, the muscle tension rises to meet the resistance, then remains the same as the muscle shortens. In eccentric, the muscle lengthens due to the resistance being greater than the force the muscle is producing.
2. Isometric contraction is the muscle contraction in which the joint angle and muscle length do not change during contraction

Equipments

1. PC Computer
2. IWX/214 data acquisition unit
3. USB cable
4. C-AAMI-504 EMG cable and electrode lead wires
5. Disposable electrodes
6. Different weights
7. Alcohol swab

8. Twin axis goniometers (SG110 (elbow joint)): "SG" series twin axis goniometers (Figure 1) permit the simultaneous measurement of angles in two planes, e.g. wrist flexion/extension and radial/ulnar deviation. Referring to Figure 2 below rotation of one end block relative to the other about axis X-X is measured using the grey plug and the green plug measures the rotation of one end block relative to the other about axis Y-Y.



Figure 1: SG series twin axis goniometers

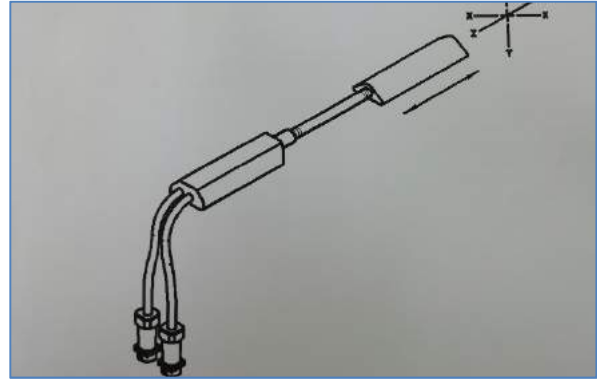
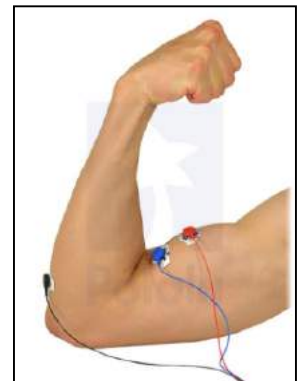


Figure 2: Twin axis goniometer SG series

EMG Cable Setup

1. Locate the C-AAMI-504 EMG cable and electrode lead wires in the iWorx kit.
2. Insert the black AAMI connector on the end of the EMG cable into the isolated inputs of Channels 1 and 2 of the IWX/214.
3. Insert the connectors on the red, black, and green electrode lead wires into the matching sockets on the lead pedestal of the EMG cable.
4. The subject should remove all jewelry from their wrists. For the first exercises in this lab, record EMGs and muscle forces from the subject's dominant arm, the arm used most often.
5. Use an alcohol swab to clean and scrub three regions on the inside of the subject's dominant arm where the electrodes will be placed. Three electrodes will be used: two electrodes for recording EMG signal and one electrode as a reference one.
6. Let the areas dry before attaching the electrodes.
7. Remove the plastic disk from a disposable electrode and apply it to one of the scrubbed areas (on the biceps muscle of the subject). Repeat for the other two areas.
8. Snap the lead wires onto the electrodes, so that:
 - The red "+1" lead and the black "-1" lead are attached to the electrodes on the biceps.
 - The green "C" lead (the ground) is attached to the electrode on the elbow.



Goniometry System Set up

1. Make certain that an appropriate Bluetooth adaptor is installed and activated.
2. Power the desired Bluetooth Data LOG ON and have any other Bluetooth Data LOG units powered OFF.
3. Launch the Data LOG software application, the unit should automatically communicate using Bluetooth. (This may take up to one minute).
4. Open the Detected Units window, if not already open. Go to >View menu>Detected Units. All Data LOG units detected and recognized by the application will be displayed.

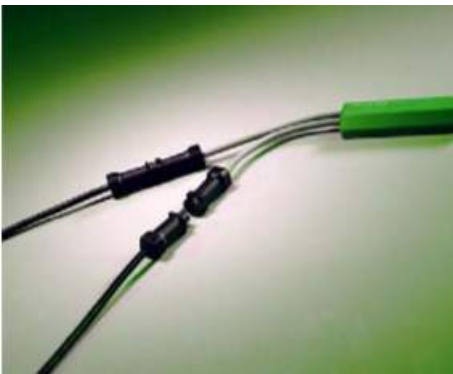
Note: If a particular Data LOG was not used the previous time with the PC, then perform the Bluetooth

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If there are any problems connecting a Bluetooth Data LOG, quit the Data LOG PC Application, turn off the Data LOG unit(s), and then try starting both again.

Connecting Biometrics' Goniometers

Elbow flexion and extension



For each channel connect the black socket of the J series lead to the black plug of the sensor ensuring that the polarization marks are aligned before insertion. (Figure 3)

Figure 3: J type interconnect leads

- Connect the plug of the J series cable to one of the Analogue Input sockets of the Data LOG. Lightly rotate the plug in the socket to align and push to engage with a click. (To remove, hold the outer case and pull until it disengages).
- Start with the subject's shoulder in abduction at 90° degrees and elbow and forearm at neutral.
- Attach the distal end block (SG 110) to the forearm with the center axis of the endblock coincident with the center axis of the forearm (figure 4).

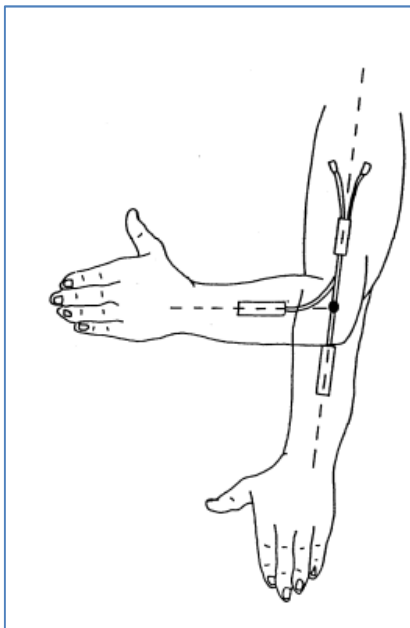


Figure 4: Goniometer's position

- With the elbow at neutral, move the goniometer to position 2 (maximum length) and attach the proximal endblock to the upper arm with the center of the endblock and the center axis of the upper arm coincident.

- The elbow may be fully flexed and extended with the distal endblock freely sliding between positions 1 and 2.
- Measurement of flexion/extension is obtained from the green plug, the grey plug being redundant. The distal endblock should be mounted in close proximity to the elbow joint. Movements of pronation and supination may be made and will affect the measurement of flexion/extension minimally.

Start LabScribe 2 Software

1. Click on the LabScribe shortcut on the computer's desktop to open the program. If a shortcut is not available, click on the Windows **Start menu**, move the cursor to **All Programs** and then to the listing for **iWorx**. Select **LabScribe** from the **iWorx submenu**. The LabScribe **Main window** will appear as the program opens.
2. On the **Main window**, pull down the **Settings menu** and select **Load Group**.
3. Locate the folder that contains the settings group, **IPLMv4.iwxgrp**. Select this group and click **Open**.
4. Pull down the **Settings menu** again. Select the **EMGGripStrength-LS2** settings file.
5. After a short time, LabScribe will appear on the computer screen as configured by the **EMG-GripStrength-LS2** settings.

Start Biometrics Software

- Configure the analog channel: from Set up menu > Analogue Inputs, the Data LOG Analogue Inputs dialogue box will be shown. (Enable the checkbox for the active channels, press Zero All before recording to perform a zero operation on analogue channels and select the sampling rate as instructed), then press Apply and OK.

Procedure

Exercise #1: Electromyogram (EMG) signal on Biceps muscle while holding different weights at various joint angles

Explain the experimental procedure of this exercise to the subject:

- Sit in a comfortable position with back upright and shoulder in abduction at 90° degrees and elbow and forearm at neutral.
- The EMG electrodes were then placed on the subject's biceps brachii muscle.
- The SG 110 goniometer was connected as above instructions to measure six different elbow joint angles: 0°, 30°, 45°, 60°, 90° and 120°.
- Carry a weight of 2 Kg with the hand where the electrodes were placed.
- Press the Start data transfer / Recording button from the Biometrics Data LOG software or from the Data LOG itself and follow the previous recording instructions and at the same time press "Record" at Labscribe2 software.
- After recording the required cycles, press Stop data transfer button.
- After data collection, a graph of the data automatically displayed.
- Hold the weight at each indicated angle for 50 s..
- Stretch the muscle and rest it for 3 minutes
- Repeat Step (2) for (2) additional weights starting with the lowest available weight as the Table below.

Data Analysis

1. Use the **Display Time** icons to adjust the **Display Time** of the **Main window** to show the complete muscle fatigue recording on the **Main window**. The complete recording can also be selected by:
 - Placing one cursor on the relaxation period just before the contraction and the other cursor on the relaxation period.

- Clicking the **Zoom between Cursors** button on the LabScribe toolbar to expand the muscle fatigue recording to the width of the **Main window**.
2. Click on the **Analysis window** icon in the toolbar or select **Analysis** from the **Windows menu** to transfer the data displayed in the **Main window** to the **Analysis window**.
 3. Look at the **Function Table** that is above the uppermost channel displayed in the **Analysis window**. The mathematical functions, **Abs. Area**, **V2-V1**, and **T2-T1** should appear in this table. The values for **Abs. Area**, **V2-V1**, and **T2-T1** on each channel are seen in the table across the top margin of each channel.

Biceps Diameter:	Age:	Gender:		Weight:	Fitness level: (how often do they do weight training)	
	EMG (RMS)					
Elbow joint angle	0°	30°	45°	60°	90°	120°
Weight (2 Kg)						
Weight (4 Kg)						
Weight (5 Kg)						

Experiment #3 Force Plate

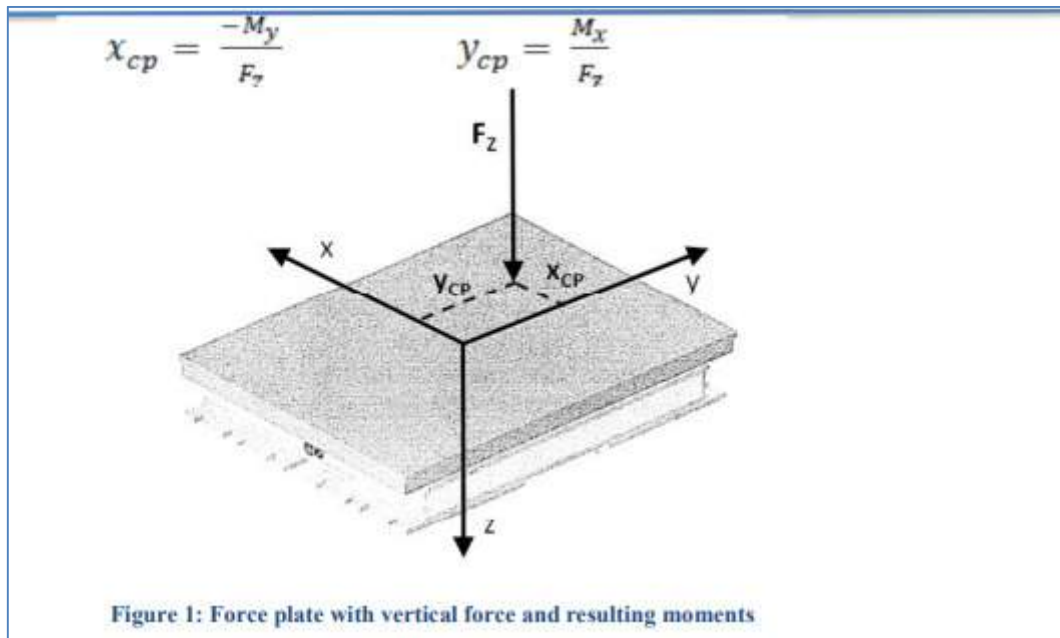
Objectives

1. Understand COP.
2. To learn how to compute the location of the center-of-pressure (COP) under the feet.
3. To perform a balance assessment of a test subject via measurement of COP with different cases.
4. To apply Newton's second law.
5. To understand the forces involved during walking, countermovement jump and running.
6. To observe how the center of pressure changes during different dynamic activities.
7. To calculate the flight height of a jump from the time of flight.

Background

Part A: Quiet Standing Static / Postural Measurements:

Force/ Moment measurements while the body is in a single position without any movement. Center of Pressure: to the point of application of the ground reaction force vector. The center of pressure is not constant and is under the influence of sensory feedback of more than one system. This includes the visual, auditory, and muscular systems. A force plate is an instrument that measures ground reaction forces and is often used in Biomechanics to analyze human posture, gait, and balance. It is also a popular instrument in medicine and for sports evaluation. Assume a vertical force F_z is applied a distance x_{cp} and y_{cp} from the center of the force plate coordinate system. The force plate would measure the force F_z and the associated M_x and M_y moments generated by the force about the force plate's x and y axes, respectively. Knowing this information, you can then compute the x and y locations of the center of pressure as follows:



The center of pressure when standing is always within the base of support which when standing erect is the feet. As long as the COP is within the BOS the subject would not fall/ move. A stabilogram can be plotted to track the COP and is often used by clinicians to evaluate different balance related disorders such as those related to the vestibular system.

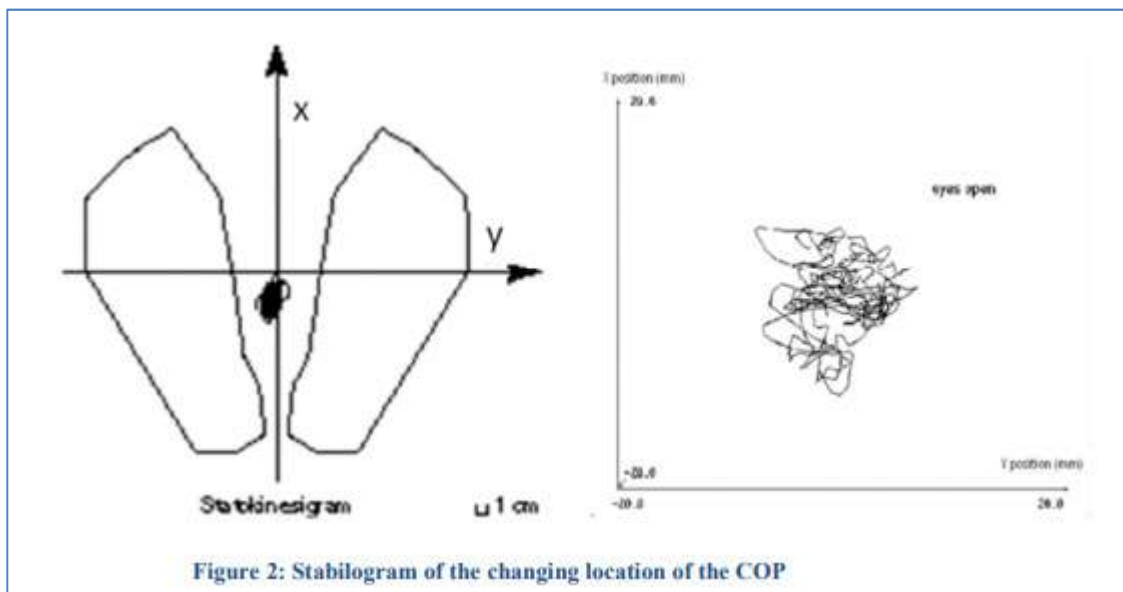


Figure 2: Stabilogram of the changing location of the COP

Part B: Vertical Jump

The vertical jump is an essential motor skill in many sports. The success or failure of a sportive action strongly depends on the ability of the athlete to jump high and fast. This is the reason why many studies have analyzed the vertical jump from a physical point of view, to establish the factors that have to be improved to increase jump height.

There are two types of standing vertical jump: "countermovement jump" and "Squat jump". In a countermovement jump (which will be applied during the lab), the jumper starts from an upright standing position, makes a preliminary downward movement by flexing at the knees and hips, then immediately and vigorously extends the knees and hips again to jump vertically up off the ground (Figure 1). A countermovement jump is an example of a movement that benefits from the "stretch-shorten cycle." Many human movements such as running, jumping, and throwing involve muscle actions in which the desired motion is preceded by a movement in the opposite direction. The muscles are said to be "pre-stretched" before shortening in the desired direction. Experiments have demonstrated that a pre-stretch enhances the force production and work output of the muscles in the subsequent movement.

In a squat jump, the jumper starts from a stationary semi squatted position then vigorously extends the knees and hips to jump vertically up off the ground.

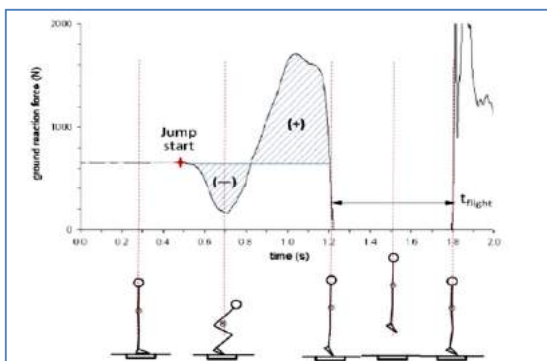


Figure3: Vertical ground reaction force (Fz) measured by the force plate during a standing vertical jump

Remember:

$$\sum \vec{F} = m\vec{a} = m \frac{d\vec{v}}{dt} \quad \text{Eq. (1)}$$

Considering just the vertical component of this vector equation, the forces acting on the body in the z-direction are the ground reaction force $F_z(t)$ and the force due to the mass of the body, mg . This can be related to the vertical acceleration dV_z/dt .

$$\sum F_z = m \frac{dv_z}{dt} = F_z(t) - mg \quad \text{Eq. (2)}$$

Solving Eq. (2) for dv_z/dt and integrating results in an expression for the velocity of the whole body center of mass as a function of time:

$$v_z(t) = \frac{1}{m} \int (F_z(t) - mg) dt \quad \text{Eq. (3)}$$

Time of flight:

Center of mass jump height is purely a function of take-off velocity after take-off. Hence during a vertical jump, the total impulse that is imparted to the body will determine the jump height that can be achieved.

$$h_{tof} = -\frac{gt_{flight}^2}{2}$$

$$v_o = -\frac{gt_{flight}}{2}$$

Equipments:

1. Kistler type 9260AA6 force plate
2. DAQ connected to the force plate
3. PC Computer with BioWare software, connected to the DAQ

Procedure

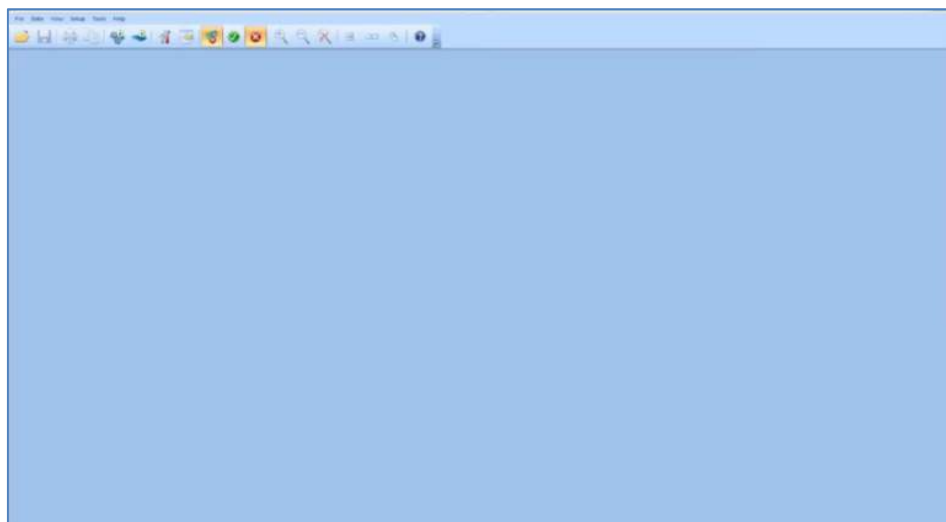
Part A:COP and Postural Balance

Starting up the equipment

- a. Turn on the computer
- b. Turn on the DAQ and let it warm up for at least 30 minutes.

Getting the force plate software ready

- Start the **BioWare** software by double clicking on the desktop shortcut or **Start** → **Programs** → **BioWare**



- From the **Tools** menu select **COP**.
- In the **Real -COP** dialog box, switch the charge amplifier from "Reset" to "Operate".
- While the offsets are being read, **do not** touch the force plate or any buttons.
- Click on the **Setup** button in the **Real-COP** dialog, and choose the rate and length of trial.
- Ask the subject to stand on the force plate.
- Click on the **Run** button in the **Real-COP** dialog box.

Postural Balance

Case	$F_z(N)$	$M_x(N.m)$	$M_y(N.m)$	Xcp (m)	Ycp (m)
Quiet standing/Heels together/eyesopened					
Quiet standing/eyes closed					
Quiet standing/eyesopened/ Mental Task					
Body Sway/Hands on Hip/ Parallel Stance					
Body Sway/Hands on Hip/ Single Leg Stance-Left					
Body Sway/Hands behind the neck/ Single Leg Stance-Left					

- To export data from BioWare, select the **Save As** option from the **File** menu.
 - ❖ Type in your desired filename.
 - ❖ Change the **Save as type** from **BioWare files (.dat)** to **Text files (.txt)** so that you can open the data in Excel or other software.
 - ❖ Check off all of the variables that you wish to export in the **Export Device Data** dialog

box that appears, and click on the **Export Data** button.

- ❖ This creates a tab-delimited text file that you can open in many different software.

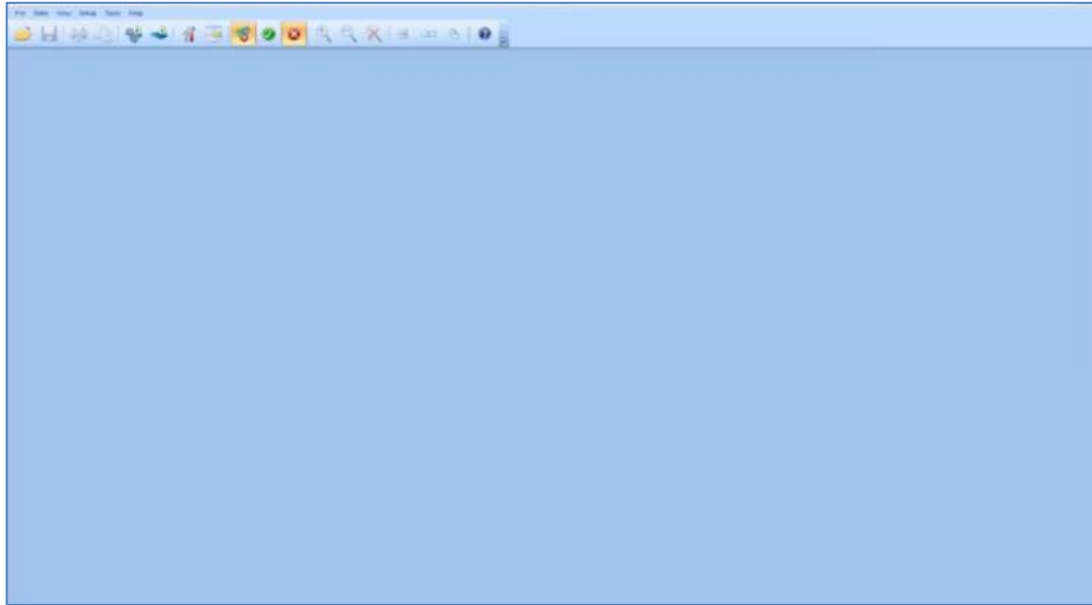
Part B: Vertical Jump

Starting up the equipment

- Turn on the computer
- Turn on the DAQ and let it warm up for at least 30 minutes.

Getting the force plate software ready

- Start the **BioWare** software by double clicking on the desktop shortcut or **Start** → **Programs** → **BioWare**.



- Select **Acquire Trial** from the **Data** menu, or press the **Acquire Trial** button underneath the menus.
- Adjust the length of the trial and the sampling rate as instructed.
- Click on the **Weigh** button in the **Acquire Trial** dialog.
- While the offsets are being read, **do not** touch the force plate or any buttons.
- Once the **Body Weight** dialog pops up, ask the subject to stand on the force plate.
- Click on the **Okay** button.

Collecting force data from a trial

- In the **Acquire Trial** dialog, click on the **Start** button.
- **Do not** touch the force plate or any buttons while the offsets are being read.
- Avoiding the platform connector, have the test subject stand on the force platform and position his/her feet to form a square on the middle of the platform. Another subject should stand next to the test subject to recording his/her jump.
- When the **Press enter to begin acquisition** dialog appears, you are ready to start the trial.
- Press **Enter**, or click on the **Okay** button to start the trial.
- Instruct the test subject to start countermovement jump: **start out standing straight up, then bend his/her knees, then push off and jump up as high as he/she could, and land back on the force plate.**
- Save and Export the data.

Data Analysis (Calculations, Results and Discussion)

Part A

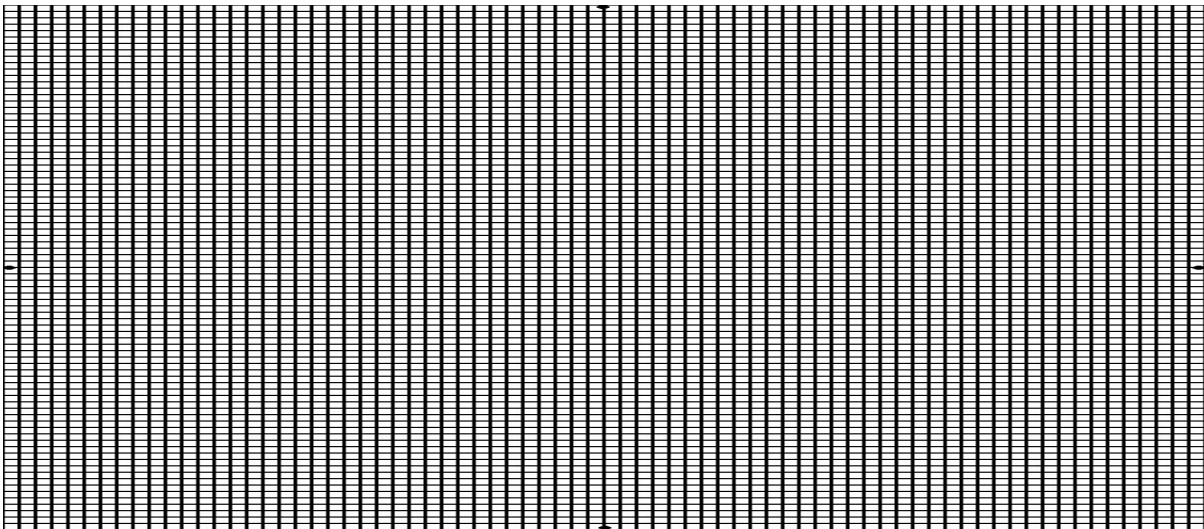
1. Regarding your experimental results during the lab, plot the stabilogram for the following cases (using excel or Matlab).

Case	F_z (N)	M_x (N.m)	M_y (N.m)	X_{cp} (m)	Y_{cp} (m)
Quiet standing/eyes opened					

Quiet standing/eyes closed					
Body Sway/Hands on Hip/ Single Leg Stance-Left					
Body Sway/Hands behind the neck/ Single Leg Stance-Left					

***Show your calculations**

1. For each stabilogram, what are the COP ranges (in cm) in both the x and y axes?
2. Plot the ground reaction force F_z (N) as a function of Time (sec) for Quiet Standing/eyes opened.

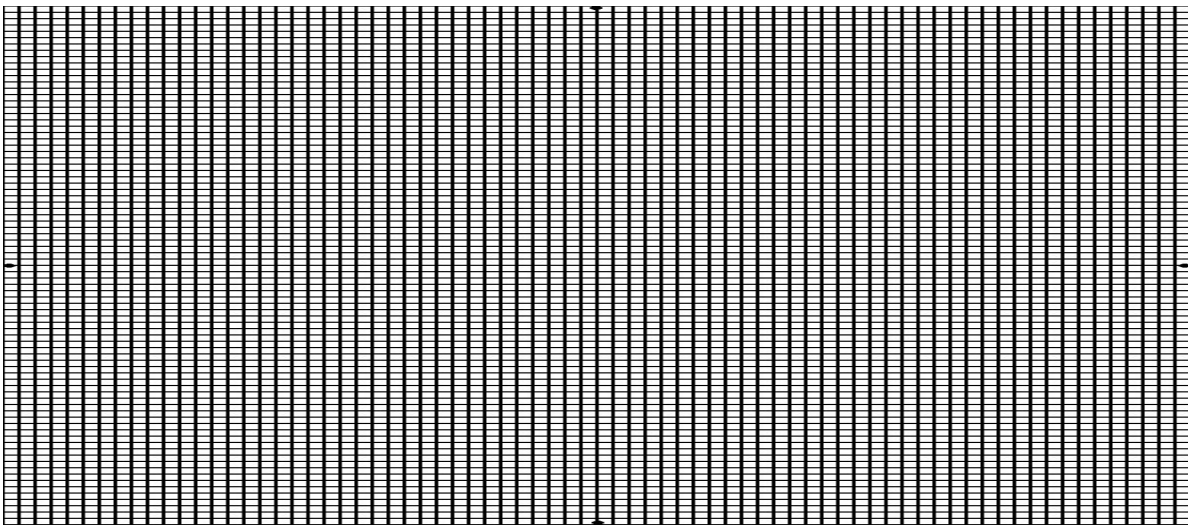


3. How does the center of pressure motion differ between the eyes opened and eyes closed conditions? Explain.
4. How does the value of F_z change during different cases?

5. Does the COP location vary more in the anterior – posterior (x-axis) or left – right (y-axis) direction? Suggest some possible reasons for your observations.

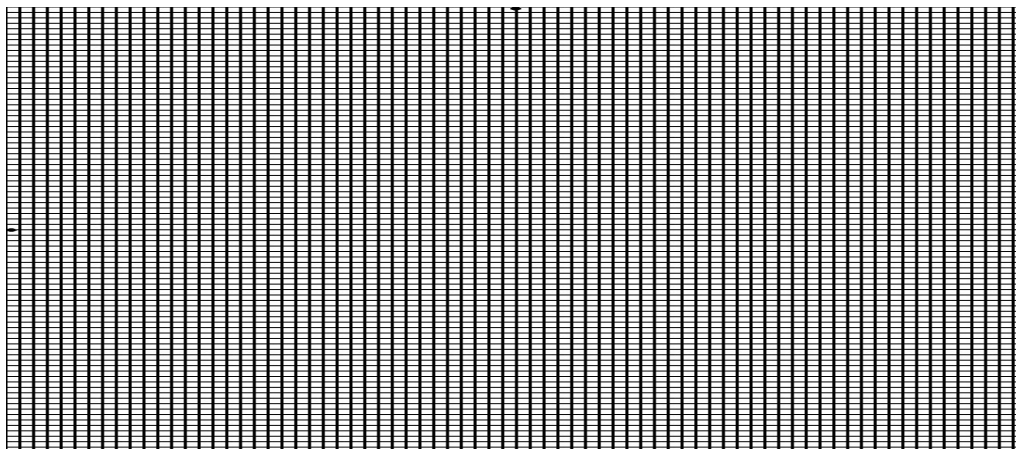
Part B

1. Plot the ground reaction force F_z (N) as a function of Time (sec).



2. Identify the point on your graph corresponding to each of the followings:
- a. The start of the crouch preceding jump
 - b. The highest point of the jump
 - c. The lowest point of the crouch
 - d. The jumper's feet touch the ground at the end of the jump
3. From the force graph, calculate the time of flight (how long you were in the air).
Flight Time =
4. From the flight time, calculate the height of the subject's jump.
Jump Height =

5. Estimate the subject's jump height from the recorded video and compare with the calculated one.
6. Plot the forces in (x) and (y) directions as a function of Time (sec).



7. Plot and explain the change of Center of Pressure during jump.
8. Describe the benefits of knees bending before start jumping and while landing.
9. Compare and discuss the results for the three subjects.
10. What are the possible errors in your calculations or measurements?

Note: You have to analyze data and answer the questions for the three tested subjects

Conclusion

Experiment #4

Gait Analysis

Objectives

1. To apply Newton's second law.
2. To understand Gait Analysis concept and its applications in biomedical engineering.
3. To learn the different methods (force plate and goniometer) used to analyze and measure gait of a human subject and compare between them.
4. To understand the forces involved during walking and running.
5. To understand the change of human patterns due to walk constrains applied on the limbs.

Theory

Part A: Gait Analysis/Walking

Gait: is the sequence of walking functions by a single limb. The gait cycle is divided into stance and swing phases (Figure1); stance is the entire period of which the foot is on the ground while the swing phase is the time the foot is in the air for limb advancement, it begins when the foot is lifted from the floor. The last part of the foot to leave the floor is the toe so that subdivision is called "toe off".

The initial double stance begins the gait cycle. It is the time both feet are on the floor after initial contact. Single limb support begins when the opposite foot is lifted for swing.

Terminal double stance: begins with floor contact by the other foot (contralateral initial contact) and continues until the original stance limb is lifted for swing (ipsilateral toe-off).

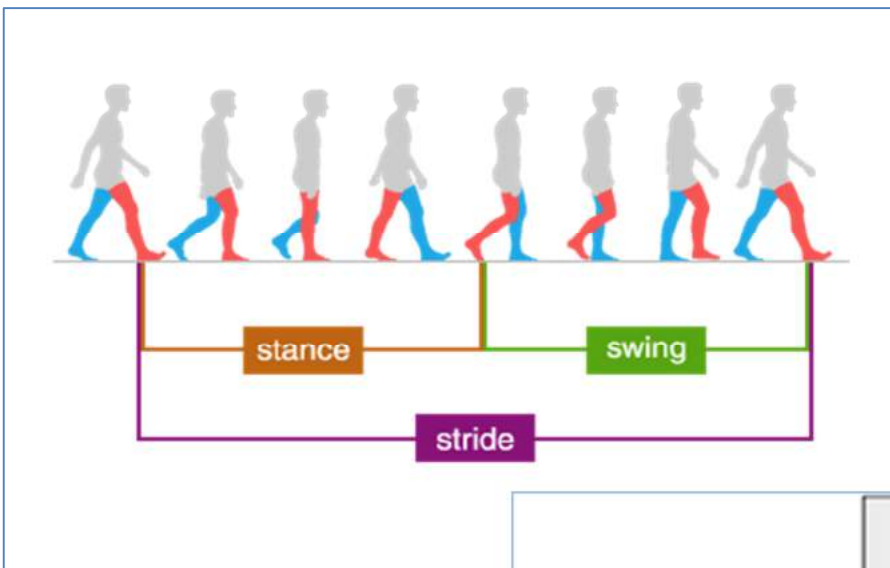
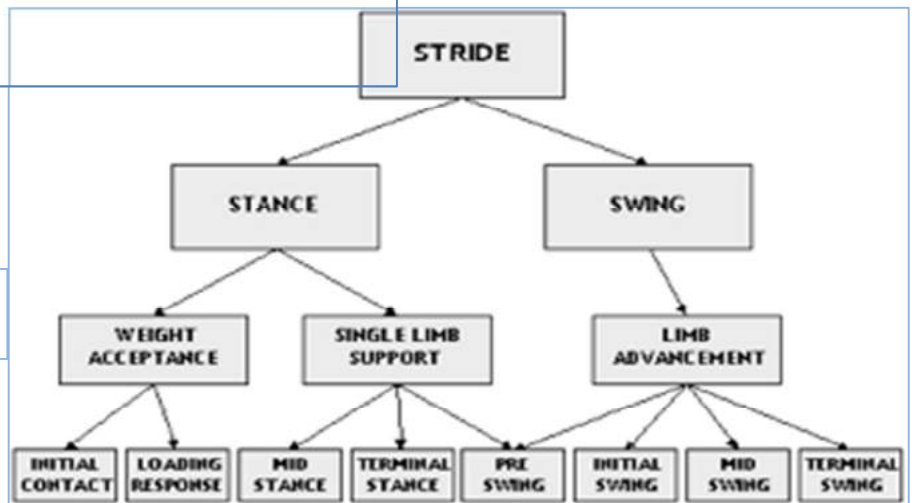


Figure1: Gait Cycle phases

Figure 2: Division of Gait Cycle phases



Part B: Gait Analysis/ Running

Running is a method of terrestrial locomotion allowing humans to move rapidly on foot. Running is a type of gait characterized by an aerial phase in which all feet are above the ground (though there are exceptions). This is in contrast to walking, where one foot is always in contact with the ground, the legs are kept mostly straight and the center of gravity vaults over the stance leg or legs in an inverted pendulum fashion. A characteristic feature of a running body from the viewpoint of spring-mass mechanics is that changes in kinetic and potential energy within a stride occur simultaneously, with energy storage accomplished by springy tendons and passive muscle elasticity. The term running can refer to any of a variety of speeds ranging from jogging to sprinting.

Running requires: greater balance, greater muscle strength, greater joint range of movement.

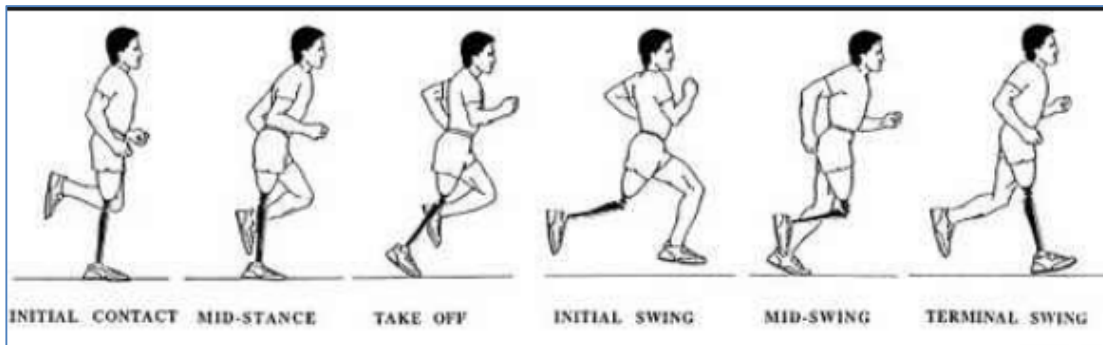


Figure 3: Phases of Running

Materials:

1. Kistler type 9260AA6 force plate.
2. DAQ connected to the force plate.
3. PC Computer with BioWare software, connected to the DAQ
4. Twin axis goniometer (SG 150)
5. DataLOG MWX8 data acquisition unit with Biometrics DataLOG software.
6. Wood pieces
7. Tape
8. Video camera

Method

Goniometry system set up

1. Make certain that an appropriate Bluetooth adaptor is installed and activated.
2. Power the desired Bluetooth DataLOG ON and have any other Bluetooth Data LOG unit powered OFF.
3. Launch the Data LOG software application, the unit should automatically communicate using Bluetooth. (This may take up to one minute).
4. Open the Detected Units window, if not already open. Go to >View menu>Detected Units. All Data LOG units detected and recognized by the application will be displayed.

Note: If a particular Data LOG was not used the previous time with the PC, then perform the Bluetooth

Scan. Switch on all the desired Data LOG units. Go to >Set up menu >Port and click on > Bluetooth Scan. The program will take several seconds to scan for the Data LOG(s) and then will communicate using Bluetooth. All the desired Data LOG Units should appear in the Detected Units window. The default name for each Data LOG is the Serial Number.

If there are any problems connecting a Bluetooth Data LOG, quit the Data LOG PC Application, turn off the Data LOG unit(s), and then try starting both again.

Connecting Biometrics' Goniometers (Knee goniometer)

- For each channel connect the black socket of the J series lead to the black plug of the sensor ensuring that the polarization marks are aligned before insertion. (Figure 4)



Figure 4: J type interconnect leads

- Connect the plug of the J series cable to one of the Analogue Input sockets of the Data LOG. Lightly rotate the plug in the socket to align and push to engage with a click. (To remove, hold the outer case and pull until it disengages).
- Start with the subject standing in neutral position with the foot on a flat surface.
- Mount the distal end block laterally on the leg so the axes of the leg and end block coincide when viewed in the sagittal plane (figure 5), with the leg fully extended in the position of reference extend the goniometer to position 2 (maximum length) and attach the proximal end block to the thigh so the axes of the thigh and end block coincide. The knee may now be flexed or extended with the goniometer freely sliding between positions 1 and 2.
- Measurements of flexion/extension may be monitored using the green plug, the grey plug being redundant.
- Configure the analog channel: from Set up menu > Analogue Inputs, the Data LOG Analogue Inputs dialogue box will be shown. (Enable the checkbox for the active channels, press Zero All before recording to perform a zero operation on analogue channels and select the sampling rate as instructed), then press Apply and OK.

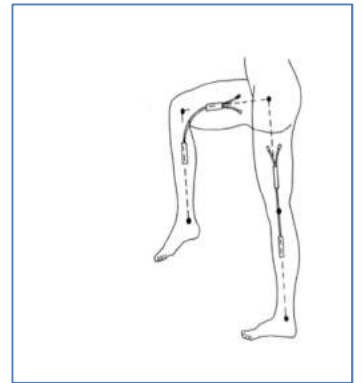
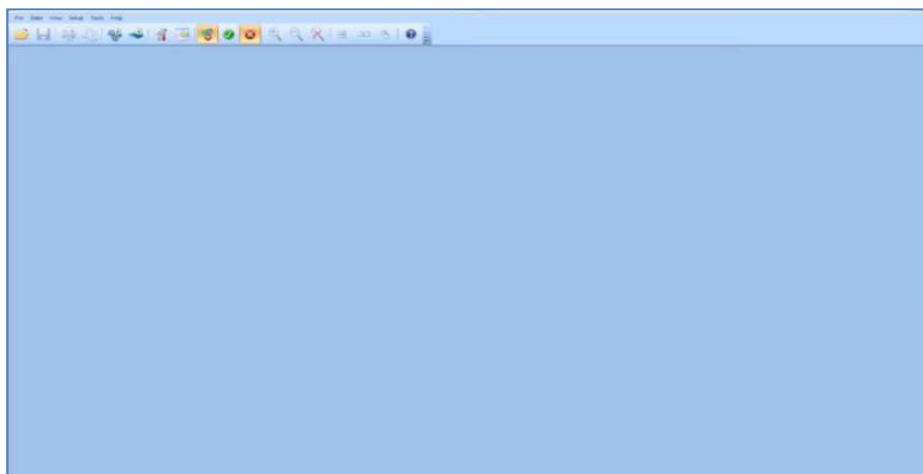


Figure 5: Knee goniometer position

Getting the force plate software ready

- Turn on the computer
- Turn on the DAQ and let it warm up for at least 30 minutes.
- Start the **BioWare** software by double clicking on the desktop shortcut or **Start** → **Programs** → **BioWare**.



- Select **Acquire Trial** from the **Data** menu, or press the **Acquire Trial** button underneath the menus.
- Adjust the length of the trial and the sampling rate as instructed.
- Click on the **Weight** button in the **Acquire Trial** dialog.
- While the offsets are being read, **do not** touch the force plate or any buttons.
- Once the **Body Weight** dialog pops up, ask the subject to stand on the force plate.
- Click on the **Okay** button.
- In the **Acquire Trial** dialog, click on the **Start** button.
- **Do not** touch the force plate or any buttons while the offsets are being read.
- When the **Press enter to begin acquisition** dialog appears, you are ready to start the trial.
- Press **Enter**, or click on the **Okay** button to start the trial and at the same time press the Start data transfer / Recording button from the Biometrics Data LOG software or from the Data LOG itself and follow the instructions for each part.

Part A: Normal gait/ Walking

- Instruct the test subject to **walk normal** along the length of the walkway and making sure that he/she starts and ends walking before going on the walkway.
- Another subject should stand next to the test subject (from the sagittal and the frontal levels) to recording his/her walking (make sure it captures the motion of the lower limbs and covers the length of the platform).
- Repeat the steps above for other two subjects.
- Use one of the following soft wares to analyze the angles of the knee joint:
 - a) Photoshop
 - b) ImageJ from: <https://imagej.nih.gov/ij/>
 - c) Kinovea from: <http://www.kinovea.org/en/>

Part B: Normal gait /Running

- Instruct the test subject to **run** along the length of the walkway and making sure that he/she starts and ends walking before going on the walkway.
- Another subject should stand next to the test subject (from the sagittal and the frontal levels) to recording his/her walking (make sure it captures the motion of the lower limbs and covers the length of the platform).
- Repeat the steps above for other two subjects.
- Use one of the following soft wares to analyze the angles of the knee joint:
 - a) Photoshop
 - b) ImageJ from: <https://imagej.nih.gov/ij/>
 - c) Kinovea from: <http://www.kinovea.org/en/>

Part C: Abnormal gait /Walking

- Extend the test subject knee (the one that is not connected to the goniometer) and fixed it by using two pieces of wood with tape (make sure that the knee could not move any more).
- Instruct the subject to try walking for a short time before start collecting data, until he/she is ready to walk with this abnormality.
- Instruct the test subject to **walk** along the length of the walkway and making sure that he/she starts and ends walking before going on the walkway.
- Another subject should stand next to the test subject (from the sagittal and the frontal levels) to recording his/her walking (make sure it captures the motion of the lower limbs and covers the length of the platform).
- Repeat the steps above for other two subjects.
- Use one of the following soft wares to analyze the angles of the knee joint:

- a) Photoshop
- b) ImageJ from: <https://imagej.nih.gov/ij/>
- c) Kinovea from: <http://www.kinovea.org/en/>

Note:

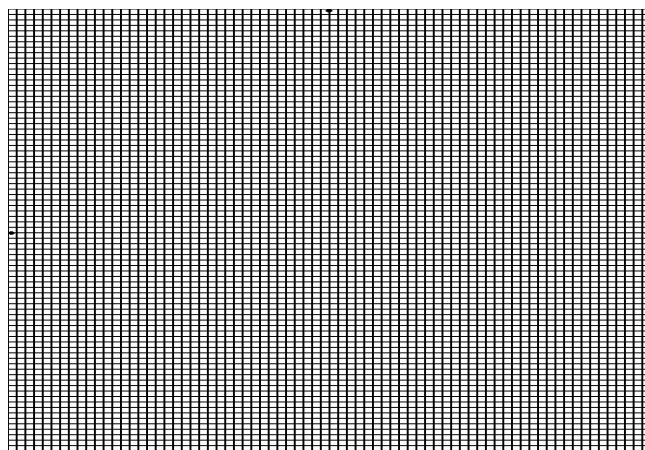
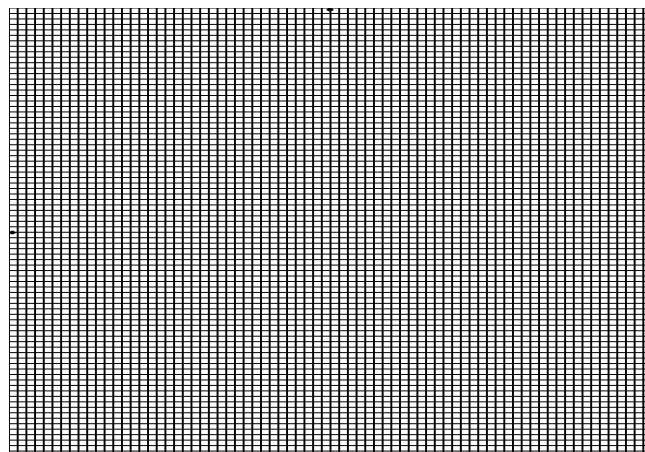
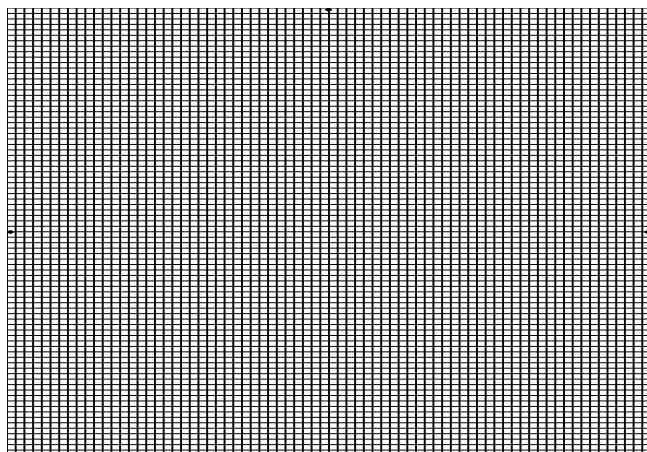
- To export data from **BioWare**, select the **Save As** option from the **File** menu.
 - ❖ Type in your desired filename.
 - ❖ Change the **Save as type** from **BioWare files (.dat)** to **Text files (.txt)** so that you can open the data in Excel or other software.
 - ❖ Check off all of the variables that you wish to export in the **Export Device Data** dialog box that appears, and click on the **Export Data** button.
 - ❖ This creates a tab-delimited text file that you can open in many different software.

- For Biometrics DataLOG software
 - After recording the required gait cycle, press Stop data transfer button and a graph of the data automatically displayed.
 - Export the collected data into a specified file by choosing "Export" from File menu.
 - Determine the exported trace and file type from the Export Data File format dialogue box. Then press "OK" button.

Data Analysis (Calculations and Results)

Force Plate and Gait Analysis

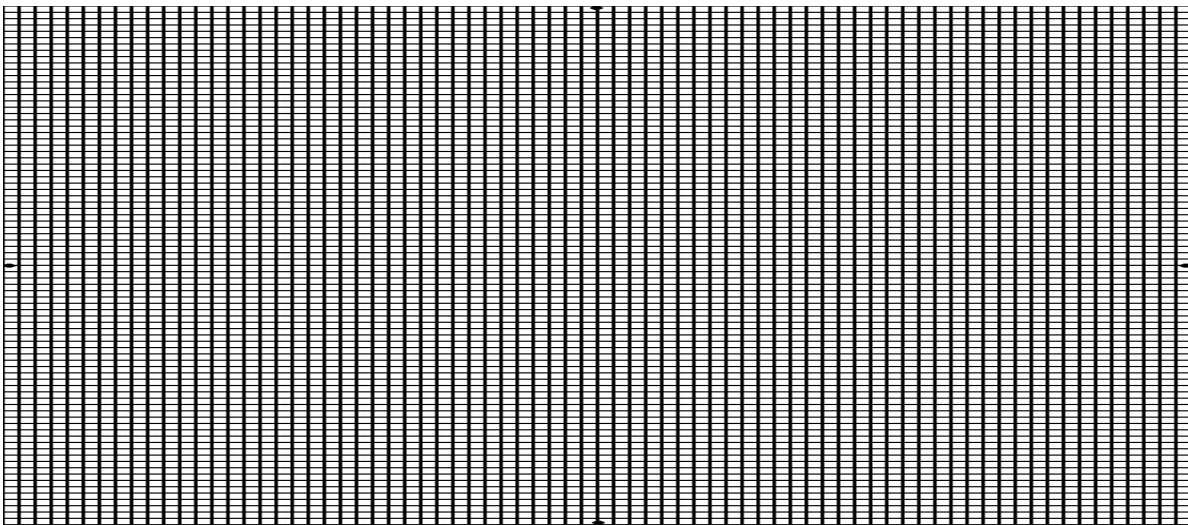
1. Plot the ground reaction force F_z (N) as a function of Time (sec) for normal gait during walking and running and abnormal walking gait for each subject.



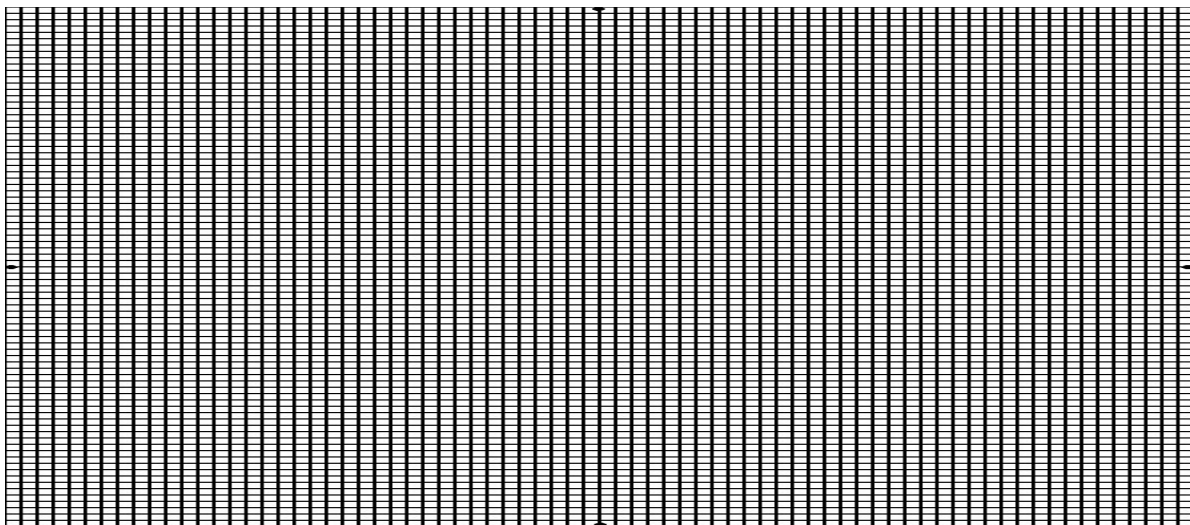
2. Measure the time interval for stance phase and swing phase for one foot during walking (normal and abnormal gait) and running for each subject. Compare between the three motion patterns.
3. Discuss the change in the test subject response to overcome the abnormality during walking?

Goniometer and Normal Walking Gait Analysis

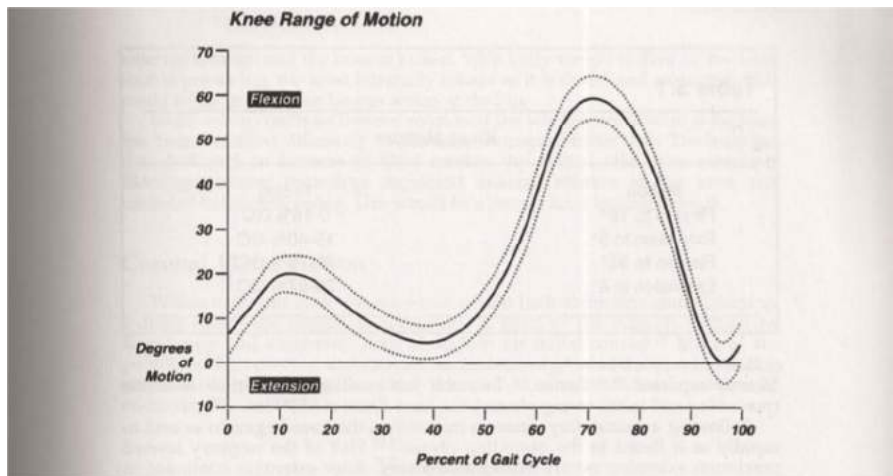
4. Plot the knee joint angle as a function of Time (sec) recorded by Biometrics DataLOG software.



5. Plot the knee joint angle as a function of Time (sec) recorded by the video camera.

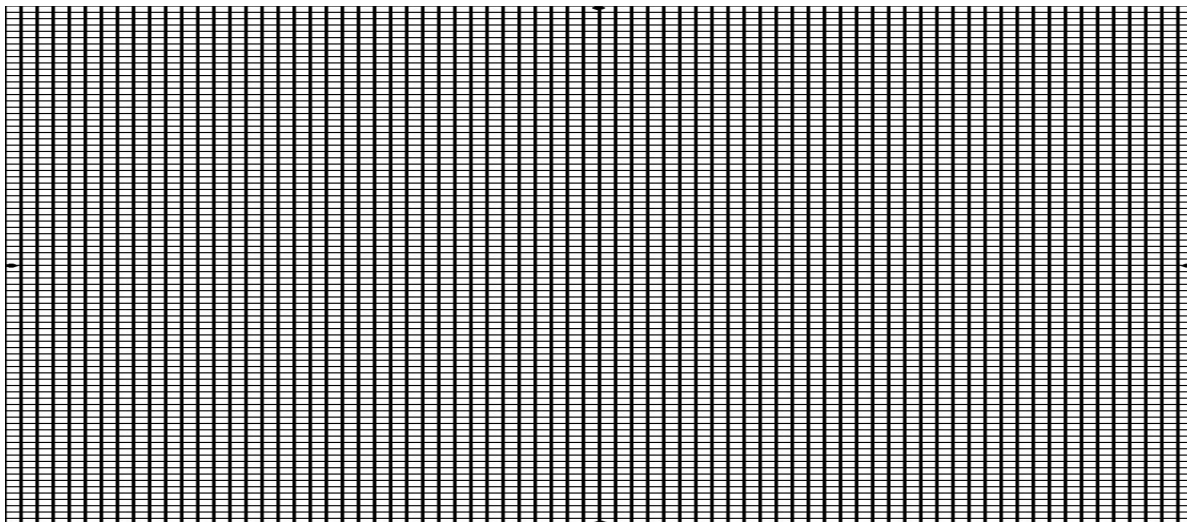


6. Compare the two plots (Questions 4 and 5) above with the expected normal range of knee motion as the figure below.

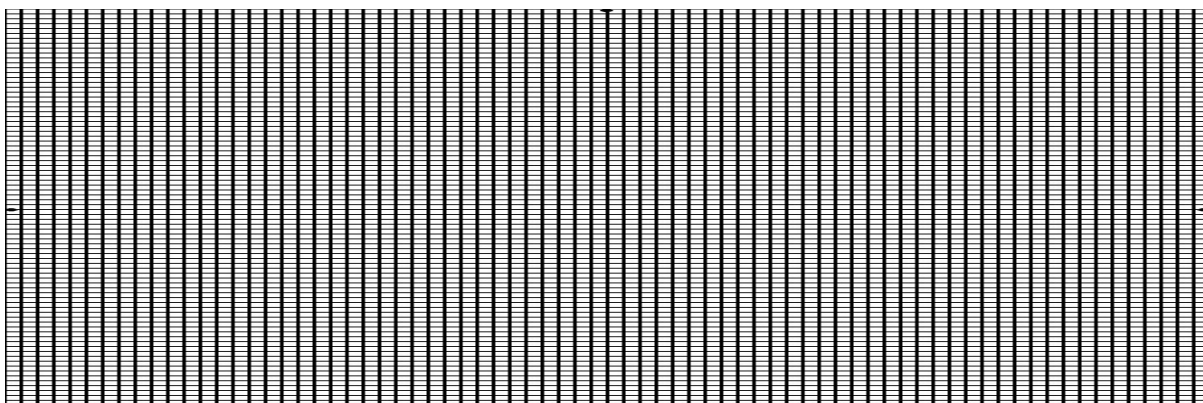


Goniometer and Abnormal Walking Gait Analysis

7. Plot the knee joint angle as a function of Time (sec) recorded by Biometrics DataLOG software.



8. Plot the knee joint angle as a function of Time (sec) recorded by the video camera.



9. Compare the two plots (Questions 7 and 8) above with the expected normal range of knee motion as the figure in question (6).

Note: You have to plot the graphs by Matlab or Excel

Part II: Mechanical Properties of Biomaterials

Objectives

- Understand the principle of tension and compression tests.
- Understand the Stress-Strain curve and learn how to use it in determining various mechanical properties of different materials: modulus of elasticity, yield strength, ultimate tensile strength and elongation (ductility).
- Apply the creep test for different materials.

Preface

Materials that are used for biomedical applications are known as biomaterials. Properties of biomaterials that have been used for implants directly influence and control the tissue interface dynamics from the time of initial in vivo placement until final disposition.

Three requirements must be met to classify the material for biomedical application: the first requirement is that the material must be biocompatible; it means that the organism should not treat it as a foreign object. Secondly, the material should be biodegradable; the material should harmlessly degrade or dissolve in the body of the organism to allow it to resume natural functioning. Thirdly, the material should be mechanically sound; for the replacement of load bearing structures, the material should possess equivalent or greater mechanical stability to ensure high reliability of the graft.

Biomaterials played a significant role in the development of new medical innovations and research. Developments in areas such as 3D printed medical devices, bio fabricated tissue engineering scaffolds, and biodegradable meshes provide a basis for future clinical treatments. These innovations have the capability to disrupt the current medical industry by providing novel solutions to historical challenges in patient health.

Biomedical engineers use biomaterials for the following broad range of applications:

- Medical implants, including heart valves, stents, and grafts; artificial joints, ligaments, and tendons; hearing loss implants; dental implants; and devices that stimulate nerves.
- Regenerated human tissues, using a combination of biomaterial supports or scaffolds, cells, and bioactive molecules. Examples include a bone regenerating hydrogel and a lab-grown human bladder.
- Molecular probes and nanoparticles that break through biological barriers and aid in cancer imaging and therapy at the molecular level.
- Biosensors to detect the presence and amount of specific substances and to transmit that data. Examples are blood glucose monitoring devices and brain activity sensors.

Experiment #5

Tension and Compressive Tests

Objectives

1. To be familiar with the material testing machine(810LE4) and provide a practical exercise for using it to determine the mechanical properties of different materials.
2. To understand the principle of tension and compression tests as well as practice how to operate the universal testing machine (810LE4) in a tension and compression manners.
3. To understand the behavior of a material while it experiences a compressive load by measuring fundamental variables, such as, strain, stress, and deformation.
4. To understand the Stress-Strain curve and learn how to use it in determining various mechanical properties of different materials (Aluminum, Copper, Cast iron and Stainless Steel): modulus of elasticity, yield strength, ultimate tensile strength and elongation (ductility).

Theory

The evaluation of the mechanical behavior of a sample under conditions of tension and compression can be performed to provide basic material property data that is critical for component design and service performance assessment. The requirements for tensile and compression strength values and the methods for testing these properties are specified in various standards for a wide variety of materials. Testing can be performed on machined material samples or on full-size or scale models of actual components. These tests are typically performed using a universal mechanical testing instrument.

A tensile test, also known as tension test, is probably the most fundamental type of mechanical test you can perform on material to recognize its strength and its mechanical behavior.

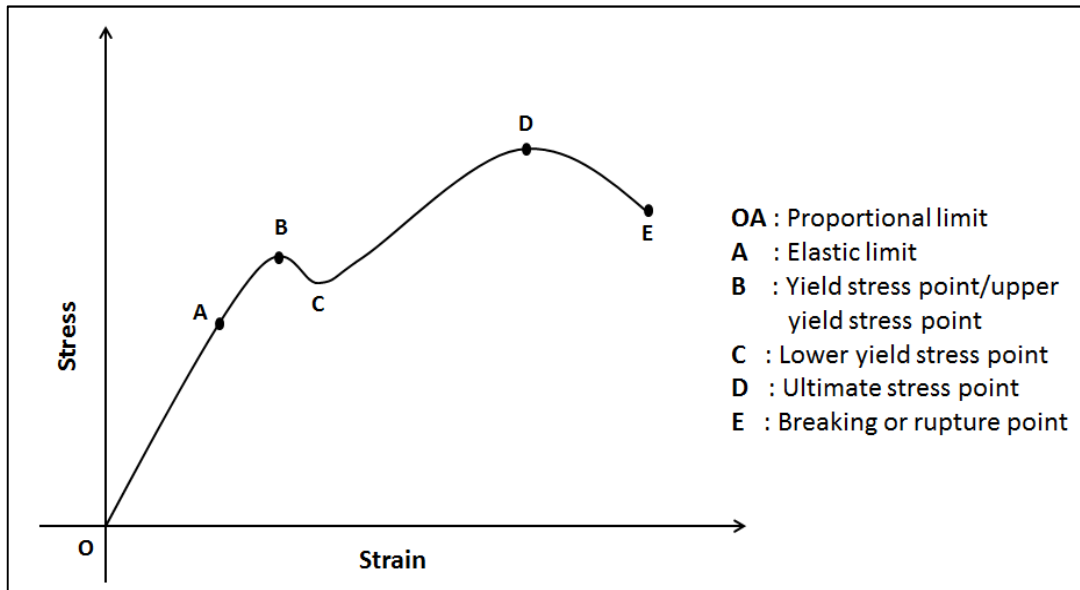
Tension test, in which a strip or cylinder of the material, having length L and cross-sectional area A , is anchored at one end and subjected to an axial load P – a load acting along the specimen's long axis – at the other. As the load is increased gradually, the axial deflection δ of the loaded end will increase also. Eventually the test specimen breaks or does something else catastrophic, often fracturing suddenly into two or more pieces.

The strain resulting from the stress applied is proportional to the stress and is directly related to it with a proportionality constant called the Elastic Modulus/ Young's Modulus. This constant is material dependent and only applies in what is called the "**elastic region**" of a material's behavior through the following equation:

$$\sigma = E\varepsilon$$

Where (σ) is the Stress in Pascal, (ε) is the Strain and (E) is the Elastic Modulus or Young's Modulus

A typical stress-strain curve is shown in the figure below:



Stress versus Strain Curve

Note that stress - strain proportionality only applies in the elastic region (up to the yield stress point), also note that this curve assumes a constant cross-sectional area and does not take into consideration the Poisson's Ratio. The Poisson's Ratio (ν) is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force and is approximated to be $1/3$ for isotropic metals and $1/2$ for anisotropic polymers.

A compression test is a method for determining the behavior of materials under a compressive load. Compression tests are conducted by loading the test specimen between two grips, and then applying a force to the specimen by moving the crossheads together. During the test, the specimen is compressed, and deformation versus the applied load is recorded. The compression test is used to determine elastic limit, proportional limit, yield point, yield strength, and (for some materials) compressive strength.

Definitions

- **Gauge Length (L)** - length of the test specimen on which elongation is measured at any moment during the test [m]
- **Original Gauge Length (L_0)** - gauge length before application of load [m]
- **Final Gauge Length (L_u)** - gauge length after rupture of the test specimen [m]
- **Elongation** - increase in the original gauge length at the end of the test
- **Stress (σ)**- load at any moment during the test divided by the original cross-sectional area of the test specimen [$\text{Pa}/(\text{N}/\text{m}^2)$]
- **Strain**- It is the ratio of change in length to the original length ($\epsilon = \frac{\Delta L}{L_0}$)
- **Elastic Modulus**-a measure of the stiffness of the material, but it only applies in the linear region of the stress – strain curve ($E = \sigma/\epsilon$), [Pa]
- **Yield Stress (σ_y)**-when the material exhibits a yield phenomenon, a point is reached during the test at which plastic deformation occurs without any increase in the load [$\text{Pa}/(\text{N}/\text{m}^2)$]
- **Ultimate Tensile Stress (σ_u)**-the maximum load the specimen sustains during the test [$\text{Pa}/(\text{N}/\text{m}^2)$]

Materials

1. PC Computer
2. Universal Testing Machine (800LE Series Hardware)
3. Vernier Caliper and scale
4. Tested Specimens

Universal Testing Machine Overview

Biomaterial testing machine is used to generate force and measure fatigue, fracture, tensile and compression test results on mechanical test samples. They are capable of producing static and cyclic loads in tension or compression and operate to speeds of depending on the system performance

System Components

Test system typically consists of:

1. Frame
2. Actuator
3. Power module electronics
4. Controller with interconnect cables

Each system includes a power pack with the following operator indicators and switches:

- System ON/OFF
- System Enable LED
- Emergency Stop

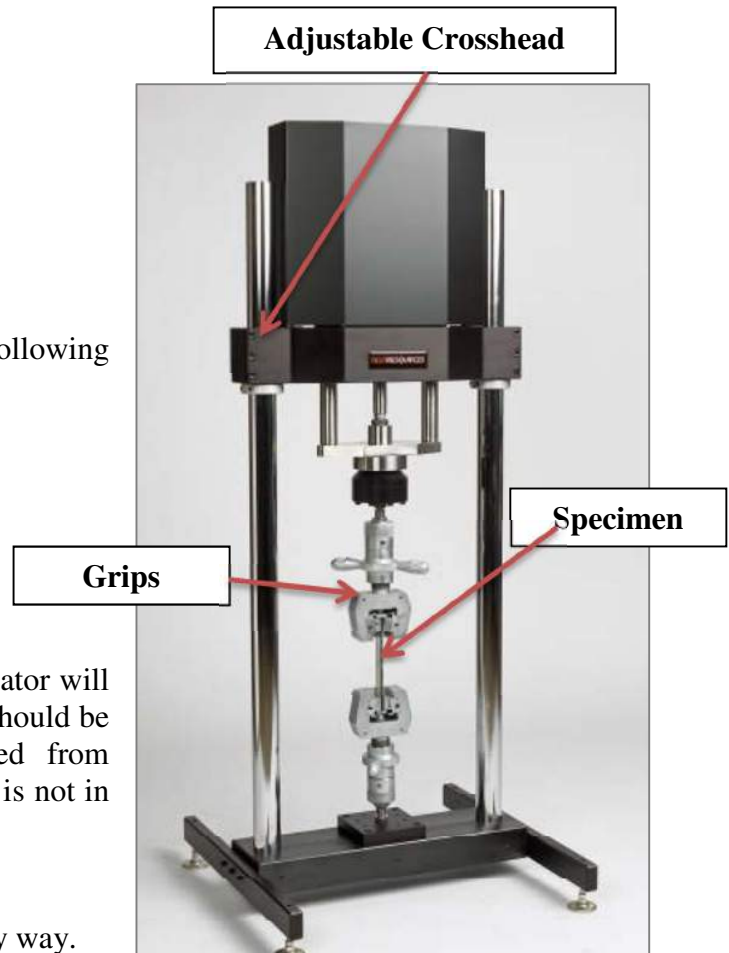
Safety Warnings

1. Excessive side load on the output rod of the actuator will dramatically reduce the life of the Actuator and should be avoided completely. Side load can be caused from misalignment or Loading of the specimen which is not in line with the axis of motion.
1. The equipment may be so heavy. Don't move it.
2. Never lift the equipment by the actuator rod.
3. Never use the system if it appears damaged in any way.
4. This equipment may contain sensitive position sensors and should be handled with care.

General Safety Concerns

Mechanical testing is an inherently dangerous activity since the product being tested may behave or fail in a way that is not expected. The nature of testing is to determine what happens when various conditions are present that have never been tested before In addition, servo-controlled systems, by their nature have many variables that must be factored in real time by the operator of the machine. In many cases, the person wanting to operate the machine may be lacking in training or experience and so may choose to place a sample in a dangerous mode. This is the nature of performing research on new products and materials. Since all materials and products fail in different modes, the user is responsible to determine the risk and to solve the problem of minimizing it.

For example, if the material tested is brittle and fails in a catastrophic and dangerous manner, a safety enclosure is recommended to contain the product being tested.



Method

Part A: Tension Test

1. Prepare Test Specimen: During the lab different materials with different properties will be used.

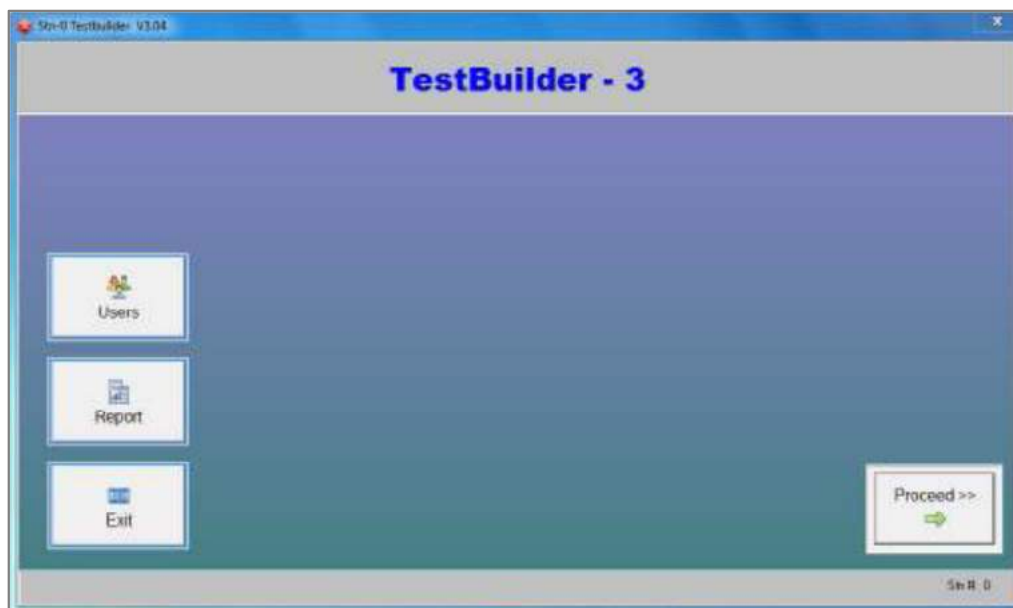
For each test specimen, determine the following parameters as the table below:

Parameter	Type of Test Specimen -----	Type of Test Specimen -----
Gauge length (L_0) (mm)		
Width (w) (mm)		
Thickness (t) (mm)		

2. Check that all cables are properly and securely connected. Switch on all power Switches in the following sequence:
 - a. Main power switch
 - b. Control Power
 - c. Computer.

A Five minute warm up period is necessary before starting your test.

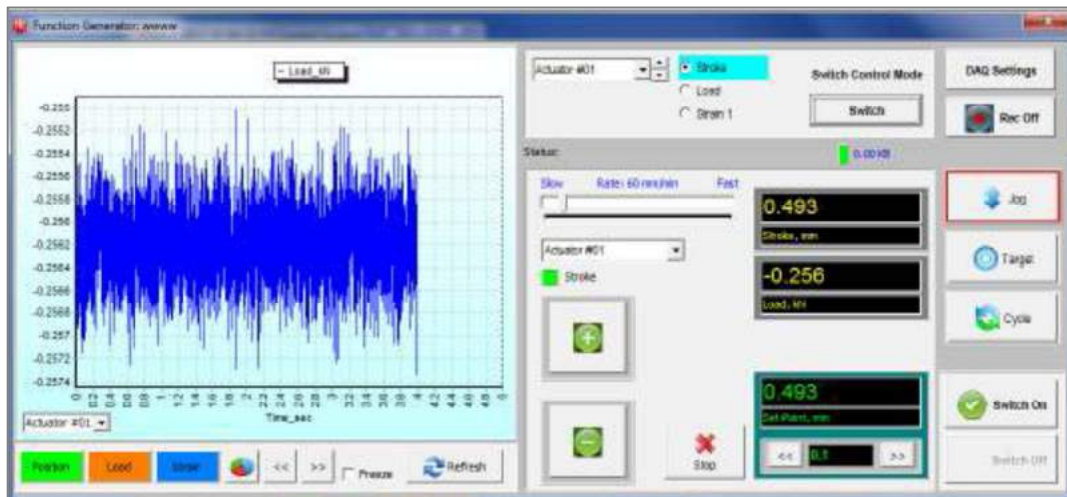
3. Start the Software:
 - a. Double click on the "TestBuilderV3" icon. The software will connect automatically.



- b. Click on the "proceed " button
- c. The TestBuilderV3 main screen will appear as shown below.



- d. Click on the "Function Generator" The function generator application is intended for simple movement of the actuator.

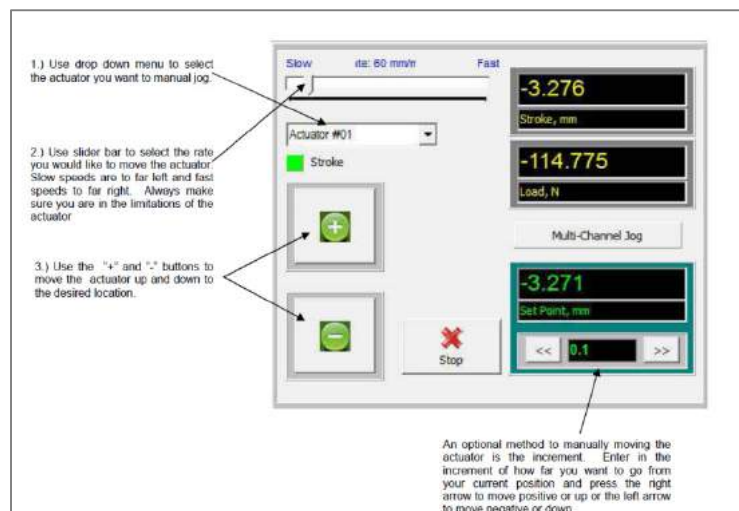


- e. Use position mode to jog the load cell and



fixtures.

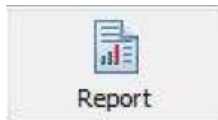
- f. Select the Jog button down the right hand side of the software screen. The Jog panel allows you to



- g. Tare readout: In most cases before you, insert your sample into the fixtures on the test machine you will want to tare or zero the weight of the fixture, because this is not load seen by the sample. To tare or zero the weight of the fixture. Click on the setup on the top menu bar as shown below and click on “offset Readout”.
- h. Start the tensile test (Tension) by carrying out the following procedure:
 - Click the DAQ button enter the DAQ rate use 50 for static test then save your folder
 - Start you test by switch on the function generator

Note: You could always stop a test by pressing the Emergency Stop Button, which isa large, round, red button located on the front of the load frame. Press this button to Stop crosshead travel immediately when a condition develops that could affect the Safety of persons operating the system, or could damage the specimen or the test Fixtures. Pressing the Emergency Stop Button stops the system instantly and disables the frame’s drive motor.

- Once you’ve completed your test Click on the Report icon to generate a report and export to excel.



- Once tensile testing is complete, remove the test specimen from fixtures.
- Repeat the procedure for the second specimen.

Part B: Compression Test

1. Measure and record the specimen dimensions prior to testing as the table below.

Parameter	Specimen #1 -----	Specimen #2 -----
Gauge Height (H_0) (mm)		
Gauge Diameter (D_0) (mm)		

2. Load the specimen between the two grips of the Universal Testing Machine.
3. Start the compression test (as Lab instructions).
4. Once compression test is complete, remove the test specimen from grips.
5. Measure the final diameter and height of the specimen.

Parameter	Specimen #1 -----	Specimen #2 -----
Final Height (H_f) (mm)		
Final Diameter (D_f) (mm)		

Experiment #6 Creep Test

Objectives

1. To understand the principle of Creep test.
2. To study the time-dependent deformation (creep) of different materials (Lead).
3. To calculate the creep rate (ϵ) and the strain hardening (n) coefficient.

Theory

When the stress on a material takes the material above its elastic limit into its plastic region, then the material **permanently** deforms. If the stress is maintained, the deformation (strain) continues. This slow, gradual deformation is called '**creep**'. It is an increase in strain over time. Creep happens due to long term stress levels that are below yield stress. The material permanently deforms to relieve the stress. Creep is easily measured in pure metals when their temperature is one third (or 30%) of their melting temperature.

Four main things determine the speed and amount of creep:

- **Applied load** - higher loads give higher stresses that increase the speed of creep
- **Type of material** - softer materials creep more quickly for the same value of stress
- **Dimensions of the material** - thinner materials take higher stresses for the same value of load
- **Temperature of the material** - higher temperatures encourage faster creep

Creep testing aims to investigate plastic deformation of a material when subjected to a constant load or stress at varying temperatures. Temperature allows materials to deform more easily since atoms can move more readily, hence, greater movement of dislocations or slips.

New slip systems and grain-boundary movement are also possible at higher temperatures. Therefore, engineering alloys utilized at high temperatures is susceptible to creep as well as recrystallization and grain coarsening. In the case of age-hardened metals, over-ageing is feasible, which results in reduced hardness and strength due to the coarsening of the second phase precipitates.

Due to a significant degradation of mechanical properties with time, structural materials can generally withstand mechanical loading at different temperatures in a certain period of time (strong time dependence of strength). Maintenance or replacing of new materials is therefore necessary for safety reasons.

Note that creep testing is noticeably different from tensile testing. For example, a tensile test requires less time to actually finish the test. A creep test might require 10,000 hours to finish the test. Therefore, creep study is required for materials subjected to high loads for extended periods of time to prevent creep failure during service operations.

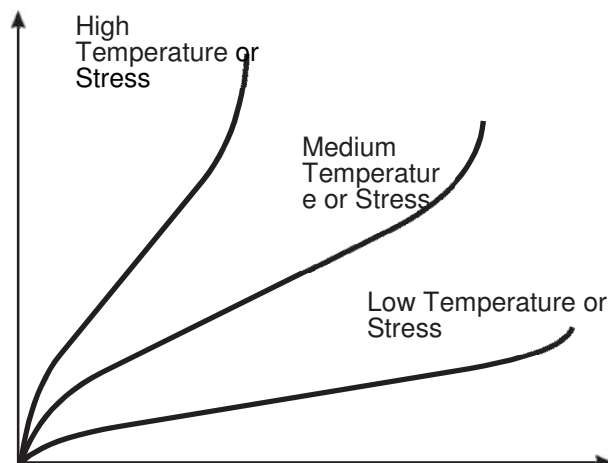


Figure 1: Curves of Creep at Different Temperatures

Material Failure (Fracture)

When a material is subject to creep, after enough time, the material will fail (fracture). Different materials will fracture after different amounts of deformation.

Rubber materials can deform much more than plastic materials before they fail. Plastic materials can deform much more than metals before they fail. Metals can deform much more than silicone based material before they fail. This is because the failure is determined by the molecular structure of the material.

Three Stages of Creep

Even though the applied stress and temperature on a piece of material may be constant, creep is not completely linear. It has three main stages:

- **Primary creepor ‘Transient’ Creep:** in which the creep resistance increases with strain leading to a decreasing creep strain rate.
- **Secondary (Steady State) creepor ‘Quasi-viscous’ Creep:** in which there is a balance between work hardening and recovery processes, leading to a minimum constant creep rate.
- **Tertiary creep:** in which there is an accelerating creep rate due to the accumulating damage, which leads to creep rupture, and which may only be seen at high temperatures and/or stresses and in constant load machines.

Each stage of creep behavior is influenced from both work hardening and annealing mechanisms occurring at the same time. However, work hardening and annealing will take place at different rates depending on response of metals to applied tensile force with time. The creep rate therefore changes accordingly.

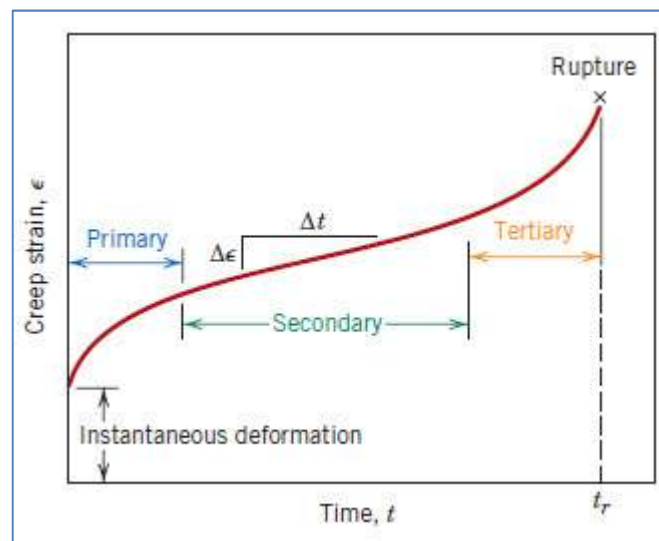


Figure 2: Standard creep figure

- ❖ **Primary creep does not start until the material has passed its elastic limit.**

The **secondary creep stage** is almost linear because this is the stage where the material is actually becoming ‘work hardened’, which helps to resist the load. **The gradient of the secondary creep determines the creep rate for the material.**

The point between the second and third stage is the ‘Transition Point’. This indicates that the material is starting to fail and may already start to crack in places.

Engineers must realize that they can allow materials to enter the first and second stages of creep, but never the third, as the part (or structure) will fail. It is important for engineers to know the second stage creep rate, so that they when to change a part in a machine or structure.

Calculation of Creep Rate (secondary creep)

Secondary creep rate is linear, so to find it you only need a measurement of the change in dimension (strain) of the material over time, from a test at a constant temperature and stress. The equation for this is:

$$\dot{\epsilon} = \frac{\Delta\epsilon}{\Delta t}$$

Useful Equations

Strain-Hardening Coefficient (n)

When many materials are stressed they actually become harder and resist the stress. This is also known as work hardening. It is the gradient of a graph of the natural log values of stress and strain in a material in its plastic region.

It is found by the equation:

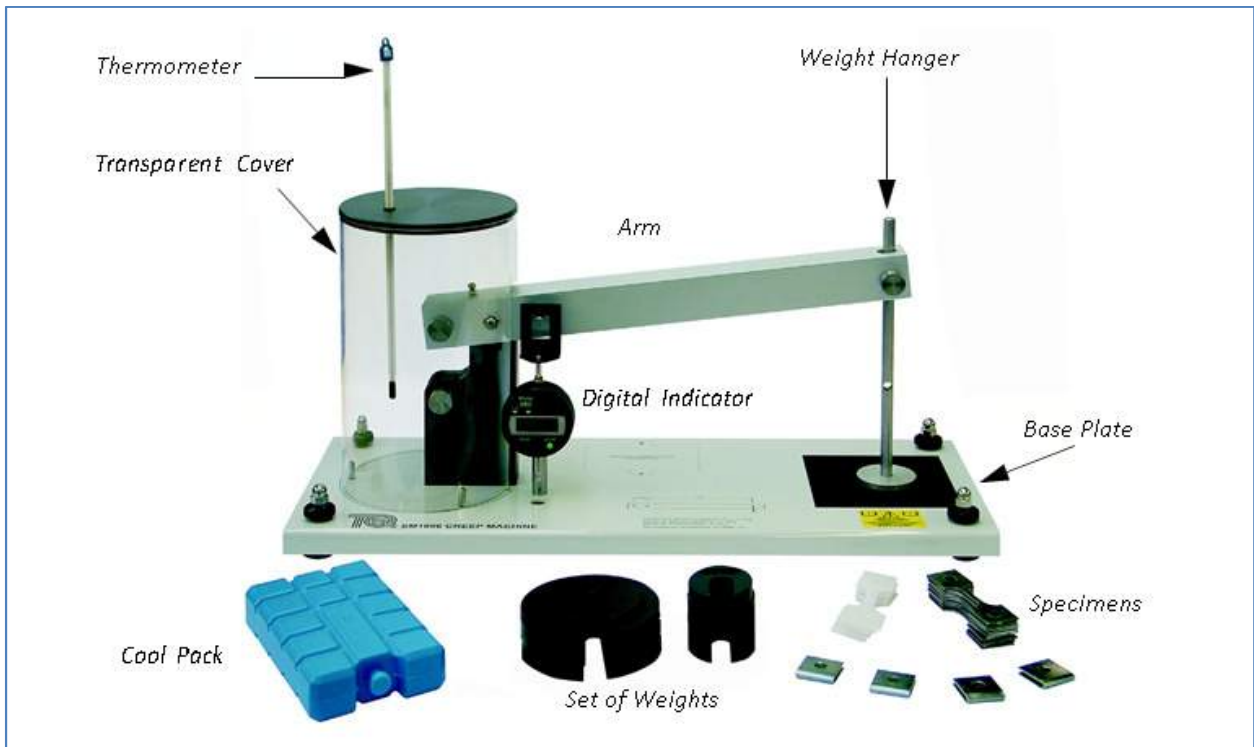
$$n = \frac{\Delta \ln \sigma}{\Delta \ln \epsilon}$$

Equipments

9. Creep Machine SM1006
10. Test specimens: Lead, Polypropylene
11. Stopwatch
12. Vernier caliper

Creep Machine Description:

The Creep Machine is a simple lever and weight machine. It has a long lever (Arm) with a pivot point near to one end. The pivot point is a bearing, for very low friction. Students fit specimens of different materials to the short end of the lever and known weights to the long end of the lever. The lever gives a large mechanical advantage, so that even small weights will apply a large load (tensile stress) to the specimen. This simple system gives a predictable, uniform and constant load to the specimen.



Procedure

Calculation of the Stress on a Specimen

1. Calculate the total mass at the end of the Arm (point 'P'). To do this, add together:

- The value of the weight you are to add to the Weight Hanger
- The Effective mass of the Arm at 'P'
- Mass of the Weight Hanger
- Mass of the Support Pin

* The mass of these parts is written on the Base Plate of the Creep Machine

2. Multiply the total mass by 8 (the mechanical advantage of the Arm), and then by 9.81 (acceleration due to gravity). This will give the total force on the specimen in Newtons.
3. Calculate the cross sectional area of the specimen (width x thickness) in m^2 .
4. Divide the total force (Newton) by the cross sectional area (m^2) to find the stress on the specimen (in $N.m^{-2}$).

Prepare the Specimen

5. Accurately measure and record the width and thickness of each tested specimen.

Parameter	Type of Test Specimen -----	Type of Test Specimen -----
Gauge length (L_0) (mm)		
Width (w) (mm)		
Thickness (t) (mm)		

Part III: Biofluid Mechanics

Objectives

- Emphasize the application of fluid mechanics principles to major human organ systems.
- Principles such as the conservation of energy and mass will be applied to various human body systems in addition to fundamental equations including continuum equations.
- Examine the flow pattern around a body or over its surface.

Preface

Biofluid mechanics is a vast field that involves fluid motion inside and outside living organisms. The human circulatory system illustrates some of the many challenges associated with understanding and modeling biological fluid flows. It is a branched network of flexible-wall vessels through which a non-Newtonian fluid flows in an unsteady manner. The branched geometry of the blood vessels minimizes flow resistance while providing a large surface area at the capillary level for the exchange of oxygen, nutrients, and wastes that are carried to or from the body's tissues. The flexibility of the large arteries partially smooth the pressure pulses produced by the heart's rhythmic pumping. Both the protein content and the presence of red blood cells contribute to the shear thinning character of blood. Models of steady and unsteady flow in straight tubes having appropriate properties are reasonably successful in explaining many features of human blood circulation.

Experiment #7 Venturi Meter

Objectives

1. To understand the principle of venturi meter
2. Show the relationship between flow area, pressure head, velocity head, and head loss through an expansion.
3. Calculate the flow rate given the drop in pressure through the contraction and the area of the two cross-sections

Background

The Venturi Effect and Bernoulli's Theorem

The Venturi Effect is named after an Italian physicist - Giovanni Venturi from the 18th century. He found that the pressure of a moving fluid drops when it passes through a constriction in a pipe. Around the same time, a dutch-swiss mathematician - Daniel Bernoulli experimented with fluid dynamics, leading to Bernoulli's principle. This principle stated that a change in fluid velocity is directly linked to a change in its pressure (or potential energy).

Bernoulli's principle assumes that the fluid flow is inviscid - the fluid has no viscosity. In reality most fluids have some value of viscosity.

To obey the laws of fluid dynamics for an incompressible fluid, its velocity increases as it passes through a constriction, thereby conserving mass. If the flow remains constant, its pressure must decrease, thereby conserving energy.

Figure 1 shows an incompressible fluid flowing along a convergent-divergent pipe with three pressure tapplings. One tapping measures upstream pressure at section 1, the second measures pressure at the throat (section 2) and the third measures pressure downstream (section 3). The cross-sectional area at the upstream section 1 is a_1 and at throat section 2 is a_2 . Any other arbitrary section n is a_n . Piezometer tubes at these sections register h_1 , h_2 and h_n as shown.

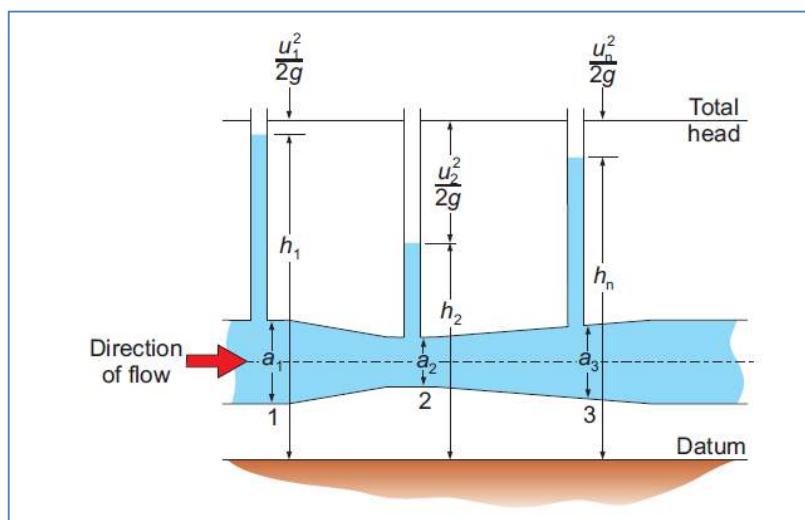


Figure 1: Ideal Conditions in a Venturi Meter

A venturi meter is a measuring or also considered as a meter device that is usually used to measure the flow of a fluid in the pipe. A Venturi meter may also be used to increase the velocity of any type fluid in a pipe at any particular point. It basically works on the principle of Bernoulli's Theorem. The pressure in a fluid moving through a small cross section drops suddenly leading to an increase in velocity of the flow. The fluid of the characteristics of high pressure and low velocity gets converted to the low pressure and high velocity at a particular point and again reaches to high pressure and low velocity. The point where the characteristics become low pressure and high velocity is the place where the venturi flow meter is used.

Assuming that there is no loss of energy along the pipe, and that the velocity and piezometric heads are constant across the cross-sections of each of the sections considered, then Bernoulli's theorem states that:

$$\frac{u_1^2}{2g} + h_1 = \frac{u_2^2}{2g} + h_2 = \frac{u_n^2}{2g} + h_n \quad (1)$$

where u_1 , u_2 and u_n are the velocities of flow through sections 1, 2 and n.

The equation of continuity assumes constant **flow volume** (not velocity) along the pipe, so:

$$u_1 a_1 = u_2 a_2 = u_n a_n = Q \quad (2)$$

Substituting in Equation 1 for u_1 from Equation 2:

$$\frac{u_2^2 \left(\frac{a_2}{a_1}\right)^2}{2g} + h_1 = \frac{u_2^2}{2g} + h_2$$

and solving this equation for u_2 leads to:

$$u_2 = \sqrt{\frac{2g(h_1 - h_2)}{1 - (a_2/a_1)^2}}$$

so that the discharge rate (volume flow), from Equation (2) becomes:

$$Q = a_2 \times \sqrt{\frac{2g(h_1 - h_2)}{1 - (a_2/a_1)^2}} \quad (3)$$

The flow actually loses some energy between sections 1 and 2, and the velocity is not absolutely constant across either of these sections. As a result, the measured value of Q is always slightly less than the value calculated from theory - Equation (3). To allow for this, the equation becomes:

$$Q = C a_2 \times \sqrt{\frac{2g(h_1 - h_2)}{1 - (a_2/a_1)^2}} \quad (4)$$

where C is an adjustment factor called the **coefficient of discharge** for the meter, which you can find by experiment. Its value varies slightly from one meter to another and, even for a given meter it may vary slightly with the discharge, but is usually between 0.92 to 0.99 for a convergent-divergent (Venturi) meter.

Finding the Coefficient of Discharge (C)

Equation 4 can be re-arranged to give:

$$Q = C \times a_2 \sqrt{\frac{2g}{1 - (a_2/a_1)^2}} \times \sqrt{(h_1 - h_2)} \quad (5)$$

As the dimensions of the Venturi (a_1 and a_2) and gravity (g) remain constant, the middle of the equation can simplify to a constant (k), so that:

$$k = a_2 \sqrt{\frac{2g}{1 - (a_2/a_1)^2}}$$

$$Q = C \times k \times \sqrt{h_1 - h_2} \quad (6)$$

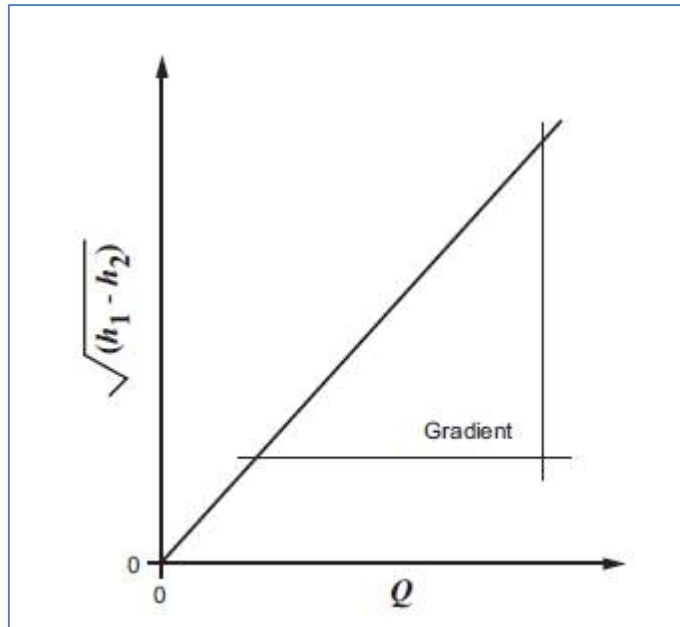
and therefore:

$$C = \frac{1}{k} \times \frac{Q}{\sqrt{h_1 - h_2}} \quad (7)$$

Showing a linear relationship between flow, flow coefficient and the square root of head difference.

Average Coefficient of Discharge

From Equation 7, assuming C and k remain constant, a chart $h_1 - h_2$ against Q (see Figure below) should produce linear results. You can then use **the inverse gradient** of the results to give an average value that you can substitute for the right hand side in Equation 7.



Dimensionless Calculations of Pressure

From Bernoulli's equation the difference in head between any point and the inlet pressure may be found from:

$$h_n - h_1 = \frac{u_1^2 - u_n^2}{2g}$$

To easily compare actual results with theory, you must convert these terms into dimensionless calculations. To do this, dividing through by $(u_2^2/2g)$ gives:

$$\frac{h_n - h_1}{(u_2^2/2g)} = \frac{u_1^2 - u_n^2}{u_2^2}$$

Using the equation of continuity (2) to substitute area ratios in place of velocity ratios, this becomes:

$$\frac{h_n - h_1}{(u_2^2/2g)} = \left(\frac{a_2}{a_1}\right)^2 - \left(\frac{a_2}{a_n}\right)^2 \quad (8)$$

Therefore, calculating the area ratios gives the *theoretical or 'ideal'* dimensionless pressure difference, otherwise known as *ideal piezometric head coefficient*:

$$\left(\frac{a_2}{a_1}\right)^2 - \left(\frac{a_2}{a_n}\right)^2 \quad (9)$$

and the *actual* dimensionless pressure distribution (otherwise known as *actual piezometric head coefficient*) is found from:

$$\frac{h_n - h_1}{(u_2^2/2g)} \quad (10)$$

Equipments

1. Venturi Meter (H5)
2. Digital Hydraulic Bench (H1F)
3. Two supply hoses

Venturi Meter Description:

Figure 2 shows the arrangement of the Venturi Meter. Water enters from a TecEquipment Hydraulic Bench (supplied separately) and passes through a flexible hose into the meter. A control valve downstream of the meter controls flow. After the control valve a further flexible hose leads to the central hole in the Digital Hydraulic Bench (H1F) or the measuring tank of existing Volumetric and Gravimetric Hydraulic Benches (H1D and H1).

Tubes connect to pressure tapings along the Venturi wall. The tubes connect to vertical manometer tubes mounted in front of a scale for direct readings of pressure head difference in millimeters of water. The manometer tubes connect at their top ends to a common manifold that has a small air valve. the hand pump (supplied) allows the user to adjust the air pressure in the manifold and therefore uniformly adjust the water levels in the manometers, so they fit in the measuring range of the scale.

A base with adjustable feet holds the whole assembly of Venturi Meter, manometer tubes, scale and manifold.

Normally, when used for flow measurement, Venturi meters only use two tapings: one at the entrance and one at the throat. The Venturi Meter (H5) has more tapings to show the distribution of pressure along the length of the convergent-divergent passage.

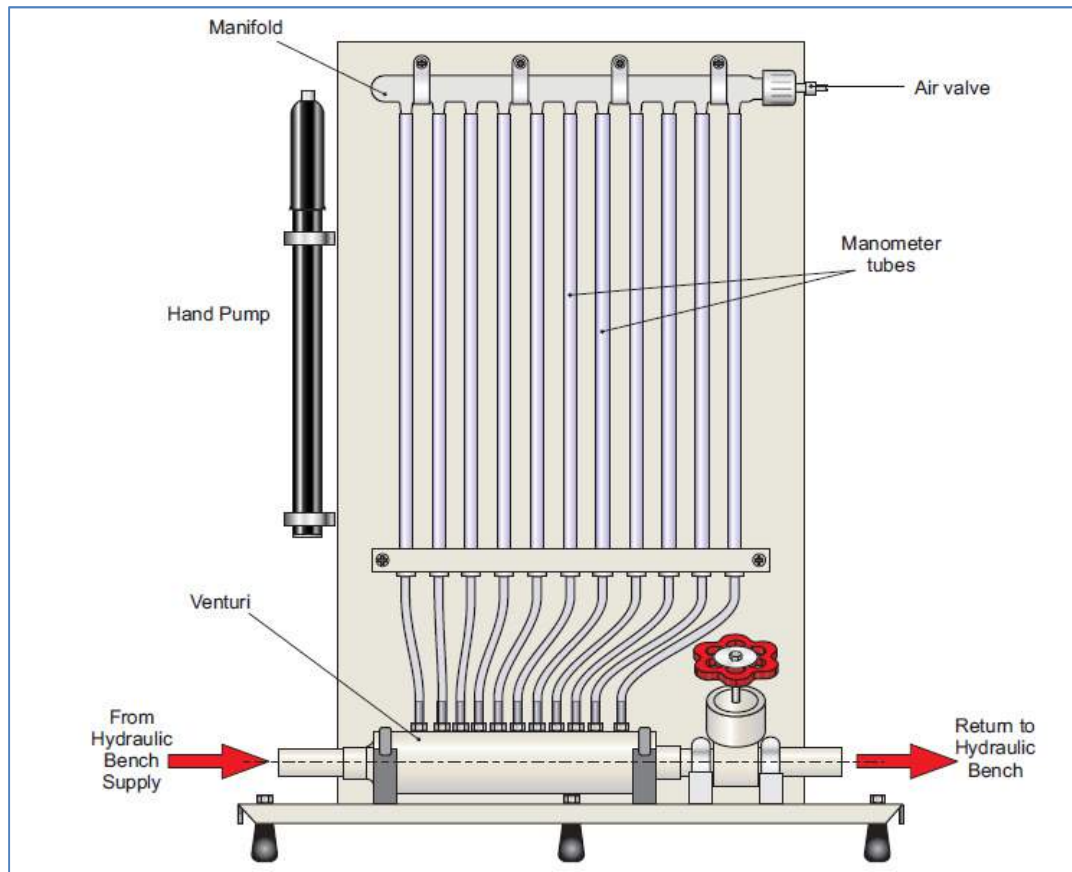


Figure 2: Venturi Meter

Procedure

1. Put the apparatus on the top of a TecQuipment Hydraulic Bench (supplied separately).
2. Connect the bench supply hose to the upstream (left) side of the Venturi meter.
3. Connect the downstream end of the Venturi Meter to the plastic tube supplied and direct it back to the large central hole of the Digital Hydraulic Bench (H1F), or the measuring tank of the Volumetric (H1D) or Gravimetric (H1) Hydraulic Benches for flow measurement.
4. Set both the apparatus flow control and bench supply valve to approximately one third fully open positions.
5. Check that the air valve on the upper manifold is tightly closed.
6. Switch on the bench supply and allow water to flow. To clear air from the manometer tubes it may help to slightly tilt the apparatus or lightly tap the tubes with your finger.
7. Shut the apparatus flow control valve. Air will now be trapped in the upper parts of the manometer tubing and the manifold.
8. Open the air valve just enough to allow water to rise approximately halfway up the manometer scale.
9. Shut the air valve.
10. Adjust both the bench supply and the apparatus control valves to give full flow.
At this condition the maximum pressure difference between the Venturi inlet and throat should be about 240 mm. You may need to connect the pump to the air valve, and add some air to see all levels on the scale.
11. Watch the water levels for a few moments to ensure the air valve is sealing properly.
If the air valve leaks there will be a steady rise in the levels.
If tightening the valve does not stop the leak, replace the seal in the valve.
12. Now slightly reduce the flow rate through the meter, and wait for it to stabilize. Use the hydraulic bench to measure the flow.

Experiment #8

Flow Visualization

Objectives

- Recognize flow in different cases and its relation with human organ systems

Theory

In general, flow visualization is an experimental means of examining the flow pattern around a body or over its surface. The flow is "visualized" by introducing a dye to the flow in the area under investigation. The primary advantage of such a method is the ability to provide a description of a flow over a model without complicated data reduction and analysis.

There are three types of line patterns to visualize flow:

1. Streamline: a line everywhere tangent to the velocity at a given instant.
2. Path line: actual path traversed by a given fluid particle.
3. Streak line: locus of particles which have earlier passed through a prescribed point.

Under the steady flow condition, all the three types of line pattern are identical. An important distinction in single phase flow is whether the flow is laminar or turbulent or whether flow separates or secondary flows exist. This information helps in modeling specific phenomena because one has an indication of the flow character for a particular geometry.

Several elements in flow visualization:

- **Reynolds Number:** It is the ratio of inertia force to the viscous force acting in any flow phenomenon.

Inertia force = mass X acceleration

Viscous force = viscous shear stress X area of flow

For open channel, **Reynolds Number (Re) = $\rho VR/\mu$**

Where, V = avg. velocity of flow in channel, R = Hydraulic radius (ratio of area of flow to wetted parameter).

Reynolds number is very useful in predicting whether the flow is laminar or turbulent and for finding out the coefficient of friction in order to determine the frictional loss of head accurately.

- **Laminar flow:** When the fluid particles move in layers called lamina, then the flow is called laminar flow. Laminar flow occurs when velocity of flow is small and viscous forces are predominant. It is smooth and regular and thus also known as stream-line flow. There is practically no influence of fluid particles of one layer over those of the adjacent layer. Velocity at any point remains nearly constant in magnitude and direction. Flow through circular pipes with Reynolds number < 2000 is always laminar. In case of channel flow, if Reynolds number < 500, then the flow is laminar.
- **Turbulent flow:** When the velocity of flow reaches a certain limit the fluid particles no longer move in layers or lamina. Violent mixing of fluid particles takes place due to which they move in chaotic and random manner. As a result the velocity at any point varies both in magnitude and direction from instant to instant. Such a flow is known as turbulent flow. Flow through circular pipes with Reynolds number > 4000 is turbulent. In case of channel flow, flow with Reynolds number > 2000 is turbulent.
- **Steady and unsteady flow:** If the condition of flow e.g. depth of flow, velocity etc. do not vary with respect to time, then the flow is said to be steady. Otherwise it is unsteady flow.
- **Stagnation point:** point where streamline meet at the leading edge, velocity is zero.
- **Boundary layer:** Region where velocity gradient at the surface of obstacle is zero and gradually increasing and ends when its velocity is constant. Heavily affected by viscous friction force.

- **Separation point:** point where boundary layer separates far away from the surface of object.

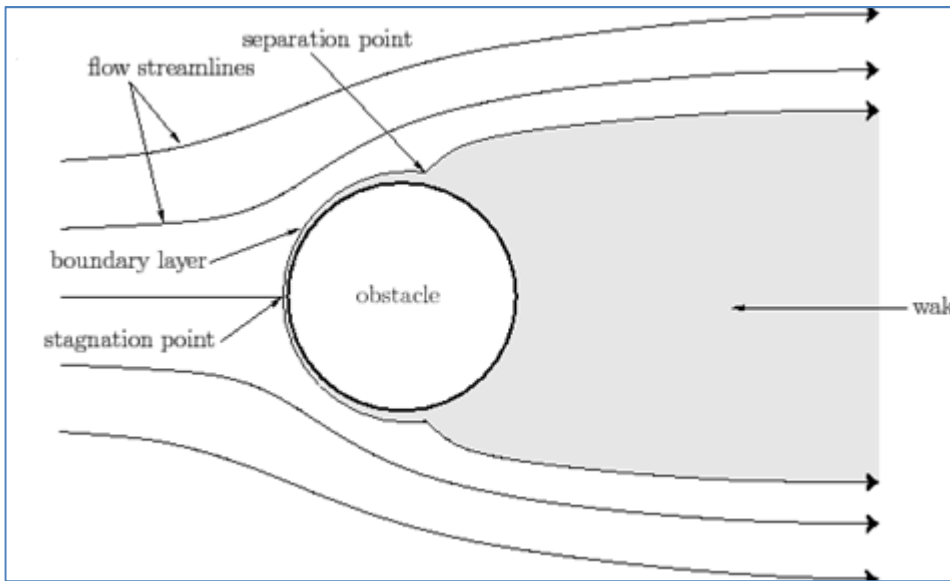


Figure 1: Elements in flow visualization

The Hele-Shaw apparatus that will be used during this experiment produces streamlines in a laminar, steady flow. It allows students to study various source and sink arrangements, and look at flow around an unlimited variety of different shaped models. The apparatus can represent water seepage through solids and can simulate any process satisfying the Laplace equation in two dimensions. The apparatus works with a steady, air-free water supply and suitable drain. The equipment consists of a channel formed between two plates. Water flows along the channel at a low Reynolds number, so the inertia forces are not important.

A dye flowing through several small holes at the upstream end produces streamlines. The removable top glass plate has grid-lines to help analysis of the flow patterns. The apparatus comes with a rubber sheet from which to cut out various shapes of models. When placed between the two plates, students can see the streamline patterns flowing around the models. Also, valves and a vacuum pump allow students to connect two sources and two sinks (or any combination of both).

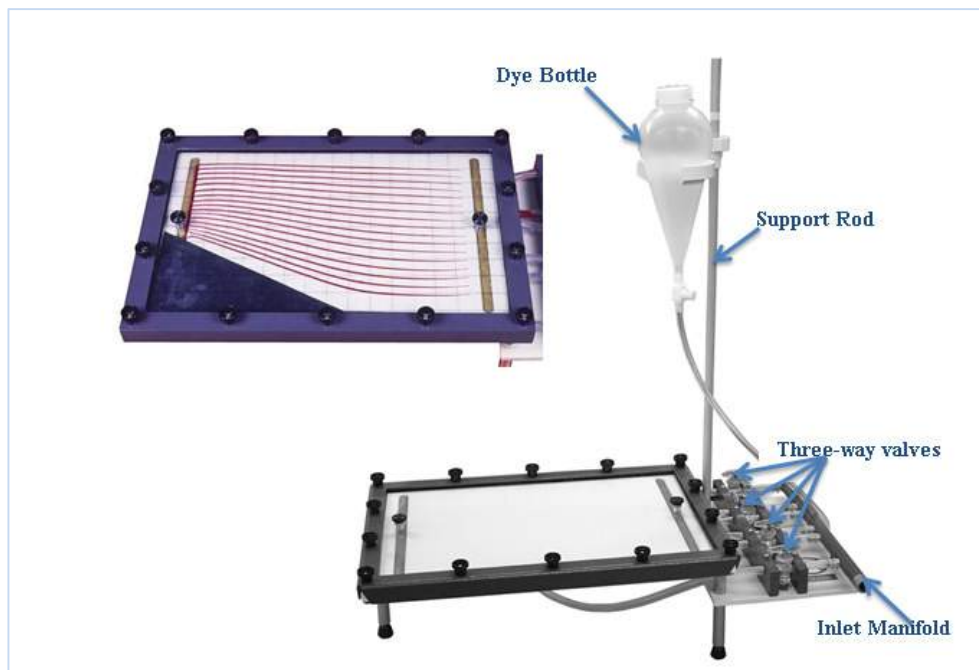


Figure 2: The Hele-Shaw Apparatus

The Momentum Equation

Consider the equilibrium of the fluid contained within a volume ABCD. AB and CD are the cross-sections of a stream tube.

From Newton's second law:

$$pA - [pA + \delta(pA)] + \bar{p}\delta A - \tau_0\delta L\bar{P} \cos \theta - \rho\bar{A}\delta Lg \sin \alpha = PAv[(v + \delta v) - v]$$

where:

P = perimeter

p = pressure on face AB

A = Area of cross section AB

δL = Length

τ = wall shear stress

v = fluid velocity at AB (assumed to be uniform)

ρ = Fluid density

θ = angle between the pipe wall and its centreline

α = the angle between δL and horizontal

The bar above the letters show mean quantities over the length δL

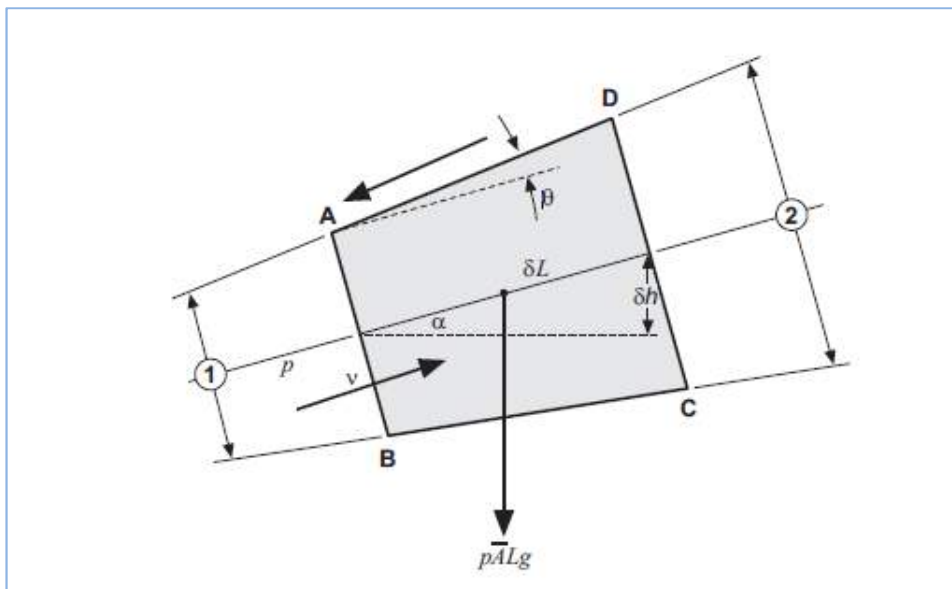


Figure 3: The Momentum Equation

Dividing by $\rho Ag \delta L$ and proceeding to the limit:

$$\frac{-1}{\rho g} \times \frac{\delta p}{\delta L} - \frac{P}{A} \times \frac{\tau_0}{\rho g} \cos\theta - \frac{\delta h}{\delta L} = \frac{v}{g} \times \frac{\delta v}{\delta L}$$

Integrating with respect to 1 from stage 1 to stage 2 for an incompressible fluid flowing through a duct for which $\cos\theta = 1$ having hydraulic radius $m = A/P$.

$$\left[\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + h_1 \right] - \left[\frac{p_2}{\rho g} + \frac{v_2^2}{2g} + h_2 \right] = \frac{1}{m\rho g} \int_1^2 \tau_0 \delta L$$

Writing

$$\frac{p}{\rho g} + \frac{v^2}{2g} + h = \text{Total Head } H$$

$$\Delta H = h_2 - H_1 = \frac{1}{m\rho g} \int_1^2 \tau_0 \delta L \quad (1)$$

The Laminar Flow Relationship for Flow between Two Parallel Plates

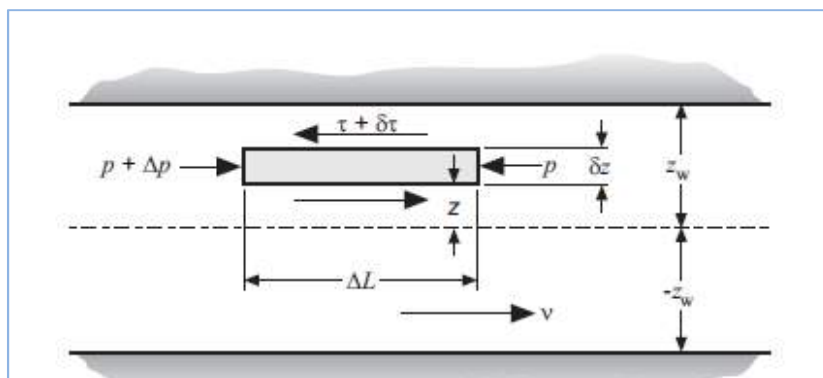


Figure 4: Flow between two parallel plates

For steady laminar flow of liquid between two plates, a distance of $2z_w$ apart:

where b is the flow channel breadth.

Hence

$$\bar{V} = \frac{2}{3}V$$

and from Equations (2) and (3) since

$$\mu V = \frac{1}{2} \times \frac{\Delta p}{\Delta L} z_w^2 = \frac{1}{2} \times \frac{\tau_0 z_w^2}{z_w}$$

$$\bar{V} = \frac{\tau_0}{3\mu} z_w \quad (4)$$

Inserting this value in Equation (1) and substituting:

$$m = \frac{A}{P} \cong z_w$$

gives

$$\Delta H = \frac{-\tau_0}{m\rho g} \Delta L = \frac{-3\mu}{z_w^2 \rho g} \bar{V} \Delta L \quad (5)$$

This is an example of d'Arcy's equation.

The discharge between the plates is

$$2bz_w \bar{V} = 2b \int_0^{z_w} v dz$$

Mean Velocity Equations for Flow in the Apparatus and for Seepage in Soils

Assuming the flow velocity through the apparatus is low enough for the inertia force to be negligible, from Equation (5):

$$\Delta \left[\frac{p}{\rho g} + h \right] \propto V \quad (6)$$

Equation (6) is satisfied for incompressible fluid flow through the Hele-Shaw apparatus, in which case we may write:

$$\Delta p \propto \bar{V}$$

If x denotes distance in the direction of the free stream and y denotes the distance at right angles in a plane parallel with the walls,

$$\frac{\partial p}{\partial x} \propto \bar{V}_x$$

$$\frac{\partial p}{\partial y} \propto \bar{V}_y$$

But V_x and V_y are functions of x and y and in exactly the same way as that outlined in Equation (9), by the principle of continuity:

Materials and Methods

- Hele-Shaw apparatus
- Dye
- Header Tank

Procedure

Exercise #1: Source in a Uniform Stream

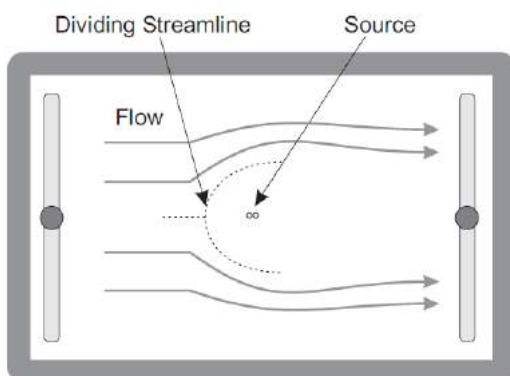


Figure 5: Source in a uniform stream

1. Set the relevant three-way valve to supply water to one of the sink/source points.
2. Start the water supply and open the dye bottle tap just enough to produce easily visible streamlines.
3. Fit and use the transfusion clamps (supplied) to adjust either the source supply or the free stream supply. This will adjust the strength of the source relative to the free stream.
4. You should see a streamline pattern with flow around the dividing streamline as shown in Figure 5.

Exercise #2: Sink in a Uniform Stream

1. Set the relevant three-way valve to allow water to flow from one of the sink/source points to drain.
2. Start the water supply and open the dye bottle tap just enough to produce easily visible streamlines.
3. Fit and use the transfusion clamps (supplied) to adjust the flows. If necessary, use the vacuum pump (supplied) to increase the sink flow.

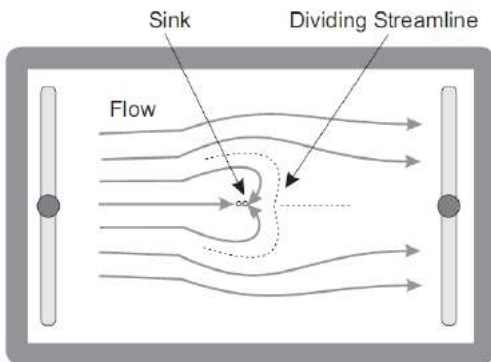


Figure 6: Sink in a uniform stream

Exercise #3: Flow Through a Diffuser

To make this work, cut two identical shapes (see Figure 7) from the sheet. Put them in the middle of the flow channel as shown in Figure 7. This forms a diffuser or nozzle. Block the flow to or from the source and sink points (using the clamps where necessary). The dye should flow in thin streams through the nozzle to the drain header. This should give an indication of the flow contraction and expansion around the nozzle.

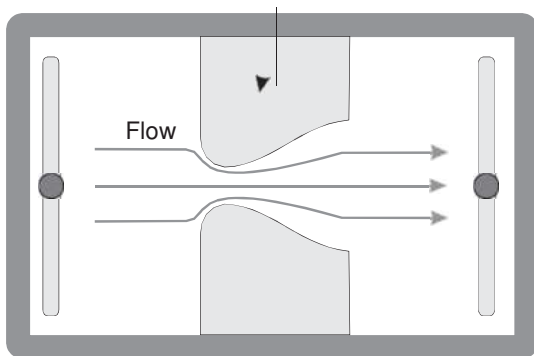


Figure 7: Flow through a diffuser