Introduction To The Modern
FOOTWEAR TECHNOLOGY

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INTRODUCTION

I had the privilege of going through the manuscript on "The Introduction to Modern Footwear Technology" and to write this preface. This book is the fifth in the series on Footwear Technology by the author, the earlier being "know your footwear", and "Shoe finishes" both published by the Central Leather Research Institute (CLRI), Adhesives in shoe manufacture and the book on " Quality Control and assessment of footwear and footwear materials"a is under publication by the Leather Technology Mission (CLRI). The author under this subject has covered various aspects of Footwear Science, Engineering and Technology, viz. The foot, footwear, materials, manufacture and testing, so that a student, consumer, a potential entrepreneur or a marketing personnel gets educated and well versed with the latest fundamental knowledge of footwear technology. The footwear industry which is traditional and confined to cottage level is slowly being revolutionalised by the application of science and engineering. Today the industry is much advanced, as seen by the use of Computers & Robots. The treatment is upto date and the latest developments in this field are highlighted. At a time when the academic institutions and the industry is in need of documental back up in the field of footwear, this book comes as a boom. The simplicity in language makes it easily understandable.

The author has done commendable job and deserves compliments for undertaking this task of bring out this document.

Place : Chennai

Dated : March 31, '97

P.S. KATHIRESAN, I.A.S.
EXECUTIVE DIRECTOR
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PREFACE

A pair of feet (right and left) are not similar in structure, size and fitting and footwear is intented for foot care and foot protection. In a pair of shoes one looks for fashion and fit, quality and comfort, at a reasonable price. It is now increasingly realised that a knowledge of foot structure and its mechanism is essential for the fabrication of footwear of comfort. The design and fabrication of footwear intended for the disabled feet and sportsmen, require an application of biometry and biomechanics of the foot, which is intended to increase the efficiency of foot and protect it from being injured. This is a subject where, pure and applied sciences play an important part. A number of footwear materials of both natural and synthetic are developed. For example one is able to fabricate a full shoe using the chemical polyurethane. To cater to the needs of a range of footwear designs, styles, more than hundred footwear making machines are developed. At the same time to assess the quality of footwear materials and footwear, a number of testing equipments, are designed and test methods developed.

In this book, an attempt is made to provide a fundamental concept on the science, engineering and technology of footwear, so that this knowledge will be helpful to personnel who opt footwear as their career. He may be a student or researcher of footwear technology, a prospective executive, a businessman, a marketing person or an entreprenuer.

Author

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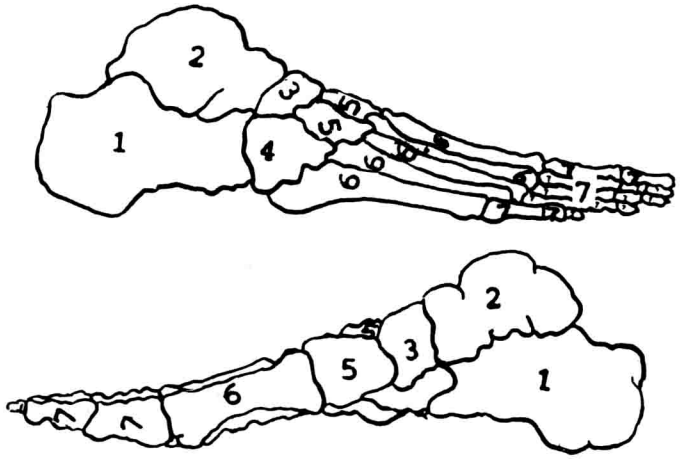
CHAPTER - 1

THE FOOT

The footwear is designed for foot care i.e., to protect the foot. The feet support the entire body weight keeping the body erect, propels the body forward as in walking, running and jumping.

(a) ANATOMY OF THE FOOT

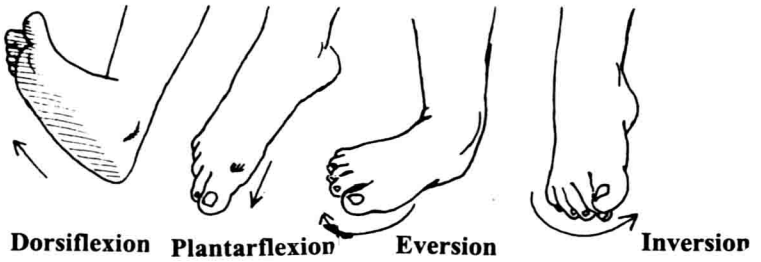
Bones of the Foot : The Foot has 26 bones divided into three groups -- tarus, metatarus and phalanges, all held together by ligaments, tendons, nerves, muscles, tissues and blood vessels. The tarus consists of seven short bones viz. Calcaneum, Talus, Navicular, Cuboid and three Cuneiform bones. The heel bone calcaneum takes 50% of the body weight. The talus links the foot with the leg and distributes the body weight to the fore part and back part of the foot. The metatarus group has five long bones, the first three connected to the cuneiform and the last two to cuboid. There are fourteen phalanges constituting toe bones. The big toe has two bones.

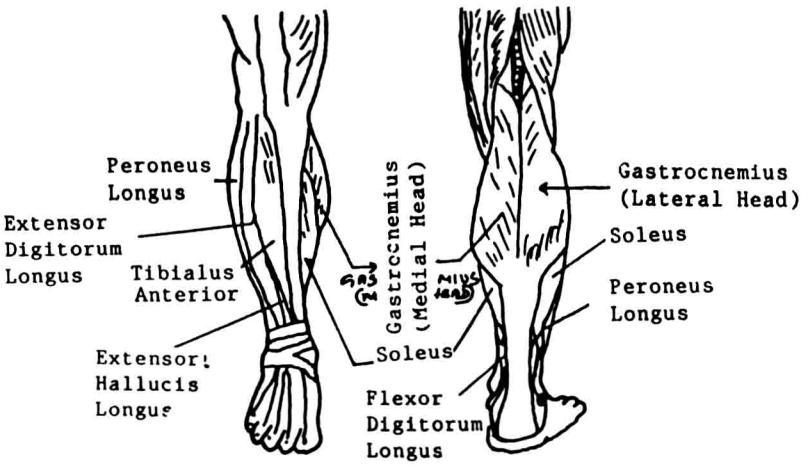


1. **Calcaneum** 2. **Talus** 3. **Cuboid** 4. **Navicular**
5 **Cuneiforms** 6. **Metatarsals** 7 **Phalanges**

Joints of the Foot : Main Joints at the lower extremity of the human body are hip joint, knee joint, ankle joint and metatarso phalangeal joints. The ankle joint is formed by TIBA and FIBULA(leg bones) . The intertarsal bones between the tarsal bones and the five metatarsal bones provide gliding movements to the foot. The foot flexion and the extension of the toes is permitted by the inter-phalangeal joints. Ligaments are elastic bands which strap round the bones to keep them in place and prevent dislocation. Muscles pass from bone to bone and are attached by tendons -- *a fibrous cord.*

Nerves stimulate muscle activity. Various joints assisted by muscles allow the movements of the foot in different directions.





MUSCLES OF THE LOWER LIMBS

Muscles of the Foot : The foot is able to move inwards (Inversion), outwards (Eversion), upwards (Dorsiflexion), downwards (extension or Plantar flexion) by the action of muscles. In plantar flexion only the heel is raised. The various movements of the foot, Inversion(I), Eversion(E), Dorsiflexion(D) and extension(P) are facilitated by means of leg muscle action.

Muscle		Action
1. Tibialis Anterior	:	D, I
2. Extensor Digitorum Longus	:	D, E Extends lateral toes
3. Flexor Digitorium Longus	:	Flexion of Toe
4. Peroneous Tertius	:	D, E
5. Peroneus Brevis	:	P, E
6. Peroneus Longus	:	P, E
7. Flexor Hallucis Longus	:	Flexion Big Toe
8. Gastrocnemius	:	P

9. Soleus	:	P
10. Tibialis Posterior	:	E, I

Muscles 1 to 4 are known as foot flexors and are brought into action in walking, running and all similar movements. Gastrocnemius is also called calf muscle, assists in knee flexion and prime mover for plantar flexion.

Movements of the Foot

Valgus : Displacement away from the middle line of the body.
Varus : Displacement towards the middle line of the body.

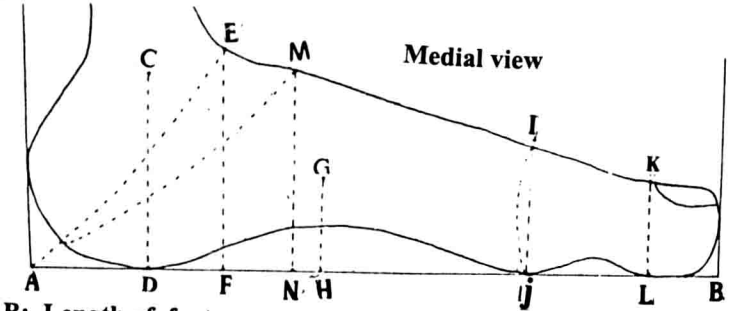
Arches of the Foot : The Arches of the foot are formed by the bones and are supported by the muscles, ligaments and tendons. The inner longitudinal arch is formed by the calcaneum, talus, navicular the cuneiforms and the first metatarsal bones. The outer longitudinal arch is formed by the calcaneum, the cuboid and the fourth and fifth metatarsal bones. The transverse arch is a dome formed by the arch formed when the two feet are placed together. The anterior metatarsal arch is formed by the metatarsal heads, with 2nd, 3rd and fourth metatarsal heads more elevated than the other two. The arches give the foot controlled resilience, provide shock resistance during walking.

(b) BIOMETRY OF HUMAN FOOT

People limping with a new ill fitting, pinching, footwear, for a few days until the shoe gets adjusted, is a common sight and experience. Leather shoes adjust to the shape of the foot and retain the shape even after the foot is removed from the shoe. But this type of adjustment is not possible in a shoe fabricated using non-leather material especially from synthetic material. A shoe should have good fitting. Bad shoes may even contribute to poor foot posture with accompanying strain and excessive fatigue. It is essential to design a shoe of correct size and fitting for the feet and this should be based on scientific facts and figures. Biometry of the human foot is, the study of various parameters of the human foot, their measurements and the relationship between them. The Shoe model last, a wooden mould, on which the shoe is shaped to the size and fitting of the foot, is designed using the foot measurements The measurements are obtained about the anatomical points on the foot.

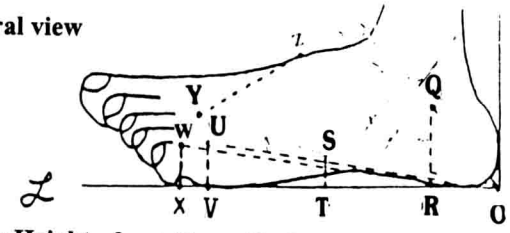
Foot Parameters - Definitions and Measurements :

1. Foot Length : The length of the foot is, from the back of the heel to the tip of the longest toe. The measurement is obtained by means of a vernier calipers, as well as from foot outline / foot plan.



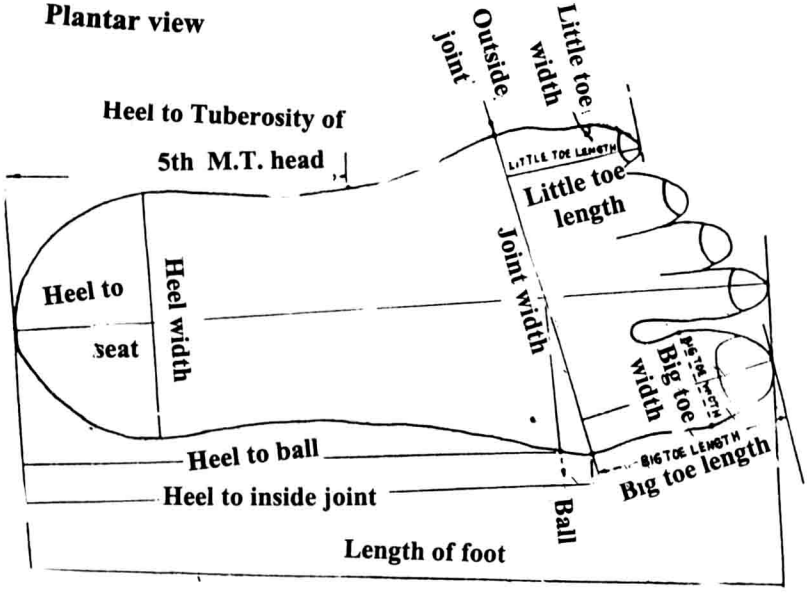
AB: Length of foot
CD: Ht. of inside malleolus
EF: Ht. of Throat.
GH: Ht. of tubercle navicular
AE: circumference measuring short heel
JI: Circumference measuring joint girth
MN: Ht. of cuneiform bone
IJ: Ht. of inside joint
KL: Ht. of big toe
AM: circumference measuring long heel

Lateral view



QR: Height of outside malleolus
SI: Height of tuberosity of 5th metatarsal head
UV: Ht.of outside joint
WX: Ht. of little toe
YZ: Length between ball & cuneiform

Plantar view



2. Foot Width : This measurement is obtained between the metatarso phalangeal joint of the big toe and the metatarso phalangeal joint of the little toe. The width of the foot is measured using a vernier calipers, as well as from the foot plan.

3. Joint Girth : This is the circumference on the foot taken around the metatarso phalangeal joint of the big toe and the metatarso phalangeal joint of the little toe.

4. Instep Girth / Circumference : i). Circumference around the foot taken about the tuberosity of the navicular and the tuberosity of the fifth metatarsal head.
ii). Circumference on the foot taken around the almost vertical plane at the first cuneiform bone i.e., bone of prominence.

5. Short heel : This is the circumference of the foot around the extreme end of the heel and the throat. The measuring tape is passed just below the external and internal malleoli.

6. Long heel : The circumference of the foot around the extreme end of the heel and the prominence of the first cuneiform bone. The measurements, joint girth, instep girth, long heel, and short heel are measured using a thin steel millimeter tape.

7. Height of the Big Toe : Height of the big toe measured from the ground, upto the first metatarso-phalangeal joint.

8. Little Toe Height : This is the highest point of the little toe, measured at metatarso phalangeal joint from the ground.

9. Height of Tuberosity Navicular : The height from the ground surface upto the tuberosity navicular.

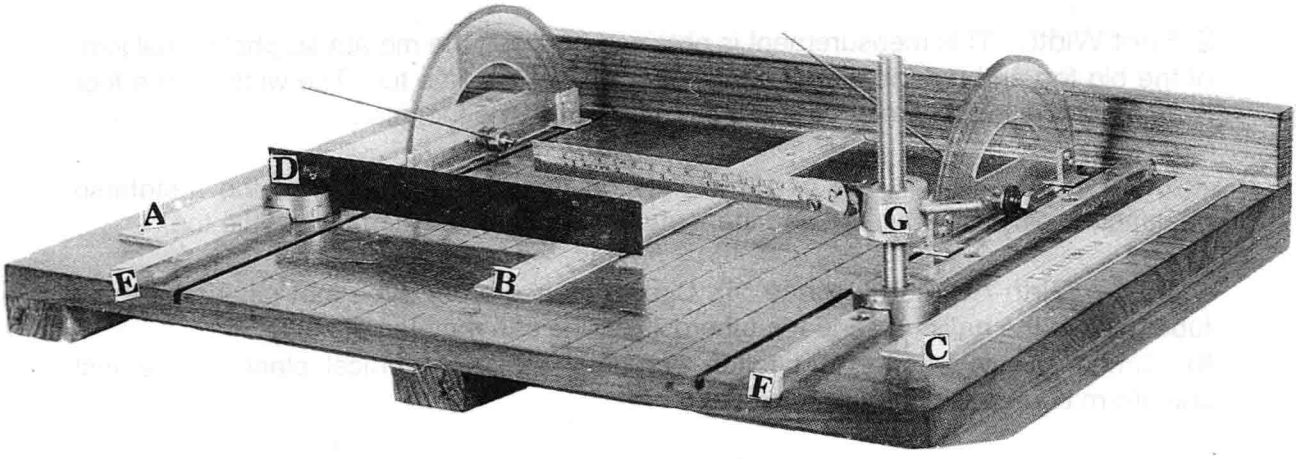
10. Height of the inside malleolus : This is the height from the bottom of the heel where it touches the ground upto the bottom of the inside malleolus.

11. Height of the outside malleolus : Height from the bottom of the heel where it touches the ground upto the bottom of the outside malleolus.

12. Height of the fifth metatarsal head : Height from the bottom of the foot [ground surface] upto the tuberosity of the fifth metatarsal head.

A simple device to measure various anatomical parameters of the foot :

A device to obtain the various anatomical measurements of the foot was designed and fabricated at CLRI. This consists of a wooden board on which three



scales A, B, and C are fixed. These scales are graduated in millimeters on one side and in inches on the other side.

A moveable head D with steel bar which is free to move over the rail E or F is used for direct measurement of the foot length. G is a measuring attachment and it can be kept at any height by operating it over a screw. The height of different anatomical joints and bones like metatarso-phalangeal joint of the big toe, metatarso-phalangeal joint of the little toe, tuberosity of navicular, tuberosity of the fifth metatarsal, heights of the external and internal malleolus, height of the cuneiform bone and the throat can be measured with this attachment.

Instruments like vernier calipers to measure foot width, depth gauge for toe heights, fine steel tape for joint girth, instep girth, long heel and short heel are also used.

Measurements from the Foot Plan : The outline of the foot is drawn in weight on position i.e., the person standing erect. A slim pen or pencil held vertically, in firm contact with the foot is moved round the foot to obtain foot plan. The position of the metatarso phalangeal joints of the big toe, little toe, the back of the heel are marked. A tangent at the extreme end of the heel is drawn. The scale is moved parallel to this tangent and when it records the maximum reading the heel width line is drawn. The width of the heel is measured.

13. The Foot length and Foot width are measured on the foot plan.

14. Length of Big Toe : The length of the big toe is the distance between the tip of the big toe and the joint width line, along a line passing and bisecting the width of the big toe.

15. Length of the Little Toe : The distance between the tip of the little toe and the joint line.

16. Big Toe Angle : The angle between the tangent at the big toe and the inside line.

17. Little Toe Angle : The angle between the tangent to the little toe and the outside line. The Constructional details are given in the figure. The measurement obtained on the foot plan are used for designing the insole of the shoe last.

Shoe Sizing and Fitting : What is a shoe size and a shoe with good fitting? Normally while buying a shoe tendency is to focus on the measurement i.e., length. The shoe size is denoted by the shoe last length. This is not enough. Feet can be long, narrow, short, broad, plump or splayed. That is why in addition to the shoe size i.e., length, fitting i.e., the other foot parameters also are important. Throughout the world there are different sizing systems and fitting scales. Different sizing systems predominantly used are the British scale, Paris point (also known as Continental scale), American system, the Mondopoint (International sizing system), and so on.

Different Sizing Systems and Fittings :

(a) Length Scales : The British system of shoe sizing is said to have been based on the length of barley corns, three of which make up one inch on an average. The sizes were arrived at by consecutive increase of the length by that of one barley corn viz. 1/3 of an inch. With the scale starting at 4" being called "Zero" size; the children's sizes are from 1 to 13 i.e., 4 1/3 " to 8 1/3 ", where as the adult sizes are again from 1 to 12, i.e., from 8 2/3 " to 12 1/3 ". Half sizes of 1/6" are also used in between two full sizes. The size of the shoe corresponding to the length of the foot is obtained from using the formula,

(Length of the foot in inches - 4) 3, --- children.
(Length of the foot in inches - 4) 3-13, --- adults.

On American system, the zero position starts at 3 11/12 " instead of at 4" on British sizing scale. Excepting for this it is similar to the British system with size intervals of 1/3 " and half sizes intervening. American sizes are shorter by 1/12 " as compared to the corresponding English sizes. But their size markings are 1 1/2 sizes greater than the English size, e.g. : English size 5 becomes American size 6 1/2. The Paris point or Continental system has a size interval of 2/3 cm with no half sizes intervening .The sizes are continuously marked without any break.

To Convert English size to Paris point :

(The English size in inches X 2.54) 3/2.

To Convert Paris point to English size :

(Paris point converted to centimeters) / 2.54.
This is converted into corresponding English size.

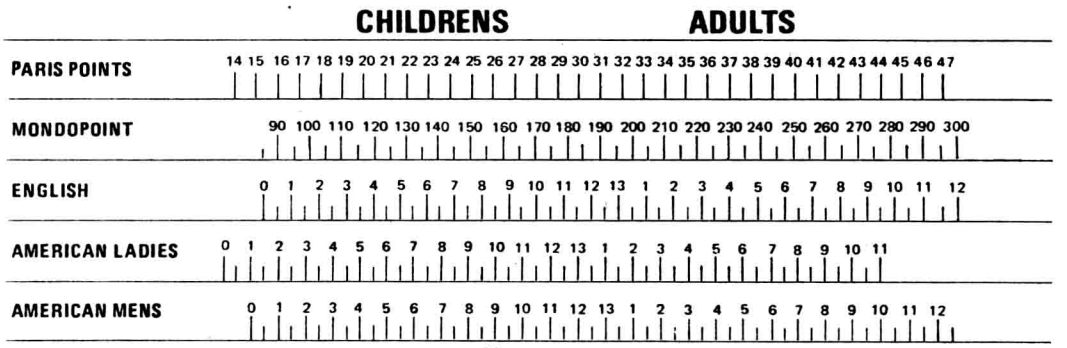
The Present sizing system has been subjected to controversy and criticism and yet it is followed. It is considered by many that a full size increases of

1/3" is too large and a half size increases of 1/6 " are too small, for a full shoe with a good fitting. Tedious calculations are involved in converting one system of shoe sizing and fittings to another, and foot measurements to shoe sizes. Also the fitting intervals vary from one manufacturer to another resulting in the shoes of same size and fitting made by two manufacturers not fitting the same foot. Proper shoes are fitted on the foot only by trial and error. A particular sizing scale adopted by a country may cater to the needs of that particular country but when it is the question of one country depending upon the another for footwear (exports or imports), difficulty may arise resulting in the large surplus stocks with the retailers at the end of the season.

Sizing System by the Foot Length and Foot Width :

Based on the work on the anatomical parameters of the foot viz. the foot length and the foot width, Venkatappaiah and Ramanathan at the Central Leather Research Institute (CLRI) suggested a new shoe sizing system. It was observed that the ratio of foot length to foot width is found to be 2.56 $\pm$ 0.1. Now the ratio of (Length) / (Width) = 2.56. An increase in footwidth by 2mm results in 2.56 x 2 = 5.12mm, or 5mm increase in length. On this scale size to size difference suggested is 5.00mm increase along the length followed by 2.00mm increase across the width. The shoe size marking on the shoe consists of two numbers (1). Foot Length in millimeters and (2). Foot Width in millimeters, fitting the shoe.

Mondopoint : On the mondopoint scale of shoe size marking consists of two numbers. e.g. 240 / 95. The first number is the size; it is an indication of the length of the foot fitted by the shoe measured in weight on position and the second number is the foot width an indication of the joint width of the foot. These measurements are in millimeters.



Comparative Sizes

International Shoe Sizing System : Mondopoint is the International Shoe sizing system, adopted by the International Standards Organization (ISO). On the mondopoint scale size to size interval is suggested at 5mm or 7.5mm.

The Shoe sizing system followed in the countries Russia, Germany, Spain, Brazil and Portugal is Paris point. In Spain and Brazil the size markings are greater by one Paris point and two Paris points respectively. Australia and Canada predominantly use both British and American sizing systems. Mondopoint is tried in South Africa, Eastern European countries and in Japan (Similar to Mondopoint).

Girth Measurements :Shoe lasts are made with different girth measurements for same length and also different girth measurements for different lengths, to enable a greater number of feet to be efficiently fitted. These are called Fittings. Difference between the fittings is not fixed but the most widely used measurement is 1/4", usually distributed with 1/12" across the tread and 1/6 on top.

Fittings -- Identification:	**Letters**	**Digits**
Extra narrow	A	1
Narrow	B	2
Very slender	C	3
Slender	D	4
Very small	E	5
Small	F	6
Medium	G	7
Large	H	8
Extra Large	XH	9

For example : Consider two sizes 6 and 7, size to size increase in length is 1/3". But for the same size 6 the increase in girth for fitting C is 8 1/2" and fitting D 8 3/4" and E 9". Similarly for size 7 at the girth measures for C, D and E, fittings respectively are 8 3/4", 9" and 9 1/4". i.e., the increase in girth measurements from size to size being 1/4".

The American sizes are marked 1 1/2 times more than the corresponding English size, and with two fittings less than the English size. Thus an English shoe 7D would become 8 1/2B on the American scale.

Multifittings : With a view to fit more number of feet, to impart foot comfort; from one fitting to another the increase suggested is 3/16 of an inch. The fitting scales on American system uses multiple lettering AAAA very narrow to EEEE very wide for the same size.

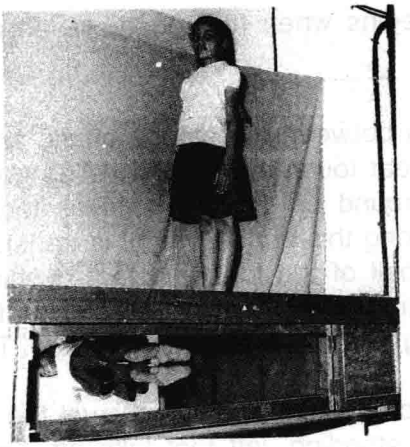
(c) BIOMECHANICS OF THE HUMAN FOOT

Biomechanics of the human foot is the study of the mechanics of leg and foot during standing, walking, running, jumping and so on. This study consists of the determination of the body weight distribution on the sole of the feet, the measurement of the angles at the joints, times of different phases of walking, ground reactions, and Kinematic parameters. This study helps in designing proper foot wear of comfort for the normal, disabled and sportsman's foot.

Distribution of Body Weight on the Feet : Distribution of body weight over the various points on the soles of the feet is an important factor in determining foot health. For instance the development of ulcers on the soles of feet, suffering from leprosy and diabetes may be attributed to the excessive concentration of weight in some localized areas on the feet. To determine the body weight distribution on the sole of the feet, ELFTMAN, used a corrugated rubber mat on an inked fabric, and a white paper under it. The person stands on the rubber mat. The relative impressions on the paper gives the intensity of pressure at the points of the foot in contact with the mat surface. Morton and Fuller using an instrument Staticometer established roughly that, when a person stands on both the feet, body weight is equally distributed between them and the distribution for each of the foot is in the ratio of 1:2:3, between the ball of the big toe, ball of the little toe and the heel. Venkatappaiah and Ramanathan at CLRI using a Barograph and Microdensitometer developed a new technique for the determination of body weight across the phalanges, metatarsals, metatarso phalangeal joints, midfoot and the heel. The weight distribution was 5% over the phalanges, 41% over the metatarsals, 5% over the midfoot and 49% on the heel. The Barograph consists of a thick glass plate and a plane mirror kept at an angle of 45°, in a wooden box. A person stands or walks on the illuminated glass plate. The illuminated foot impressions are seen on the mirror and photographed. There is a variation of intensity of illumination at various points on the feet. The intensity of illumination is more at pressure points. The photographic negative is scanned over a double beam Microdensitometer. The curves are analyzed for weight distribution on the sole of the feet.

Characteristics of Walking : The Walking cycle consists of phases of period of, support / stance phase, swing phase and the period of double support. The phase of support begins when the heel touches the ground and ends with the foot take off i.e., toe off. The swinging phase begins when the leg leaves the ground to swing forward and ends when the heel touches the ground. At the period of double support both the feet touch the ground with the other foot -- foot flat.

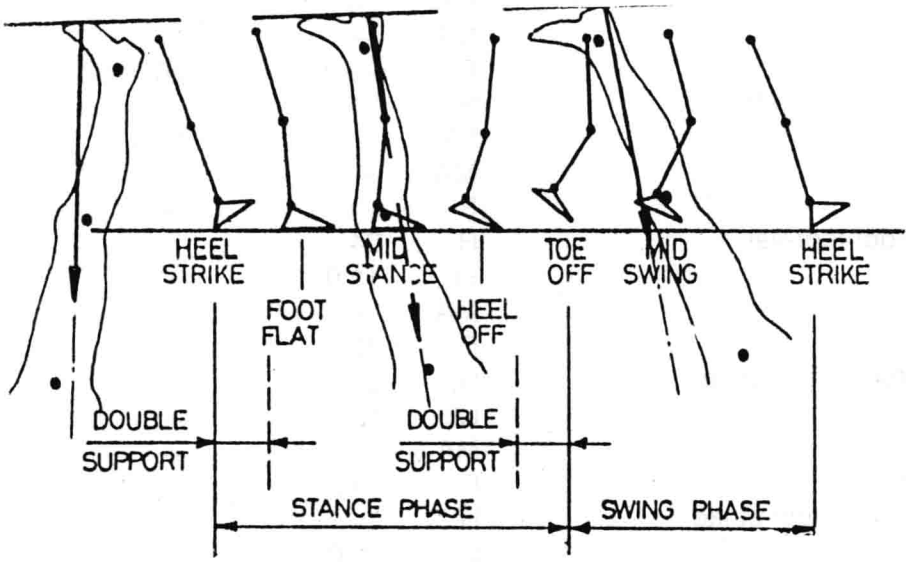
Stance Phase : The phase of support begins when the heel touches the ground and ends with the foot take off, i.e., toe off. The weight is supported by the one foot as the other foot is lifted, the leg is bent at the knee, swings forward and extended.



Barograph-foot impressions

Foot impressions during walking as obtained on barograph

Leg positions in level walking with resultant ground reaction.



Phases of the gait cycle