Design and manufacture of shoe lasts

X. MA and A. LUXIMON, The Hong Kong Polytechnic University, P. R. China

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Abstract: Shoe last design is a very important aspect in footwear design. This chapter aims to give a complete introduction to a shoe last. It starts from basic knowledge of a shoe last, including the classification, the structure and the terminologies. The relationships between different parts of the foot and the shoe last are then explained. Finally, the chapter introduces the design methods of a shoe last, followed by the manufacturing methods.

Key words: shoe last, design, manufacture, bottom pattern.

9.1 Introduction

A shoe last is an aid model used in shoe making. Shoe technology in the modern footwear industry consists of three stages:

(i) design and manufacture of the shoe last
(ii) design and manufacture of the upper pattern
(iii) design and manufacture of the sole and other accessories

The design and manufacture of the last is at the core of shoe technology. The design of the last determines the styles of the upper and other accessories. For example, the shape of an outsole is determined by the shoe last bottom pattern; the pitch of a heel must match a shank curve of the last; and the design of the toe shape of a last will influence the design of the upper. The shoe last is the mould as well as the support for joining the upper, sole and other accessories in the manufacturing process. It therefore influences not only style and aesthetics, but also the fit and comfort of shoes.

This chapter introduces the principles and processes of shoe-last design and manufacture. Section 9.2 deals with the classification and terminology. And the dimensions and related terminologies of the shoe last are introduced in Section 9.3. The next section then describes the relationship between the foot and the shoe last. Section 9.5 explains the process of designing a last bottom and profile. The chapter concludes by describing manufacturing methods.
9.2 Classification of shoe lasts

Shoe lasts can be classified into categories according to material, heel height, toe style, etc.

9.2.2 Classification by material

Shoe lasts are made from a variety of materials; typically wood, metal or plastic. Before the era of mass production, hardwood was whittled or chiselled into a wooden last (Fig. 9.1). This is an inexpensive method and the last may be easily modified. However, changes in temperature may cause expansion or contraction, thus limiting its useful life. Wooden lasts have now been replaced by plastic lasts, though there are still high-class wooden lasts designed and made by eminent craftsmen for the purposes of customisation or art.

Aluminium is the most commonly used metal for making shoe lasts, though iron is also used. Aluminium lasts are widely used in mass mechanised production, as they are stable, firm and recyclable. However, when compared with wood, aluminium is heavier and its contraction percentage may cause differences between the right and the left lasts during manufacturing.

Plastic lasts (Fig. 9.2) are the current choice of most last manufacturers. Their advantages are as follows:

- Stable and firm in various environments

![Wooden shoe lasts](image-url)
9.2 Plastic shoe last.

- High precision
- Stapled or implanted easily
- Short production cycle and long useful life
- Can be recycled and remoulded

A plastic last is manufactured by cutting a rough material mould, usually made from high-density or low-density polyethylene (HDPE or LDPE). Although this is heavier than wood and more expensive than other materials, it has become popular with the proliferation of the modern Computer Numerical Control (CNC) machine.

9.2.2 Classification by heel height

Heel height, or heel elevation, is the vertical distance between the sole salient point and the geometric centre of the heel. Shoe lasts may be categorised as flat, low, mid and high heels. A low heel is usually considered to be less than 1 inch (about 25mm), heels between 1 and 2 inches (about 50mm) are considered to be mid heels, and heights above 2 inches are classed as high heels.

The rear part of the foot is the main shock absorber in walking or running; therefore the heel of a shoe is designed as a buffer to protect the foot and ankle. Generally, flat heels are practical and comfortable, and distribute bodyweight and pressure over the whole area of the foot. They are therefore used in athletic shoes, hiking shoes, sport shoes and children’s
shoes. Although, high-heeled shoes are able to modify the kinematics and kinetics of the gait, they may also cause pain and disorders of the feet and other parts of the body. High heels shift the peak pressure from the rear of the foot when the heel height is increased. This can be transmitted up the skeleton as a ‘shock wave’ which may result in leg pain, back complaints and eventually, to degenerative joint disorders.

9.2.3 Other classifications

Toes shapes: shoe lasts may have round, pointed or square toes.
Materials: lasts may be designed for shoes made from leather, fabric, rubber, plastic, or other material.
Styles and function: there are lasts for sports shoes, hiking shoes, casual shoes, slippers, sandals, boots, etc.
Method of manufacture: lasts may be made manually or mechanically.

9.3 Shoe last dimensions and terminology

A shoe last can be divided into areas such as toe, fore part, waist and heel area, and upper part, in accordance with the corresponding parts of the foot. A last may be seen as consisting of several surfaces and curves, which include the last bottom, the inside curved surface, the outside curved surface and the top line.

Some points and lines, referred to as feature points or feature lines, are used to define the dimensions of the last. Some of these correspond to the positions on the foot, such as the feature points and widths of the last bottom. Others are designed specifically for the last, such as the heel elevation and toe allowance.

This section introduces the terminology of shoe lasts and includes the names and definitions of these feature points and lines (Fig. 9.3):

1. **Front point of the last bottom.** The centre point of the intersection line of the upper and bottom around the toe.
2. **Bottom support surface (tread point).** The point in the toe base that touches the ground plane first. It is the intersection of the longitudinal axis of last bottom (20) and the line between the points of the first and fifth metatarsal-phalange joints (25 and 26).
3. **Back point of the last bottom.** This is the centre point of the intersection line of the front upper and bottom around the heel.
4. **Maximum point of heel curve.**
5. **Back point of top line.**
6. **Front point of top line.**
7. **Toe depth.** The height of the big toe tip point.
9.3 Components and features of a shoe last.

(8) **Ball girth.** The girth of the contour though the points of the first and fifth metatarsal-phalange joints (25 and 26).

(9) **Instep girth.** The girth of the contour though the waist point (27).

(10) **Heel girth.** The girth of the contour though the front point of the top line (6) and the back point of the shoe last bottom (3).

(11) **Width of top line.**

(12) **Length of top line.**

(13) **Distance from the toe-end point to back point of the top line.**

(14) **Last toe allowance.** The distance from big toe tip point to the front point of the shoe last bottom (1)

(15) **Toe spring.** The vertical height between the front point of the shoe last bottom (1) and the ground plane.

(16) **Room around heel.** The projected distance between the back point of shoe last bottom (3) and the maximum point of the heel curve (4).

(17) **Heel elevation (heel height).** The vertical distance between the back point of the shoe last bottom (3) and the ground plane.
9.4 The relationship between the foot and the shoe last

The dimensions of a shoe last are not exactly equivalent to the homologous dimensions of the foot, though the foot is the model for it. Footwear is designed and made as a fit and a protective container for walking and other foot motions, and must accommodate both the static and dynamic states. The dimensions of a foot will differ slightly between the static state and dynamic
states, and the difference must be considered when designing a shoe last. This section is concerned with the relationship between the dimensions of the foot and the last.

9.4.1 Last length and foot length

There are three primary lengths in a shoe last: last length $l_l$, last bottom centreline length $l_c$ and last bottom length. The last designer should understand the differences between these lengths and their relationship with the foot length. The last length is the distance in a straight line between the front point and the maximum point of the heel curve (last ptternion). The last centreline length consists of a straight-line measurement of the bottom centreline, and the last bottom length is its curved length and is equal to the bottom pattern length ($l_p$).

The first step in making a shoe last is the design of the bottom pattern, which should be based on the foot length. The relationship between the foot length ($L$) and the bottom pattern length ($l_p$) is shown as follows:

$$l_p = L - r_h + r_a$$  \[9.1\]

where $r_h (OB)$ is the room around heel; and $r_a (O'A)$ is the toe allowance (Fig. 9.4).

Thus, the bottom pattern length is not equal to $AB + r_a$, but $OA + r_a$ (Fig. 9.4).

Table 9.1 lists the relationships between the other longitudinal dimensions and foot length, according to statistics derived from the dimensions of Chinese feet. The relationships between the longitudinal dimensions of the bottom pattern and the bottom pattern length can be obtained through Equation 9.1.

9.4.2 Last width and foot width

The last width is closely related to the foot print and girth, which may influence the design of the last, the fit and the aesthetics of the footwear, and also the economic use of the raw materials. However, the width of the last is not equal to the footprint width, as this must be determined by consideration of the foot shape and motion, the heel height, the type and style of shoe last and technicalities of manufacturing.

There are several definitions of foot width ($W_f$) based on the longitudinal axis of last bottom ($O'B$), the 1st and 5th MPJ ($M_1$ and $P_1$) (Fig. 9.5). The one most widely adopted is the distance between the 1st and 5th MPJ on the direction perpendicular to the longitudinal axis ($W_f = MM_1 + PP_1$). The last width ($W_l$), as previously illustrated, should be neither greater than the foot width, nor smaller than the footprint width, or the shoe will be too flat or too narrow in the MPJ area. Therefore, the last width should be an intermediate
9.4 Dimensional relationship between a foot and its shoe last.

**Table 9.1 Relationship between foot lengths**

<table>
<thead>
<tr>
<th>Length from back point of bottom to</th>
<th>Percentage of foot length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big toe tip point</td>
<td>100.0%</td>
</tr>
<tr>
<td>Big toe contact point</td>
<td>90.0%</td>
</tr>
<tr>
<td>Little toe contact point</td>
<td>78.0%</td>
</tr>
<tr>
<td>The 1st metatarsophalangeal joint</td>
<td>72.5%</td>
</tr>
<tr>
<td>The 5th metatarsophalangeal joint</td>
<td>63.5%</td>
</tr>
</tbody>
</table>

value between the two widths, according to different situations. For example, the last width for a leather shoe may be slightly narrower than the footprint width because leather is flexible, resilient and resistant to abrasion. The foot will also become wider due to the pressure created when the heel is elevated, thus a last for high heels should be designed to be wider than one for flat and middle heels.
9.4.3 Last girth and foot girth

Several foot girths may be utilised in shoe last design, such as ball girth, waist girth, instep girth, heel girth and ankle girth. The ball, waist and instep girths are fundamental for low-cut shoes, the heel girth being added in high-cut shoes.

The ball girth, which is the circumference length of the MPJ, is one of the most important dimensions in shoe last design. This joint bends and bears the bodyweight, and pressure in walking and running. The ball girth of a last is also slightly longer or shorter than the ball girth of the foot as the foot dimensions may be deformed by factors such as the environment inside the shoe and the motion of the foot. For instance, there is a variation in the ball girth during different seasons and even between day and night. The thickness of socks must be taken into account, especially when considering shoes worn in winter. The heel is elevated during sporting activity and when high heels are worn, so causing the MPJ to bear greater bodyweight. The ball girth of lasts for high heels and sports shoes should therefore be larger.

The waist girth also changes according to different situations and is smaller in lasts for high-heeled shoes.

To ensure comfortable wear, the instep girth of most lasts should be greater than that of the foot, especially for laced shoes and boots. As leather extends while on the last, and contracts when removed, the instep girth of a
last, should be greater that of the foot. The instep girth of high heels is also smaller to prevent the foot from slipping forward during walking.

9.4.4 Toe spring and heel elevation

**Toe spring**

Statistics show that there is an angle of about 15 degrees between the toes and the bottom of the foot, when the foot hangs naturally. This is called the toe spring. Shoes with appropriate toe spring are able to support the toes and reduce the bending of the MPJ during walking or running. They will also deter excessive wrinkling of the upper, and wear and tear on the outsole, so extending serviceable life. However, if the toe spring is too high, it may result in a collapse of the transverse arch, which is a cause of flat feet.

All these factors should be considered in designing shoe lasts. The toe spring of the last is usually higher than that of the shoes, because the toe spring of shoes will become lower when they are removed from the last, according to the flexibility and rigidity of the outsole. The toe spring is also reduced with an increase in heel height.

**Heel elevation**

When a forward step is taken, the heel of the foot rises about 50mm. Comfort in walking therefore requires an appropriate shoe heel to save the energy used in elevating the heel of the foot. Research shows the optimum height in most cases to be 25–45mm. However, high heels are designed mainly for fashion and aesthetics, and may be from 50mm to 80mm, and in extreme cases, over 100mm.

Heel elevation also affects the design of shoe lasts, as the room around the heel ($r_h$) of the foot will become smaller, thus altering the length of the last in accordance with Equation 9.1.

9.5 Shoe last design

As it consists of bones, muscles and tissue, the foot is flexible and asymmetrical. The shoe last should both represent the dimensions of the foot, as an intermediate modality for footwear manufacture, and take account of design factors with regard to aesthetics and fashion. The dimensions of a last will affect the fit and comfort of footwear, whereas the design of style and function must meet the demands of market trends.

Most shoes are designed for routine wear, with the exception of some art works created for fashion shows. It is therefore fundamental that lasts be designed in accordance with the anatomy and structure of the foot. Relevant
factors, such as dimensions for good fitting, the dynamics of motion and the protection of health, must be considered.

Designers of lasts must be both technically and artistically competent if footwear products are to meet customer demand. Knowledge of craft work and materials is also necessary as Computer Aided Design (CAD) is now in widespread use.

It is the last maker rather than the designer who will need to consider manufacturing technology when designing a regular last for mass production. However, to design a distinctive last, the designer must have sufficient knowledge of the manufacturing process to ensure the practicality of the design. As previously described, lasts made from different raw materials have different strengths and weaknesses that must be considered by designers if production failures are to be avoided.

9.5.1 Bottom pattern design

Each country has its own guidelines and standards for shoe-last sizing and grading. However, all shoe-last design starts from the design of the bottom pattern. Two main shoe-last design guidelines publicly available are the AKA64-WMS system and the Chinese system. The methods for bottom pattern design in these two systems are largely similar, though there is a slight discrepancy in parameters.

The template for a master shoe last is determined by a series of angles and distances. In the AKA64-WMS system, the size of the last for women is 6, and 9 for men. The flow chart of the design begins with the longitudinal axis (Fig. 9.5). Some feature points are later determined by standard angles and distances (Table 9.2). Finally, the bottom outline based on these points is drawn (Fig. 9.5).

The Chinese system provides many more detailed tables for foot and shoe-last data and the relationships between them. The bottom design involves more lengths and widths, though the drawing steps are almost the same as in the AKA64-WMS system (Table 9.2). Taking as an example size 235, which is the Chinese standard size, the design procedures are illustrated as follows (Fig. 9.6); and its values are listed in Table 9.2.

(i) Draw a straight line as the longitudinal axis, and point O is the back point of last bottom;
(ii) Locate the feature points H, W, N, M, Q, P, and A on the longitudinal axis;
(iii) Locate the horizontal feature points $H_1, H_2, W_1, N_1, M_1, Q_1, P_1, O_1$ and $O_2$;
(iv) Locate point $G(GN_1 = MM_1)$ to obtain the heel centreline $OG$;
(v) Locate points $H_1$ and $H_2$ on the line through point H, making $H_1H_2$...
Table 9.2 Bottom pattern design parameters for AKA64-WMS and Chinese system

<table>
<thead>
<tr>
<th>Parameters</th>
<th>AKA64-WMS system (size 6B)</th>
<th>Chinese system (size 235, width 1.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>231mm</td>
<td>AO</td>
</tr>
<tr>
<td>Room around heel</td>
<td>5mm</td>
<td>Room around heel</td>
</tr>
<tr>
<td>Ball girth (BG)</td>
<td>204.8mm</td>
<td>Ball girth (BG)</td>
</tr>
<tr>
<td>TA₁</td>
<td>15mm</td>
<td>AO₂</td>
</tr>
<tr>
<td>AH</td>
<td>38.5mm</td>
<td>O₁H</td>
</tr>
<tr>
<td>H₁H₂=HH₂</td>
<td>27mm</td>
<td>O₁W</td>
</tr>
<tr>
<td>T₂E</td>
<td>46mm</td>
<td>O₁N</td>
</tr>
<tr>
<td>M₁M</td>
<td>30.7mm</td>
<td>O₁M</td>
</tr>
<tr>
<td>MM₂</td>
<td>47mm</td>
<td>O₁Q</td>
</tr>
<tr>
<td>OM</td>
<td>155mm</td>
<td>O₁P</td>
</tr>
<tr>
<td>&lt;MHG₁</td>
<td>6°</td>
<td>H₁H₀=H₀H₂</td>
</tr>
<tr>
<td>&lt;T₁M₁M</td>
<td>74°</td>
<td>WW₁</td>
</tr>
<tr>
<td>&lt;T₂M₂M</td>
<td>96°</td>
<td>N₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MM₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>QQ₁</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PP₁</td>
</tr>
</tbody>
</table>

9.6 Shoe last bottom pattern design in Chinese system.
perpendicular to OG and $H_1H_0 = H_0H_2$, where $H_0$ is the foot of perpendicular.

(vi) Connect these points by smooth curves.

The shape of the curves is determined by considering aspects such as the design of the toe shape, the requirements of fitting, the comfort and the economic use of materials. Experience and practise is needed to achieve an effective bottom pattern.

The standard values of these features are not fixed. They are set principally for mass production but must also meet the needs of different groups, thus slight modifications are acceptable. According to the physiological characteristics of the foot, the value may be decreased in the muscular region and increased in the bony area. When considering the fashion element, especially that of the toe design, the corresponding dimensions may be suitably modified. The designer should also take note of the influence of foot motion, material and manufacturing technique on these dimensions.

### 9.5.2 Parameters of the shoe last body

Before drawing the last profile, several parameters should be determined. The toe spring and heel height should be decided as these are the factors influencing the shapes of the profile curves. As described in Section 9.4.4, the angle of the toe spring is less than 15 degrees and is usually determined by the style and function of the shoe and the performance of the outsole. The height of the toe spring of adult flat shoes is usually about 15mm, although the toe spring of a last for women’s shoes is smaller than that for men. The toe spring for children’s shoes is near zero. The height of the toe spring decreases with an increase of the heel height, to a difference of about 1mm. The heel height is about 5mm for men and 10mm for women. According to research on the pressure on the sole of the foot in shoes with different heel heights, the optimum heel height for women in terms of health and fashion is 20–40mm, as the pressure is then distributed evenly on the forefoot and heel. The wearing of shoes with heels over 60mm in height, particularly by young people, may deform the feet and have a serious impact upon their growth.

Other parameters of the heel region should be considered at the same time. One is the back height, which determines the height of the last top. The values are from 28% to 40% of the foot length. The former is the value for a low-cut shoe last while the latter is for a high-cut shoe last. Another important parameter is the back curve, which is decided by the room around the heel.

The toe depth is determined by the height of the big toe and is usually greater than the height of the toe to allow for movement. The width and length of the last top and other parameters should be considered carefully.
9.5.3 Shoe last profile design

The profile of a shoe last consists of the side silhouette of the last body, which is made up of several curves, including the back, instep, top line and shank curves. It refers to dimensions such as toe spring, heel height and girths, as well as to styles and designs in the toe and top regions. Once the related parameters have been determined, the drawing of the shoe-last profile is based on the bottom pattern. The specific steps are as follows (Fig. 9.7):

(i) Draw a straight line \(l\) parallel to \(O_1O_2\) as the horizontal of the profile;

(ii) Find the tread point \(T\) by connecting point \(M_1\) and \(N_1\), then find the corresponding point \(T_1\) on \(l\);

(iii) Find point \(O_4\), where the height between it and \(l\) is equal to the toe spring \(h_1\);

(iv) Find point \(O_5\), where the height between it and \(l\) is equal to the heel elevation \(h_2\); then find \(O_3\) that makes distance \(O_3O_5\) = room around heel;

(v) Find point \(A_1\) on line \(T_1O_4\) that makes \(AA_1\) is perpendicular to \(l\); then draw a perpendicular line \(A_2A_3\) of \(T_1O_4\) through point \(A_1\), where \(A_1A_3 = 2\text{mm}\), and \(A_2A_3 = h_3\) (\(h_3\) is the toe depth);

![Shoe last profile design](image-url)
(vi) Find point $O_6$ that makes the angle between line $O_5O_6$ and line $T_1O_5$ is $\theta_1$ and line $O_5O_6 = l_1$;
(vii) Find point $O_7$ by defining $O_5O_7 = l_2$ and angle $O_7O_5T_1 = \theta_2$;
(viii) Find point $T_2$ by defining $T_1T_2 = l_3$ and angle $T_2T_1O_5 = \theta_3$;
(ix) Find point $W_2$ that makes $T_1W_2 = l_4$; Draw line $W_2W_3 = h_4$ that is perpendicular to line $T_1O_5$; then, point $W_3$ is the highest point in the waist region;
(x) Find point $R$ by defining $RO_3 = h_5$, which is the maximum point of the back curve;
(xi) Lastly, connect all the boundary points by smooth curves.

The lines of these curves are largely determined by the design and details of the foot shape. Knowledge and experience of foot shape as well as repeated trials are required in making the drawings. The values of most angles and distances are derived from the bottom pattern, though some will depend on the design, such as the length and depth of the top.

### 9.6 Manufacture of shoe lasts

#### 9.6.1 Handmade shoe lasts

Traditional handmade shoe lasts were made of wood, which was once the most economical and effective material. Today, wooden lasts are still used by some manufacturers for high-class customisation and works of art. The LDPE/HDPE shoe last is widely used along with the computer numerically controlled (CNC) last lathe for mass production. However, master shoe lasts are still made by hand.

A variety of tools and working processes are used in the manual creation of shoe lasts. In the case of wooden lasts, these include woodworking tools such as axes, planes, files, sandpaper and tape, as well as templates specific to shoe-last design, such as bottom pattern, snap-gauge of shank or back curve templates. The tools for making plastic shoe lasts are principally the sand mill and sand paper, together with the necessary design tools.

The manufacturing process begins with rough grinding (Fig. 9.8). The raw plastic moulding (Fig. 9.9) is initially cut to the approximate shape of the designed last. The last bottom should be ground to match the shank curve. After the bottom pattern outline has been drawn, the lateral and medial sides are roughly ground. Margins should be left after rough grinding so that any error can be amended by consequent fine grinding as needed. The measurements should be checked frequently during grinding to ensure that the raw mould can be adjusted immediately if necessary. Figure 9.10 shows the modification of a plastic last by using molten material. When the last is almost completed, it should be modified and polished with sandpaper. A wooden last should be varnished for aesthetic and protective reasons.
Making a shoe last by hand is a complex and difficult technique and much practice and experience is required to master the skills of grinding. It is also necessary for the maker to have a thorough knowledge of the details of the last.
9.6.2 Computer aided design and computer numerically controlled machining

Handmade shoe lasts will inevitably differ slightly between different makers, which may lead to some degree of mismatch between the design and the footwear finally produced. The method is also time-consuming and costly.

Figure 9.11 illustrates the flow of modern shoe last design and manufacture. The master last is scanned by a last scanner or digitizer (Fig. 9.12) and the last data is stored in a database. It can then be used repeatedly. The last data is modified by CAD software if necessary. After machining by the CNC lathe (Fig. 9.13), the last is measured and its dimensions checked for accuracy. If necessary, it will be modified again using computer software.

Design software, such as LastElf, ShoeMaster and EasyLast, and CNC for last lathes are currently in widespread use for the mass production of lasts. The machining time is approximately five minutes, which is far shorter than the time required for manual production. Digitisation and computerisation has greatly simplified the design and modification of shoe lasts and results in a more accurate fit in the final product.

9.7 Sources of further information and advice

9.11 Procedure of modern shoe last manufacture.

9.12 Digitizer.

Standards. Shoe Trades Publishing Co. Arlington, MA. This booklet introduces the rudiments of making a last based on the AKA64 system. It provides details of last and pattern making, including standard measurement schedules, size, grades, etc., with additional information on heel layouts, heel tread, shanks and shank fit.
9.13 Shoe last CNC machine.

relationship with the foot. It introduces details of the Chinese sizing and grading system.

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9.9 Bibliography


