3-D Design Tools from the SizeChina Project

BY ROGER BALL

Design tools developed from the award-winning SizeChina anthropometry project aim to improve the fit, comfort, and safety of head gear for Chinese users.

Traditional anthropometric studies document substantial differences between Asian and Western head shapes (Annis, 1978). Even though some traditional anthropometric studies have been conducted in large populations and successfully used to design many products, including uniforms and equipment for the U.S. Army (Gordon et al., 1989) and NASA (Rajulu & Klute, 1993), traditional anthropometric head data have suffered from two limitations. First, the complex geometry of the head and face is not well described by traditional univariate measurements, which capture head length, width, and circumference only as numerical values. High-resolution 3-D data are crucial for the design of products such as helmets, which require exact body contact fit. Second, univariate anthropometric surveys have traditionally examined only Western populations; few surveys have collected data on Chinese populations.

Using 3-D data from the recent SizeChina (http://www.sizechina.com) anthropometric survey (Figure 1), we created the first 3-D design tools for Chinese fit with applications in the product design, engineering, and fashion industries, described in the following pages.

Limitations of Anthropometric Data

Some anthropometric information is not well suited for use in design. Numerical dimensions, spreadsheets, and unprocessed 3-D scans cannot be immediately integrated into the established methodology of design, which centers on sketching, model-making, rapid prototyping, animation, digitizing, computer-aided design (CAD), tooling, and manufacturing. Designers are often unwilling or unable to spend large amounts of time reviewing specialized anthropometric data to extract from it the specific information relevant to their practice. Furthermore, the aspects of anthropometric information that are critical to designers are often different from those that are important to other users of the same material, such as doctors and biologists.

Professional design consulting firms are under ever-increasing demands to design better and faster. The research phase of a design project examining basic anthropometric data can be as short as a few weeks or even a few days in rush projects. As a result, designers may often create products that do not benefit from anthropometric insight.

Any anthropometric study that aims to make its information available to designers must address the issue of communications and must create anthropometric information tools that suit designers' needs. As a client group, designers are characterized by a bias toward visual styles of thinking rather than verbal or mathematical styles. In addition, as a group, designers are creative; they tend to react to new information in ways that are innovative and unexpected. Information tools intended for use by designers should permit open-ended or intuitive interaction. Finally, data tools for designers must pay close attention to international standards in areas such as helmet safety, so that the design tools match all accepted standards in sizing and safety testing.

3-D Scanning

Anthropometric data standards are undergoing a quiet revolution with the emergence of digital three-dimensional (3-D) scanning as a measurement tool. More accurate and more consistent than measurements done manually, 3-D scanning also captures far more information. For the first time, the full spatial shape of the human body can be recorded.

Three-dimensional data are well adapted to use by designers. Because the information exists as computer data, it can be readily displayed in the form of a pictorial image, so that one can intuitively and easily understand the forms being described. It can also be manipulated within the computer's virtual environment, offering potential compatibility with the 3-D design programs used by designers.

However, there are drawbacks to 3-D scan files. The vast majority of surveys collect full-body scans that aim to define the size and shape of the body overall, for applications in the clothing and intimate apparel industries (Robinette, Daanen,

& Paquet, 1999). As a result, these surveys do not capture at high resolution small and geometrically complex parts of the body, such as feet, hands, heads, and ears. Those body parts are very important to designers of consumer products such as shoes, power tools, eyewear, helmets, and facemasks. Finally, as a new product, these 3-D scan files are not yet fully integrated with design software. The original scan files must be laboriously converted into popular CAD formats in order to fully migrate the data.

Functional Criteria for 3-D Anthropometric Tools for Designers

Product design and engineering today are dominated by the use of sophisticated, highly functional software programs in the general areas of CAD, animation, finite element analysis, and rapid prototyping. Design software is used extensively for visualization and animation, as well as for more mundane tasks, such as engineering specification, mold flow analysis, and material utilization studies. These programs have revolutionized design practice, introducing a level of precision, speed, and control unknown to previous generations of designers, who worked with clay models and manual drafting.

At the same time, the immateriality of the software has severed it from a tactile awareness of the human body. Designers working with physical models can check those models intuitively and work directly on top of them to create castings, prototypes, and design models. Designers working with software packages have no such reference point, because none of these powerful 3-D software packages offers human body templates.

Perhaps because they are so accustomed to the limitations of their current software tools, designers do not seem to question the absence of body templates. A designer creating shoes or sunglasses seems perfectly content to conceptualize the product floating in isolated cyberspace, without reference to the human form. Clearly, much better results could be achieved if the starting point was an accurate 3-D anthropometric model

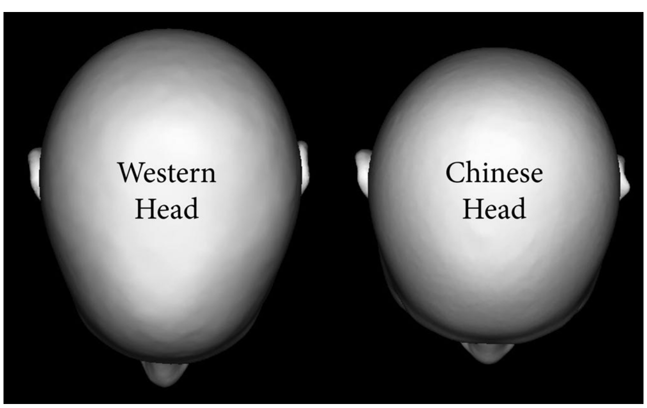

Figure 1. Head shape comparison. Mean head shapes of Chinese and Western subjects as seen from the top. © Xi, Pengcheng. This image was generated as part of a collaborative statistical shape analysis study between the National Research Council of Canada's Digital Human Modeling Lab and SizeChina. Image courtesy NRC.

FEATURE AT A GLANCE: The vast majority of consumer products for the head and face, such as helmets and sunglasses, are designed for Western populations using Western anthropometric data. These products do not fit the shape of the Chinese population well. The SizeChina survey aimed to correct this problem. The survey collected over 1,500 high-resolution 3-D head and face scans from across mainland China and processed the data into the first set of design tools for use by companies wanting to create accurate Asian-fit headgear.

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of the face or feet, allowing exploratory forms for the glasses or shoes to be "sketched" over the critical body shape right from the start.

The creation of physical and virtual body forms – 3-D anthropometric design tools – was the focus of the SizeChina project (described in more detail later).

Creating Chinese Head Forms

The first design tools created by SizeChina were a range of physical headforms suitable for use in helmet design. The European EN 960 standard "is the most widely accepted international standard specifying the performance of the headforms used in testing and design" (British Standards Institution, 1995). The EN 960 headform makes use of a total of four reference planes for cranial sizing:

- *Basic plane.* Also known as the *Frankfurt plane*, it runs through roughly the center of the head, as defined by the lower points of the bony orbit of the left eye socket (infraorbital) and the upper margin of the auditory meatus or ear canal (tragion).

- *Longitudinal plane*. Also known as the *midsagittal plane*, it runs perpendicular to the basic plane, through the midpoints of the lines connecting the right and left infraorbitals and tragions.

- *Transverse plane*. Also known as the *coronal plane*, it runs perpendicular to both the basic and the longitudinal plane while passing through the center of the ear hole immediately behind the tragions.

- *Reference plane.* Unlike the other three planes, which define anatomical landmarks, the reference plane was created purely for testing purposes. It runs parallel to the basic plane, about 24 to 30 mm above it. It defines the lowest point at which any helmet can be impact tested. Impacts made below the reference plane will not be counted in test results. The reference plane also defines minimum coverage for a helmet, as it must be entirely covered by any helmet placed on a reference headform.

The headform size is determined by the nominal inside circumference of a helmet. The measurements for headform size are from 500 to 640 mm, coded by letter (A through Q) in 10-mm increments (A = 500 mm, B = 510 mm, etc.). The headform size and the four planes must be marked on every standard test and reference headform used in International Organization for Standardization (ISO) standards-based testing. The standard gives the data of 260 points on the headform for each size, based on the European population. It has been applied widely in the Western world. It was important that the SizeChina headforms comply with that same standard as far as possible. The important aspects of this standard specify that reference headforms (a) should have a new size every 10 mm in diameter and (b) contain all reference planes.

Without anthropometric data, it has not been possible to design helmets that fit Asian users properly from the point of view of either comfort or performance. If an Asian fit helmet is to be properly designed, an Asian headform is needed. A Western headform used to create an Asian helmet does not provide accurate fit or safety.

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The second set of design tools is a 3-D digital database of Chinese head and face shapes. This database will be used for animation and game character development, facial recognition technology research, and the design and development of optical and facemask products.

SizeChina Database

SizeChina (2006) was the first 3-D digital anthropometric survey to capture the 3-D digital shape of the Chinese head. The SizeChina survey scanned only the head and neck area to obtain the highest possible level of detail in its results (Figure 2). A Cyberware 3030 Head & Face color 3-D scanner was used to collect all 3-D data. SizeChina surveyed male and female adult civilian subjects between the ages of 18 and over 70. Scanning was conducted at six sites in mainland China, chosen to represent the country's broad geographical range, recording a total of 1,620 people. Participants were selected to cover a representative range in terms of weight, ethnic origin, and socioeconomic status.

A short video introduction was presented to each person to explain the project. Participants then completed a questionnaire recording basic information such as age and birth location. Traditional anthropometric measurements were conducted next. Following the palpation of their facial landmarks and the fitting of a wig cap to reduce the effects of their hair, participants were scanned and the data were recorded by the scanner software. All participants received a gratuity and a souvenir scan print.

Data collected from each person included standard univariate measurements of weight, height, and key head dimensions; high-resolution digital photographs of front and side profiles; demographic data; and the 3-D digital scans.

The more than 2,000 raw scans collected during the SizeChina field scanning required extensive postscanning processing before they were suitable for use in the development of design tools. The scan data files were sorted into size categories, cleaned for "noise," edited for quality, aligned, averaged, and converted into CAD form. The process took 10 months, during which three programmers and statisticians worked full-time on the project. The SizeChina survey and data processing involved international collaborations with universities, institutes, and companies from China, the Netherlands, the United States, and Canada. These collaborations ensured that the survey results satisfied international standards and could be adopted worldwide.

Size categories. The first step was to sort each individual scan into its appropriate circumference size. EN 960 protocols for test headforms require a new headform for every 10 mm increase in circumference. The raw scan data were sorted according to circumference measurements gathered using the traditional tape measure method. Head circumferences were entered into spreadsheet software and sorted to establish size range distribution within the survey.

The survey of size range determined that a set of 10 headforms were required, starting at the size of 510 mm and continuing every 10 mm to 600 mm.

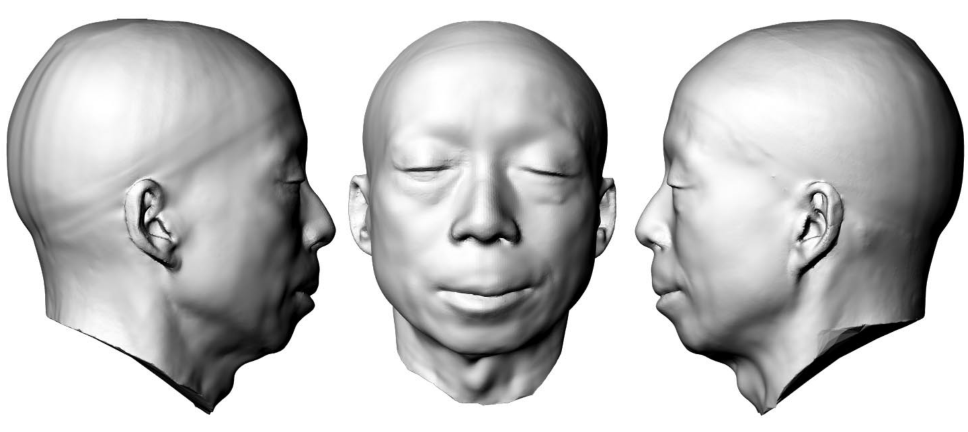

Figure 2. Scan file from the SizeChina database of a male subject in the 30–50-year-old range.

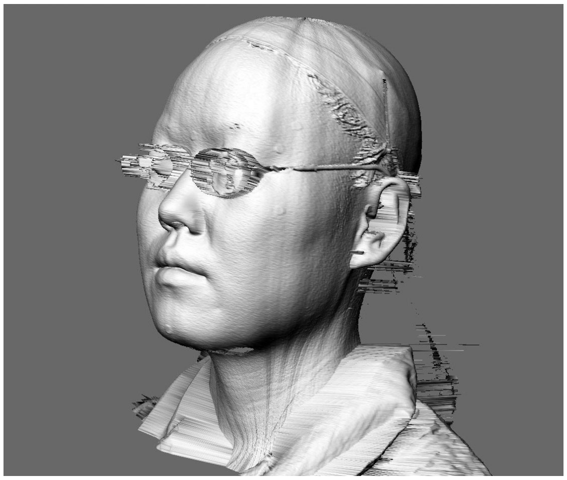

Figure 3. Noise from glasses.

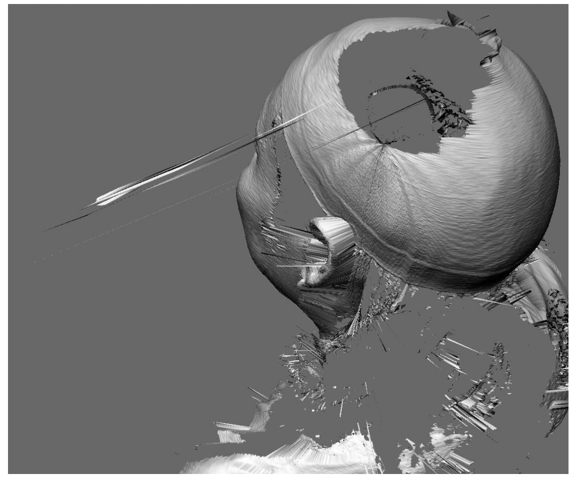

Figure 4. Noise from strong lighting.

Noise elimination. The next stage in scan processing is to clean up any scan noise. Scan noise can take two forms: It can be either "extra" data that were not part of the head or missing data that did not get picked up in the scan, creating "data holes."

Extra data were usually added by clothing or accessories, such as a loose wig cap, a bulky shirt, or eyeglasses (Figure 3) that had been overlooked on site. Extra data were also added by environmental factors. Strong daylight interfered with the reception of the laser signal, as did a camera flash going off during the scan, creating long, thin data spikes (Figure 4).

The creation of data sets for each individual size represents a significant improvement over previous design practice.

Missing data are common in the laser scanning process, which suffers from shadow effects, created when the light of the laser fails to reach into inset nooks and crannies. For example, most scans were missing information around the back of the ear and under the nose. In addition, reflective or shiny surfaces confused the laser. For example, the shiny black surface of uncovered Chinese hair created additional holes in the scan. In every case, the laser failed to completely record the very top surface of the head, where the horizontal beam of the laser was tangential to the surface and could not reflect off it.

Minor noise effects could be manually repaired. The data hole at the top of the head was repaired using a mathematical algorithm to extrapolate a continuation of the known curve of the head to fill in the missing part.

Removal of some scans from the study. Not all the scans could be repaired. Some suffered from severe noise caused by extremely bulky hair, glasses, or sunlight, and others suffered from closure shift created by movement during the scanning process. In the final review, 22% of the scans were removed from the study, reducing the final total used to 1,800 (more than the number required for statistical significance).

Alignment of scan data. During field scanning, every attempt was made to keep participants sitting in roughly similar positions. Each person was asked to stare at a fixed spot marked on a wall. A fair amount of variation in posture remained, however. Before the scans could be accurately compared with one another, it was necessary that they be reoriented to an identical plane.

The automatic software function of Frankfurt horizontal was used to align all the scans into a common *x*, *y*, *z* position. *Frankfurt horizontal* is defined as the standardized Frankfurt plane in anthropometrics. In the DigiSize™ software, as soon as the operator had identified the left and right tragions and left infraorbital sites, the Frankfurt horizontal function adjusted the head to the Frankfurt plane automatically (Figure 5).

Dimension extraction. After all the scans had been sorted by circumference into the 10 headform size categories, low-quality scans removed, data holes filled, and heads aligned, statistical work could proceed. A mesh grid defining 210 data

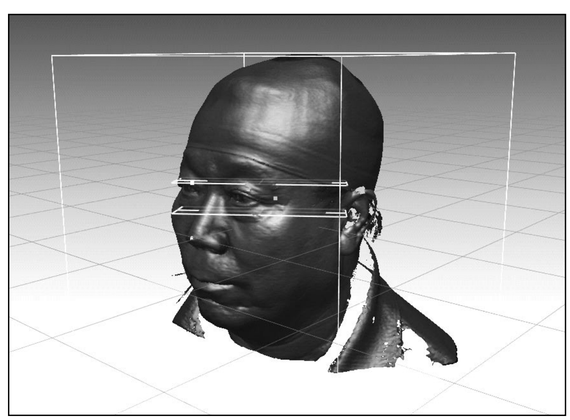

Figure 5. Design planes.

point locations was used to extract numerical values from each individual scan. These values were imported into a spreadsheet for averaging. Using spreadsheet software, the researchers calculated the average value of all 210 data points for each of 10 headform sizes. In most cases, the data points of more than 200 individual scans contributed to the calculation of a single headform size.

The creation of data sets for each individual size represents a significant improvement over previous design practice. It has been common in the past to average all head data into a single average form, which is then mathematically scaled up and down to yield the different sizes of headform. This practice will fail to detect any difference in proportion that might accompany changes in overall head size.

CAD file creation. The average values were imported into Unigraphics CAD software, whereby each was automatically assigned an *x*, *y*, and *z* coordinate. This point cloud of coordinates was then joined point by point using a spline line or curve-matching function to define the head shape geometry (Figure 6). Using this process created the head shape area of the upper part of the head on and above the reference plane.

The area below the reference plane was modeled to resemble the lower portion of a typical EN 960 headform. This standard shape is not an accurate depiction of a human face, as the headform is primarily intended to describe head shape only. The shape, however, does express accurate face dimensions of length, breadth, and chin width.

The two portions of the file were then joined (Figure 7) and given a "skin" or "surface" to complete the description of basic headform shape (Figure 8). The edges of four standard EN 960 reference planes – the basic plane, reference plane, longitudinal plane, and transverse plane – were then recessed into the headform surface as shallow surface grooves. The file was ready for export as an Initial Graphics Exchange Specification (IGES) file for rapid prototyping in stereolithography (SLA) acrylic resin.

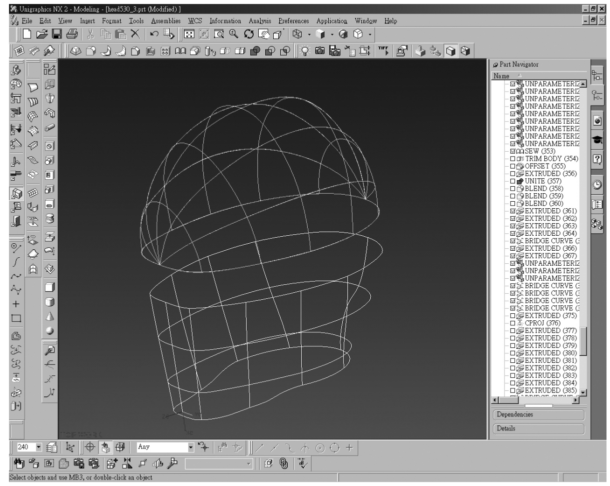

Figure 7. Joining the two halves.

Asian Fit Design Tools

As noted earlier, anthropometric surveys must address the issue of communications and create information tools that suit design needs. The creation of physical headforms and a digital database of head and face shapes was the focus of the second stage of the SizeChina project.

Chinese headforms. Two types of headforms are specified in EN 960. Testing headforms are used in dynamic helmet testing, and reference headforms are used to evaluate helmet coverage. Reference headforms are also suitable for use as a design tool for casting and modeling head shape (Figure 9).

The first 3-D design tool brought into production based on the SizeChina data set is a series of 10 physical reference headforms produced in acrylic resin using stereolithography. The Chinese headforms are painted metallic gold for quick differentiation from the metallic grey used for Western headforms, with information graphics applied to identify the headform's manufacturer, its size category, and the names of

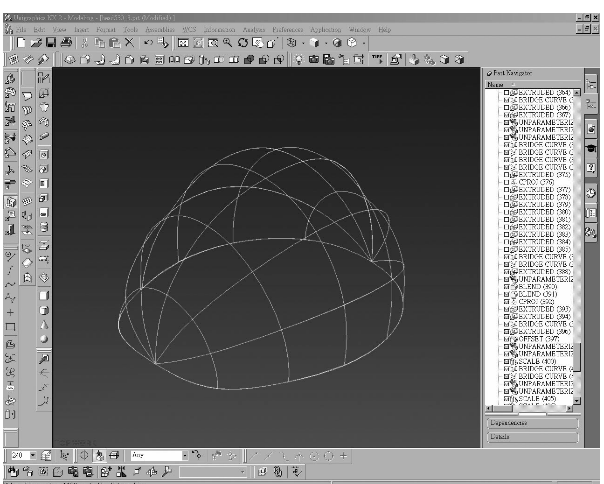

Figure 6. Joining points using spline line function.

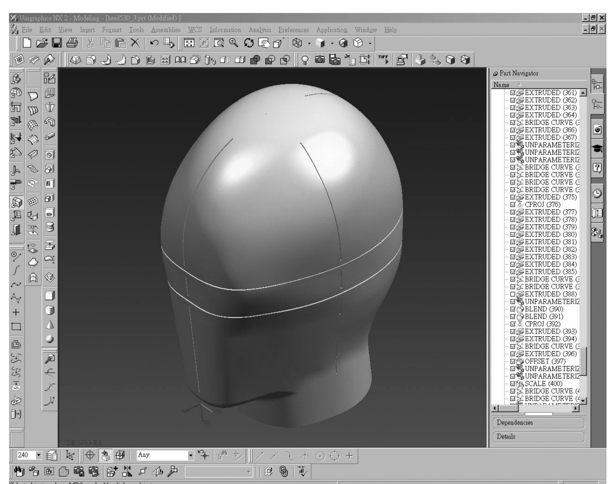

Figure 8. Final CAD headform ready for rapid prototyping.

Figure 9. Chinese Headforms. The first set of 10 headforms for use in designing Asian-fit products.

the four reference planes indicated by grooves. All written information is bilingual (English and simplified Chinese). The entire headform is coated with clear lacquer to protect it from abrasion.

Creating Chinese headforms that comply with existing international standards is intended to allow "plug-and-play" usability in terms of existing helmet-testing standards. The Chinese headform can be directly substituted for the Western headform, with no other change required in terms of testing methods or performance outcomes. When one compares SizeChina headforms and Western standard headforms, the differences are obvious. In general, Chinese headforms are slightly taller in height, rounder in 3-D shape above the reference plane, and flatter at the back of the headform.

The ultimate goal of this product is to have the Chinese headforms accepted and specified in EN 960 as an official product suitable for testing helmets for Chinese heads. Even without such formal acceptance, the headforms already offer immediate pragmatic utility to manufacturers, allowing for the creation of Asian-fit helmets for the first time.

3-D scan database. In addition to physical headforms intended for use as design tools, SizeChina created digital data products aimed at designers. A 3-D database of 1,600 individual head and face scans in a variety of file formats, with univariate landmark dimensions and participant demographics, is provided in spreadsheet format (Certiform, 2009). These products are commercially available from http://www.certiform.org.

Digital tools are intended to make it easy for designers to work with anthropometric data right from the concept stage of a project. Providing individual dimensions and demographic information allows designers to customize the information for specific needs. For example, a designer might wish to focus on the needs of extreme individuals or a particular demographic group.

Global Size and Shape

The SizeChina project has made two significant steps forward in anthropometrics. First, it has made a strong contribution to the field of ethnic anthropometrics. Following the SizeChina breakthrough in the ethical assessment of ethnic anthropometric differences, the path is clear to undertake similar projects on other parts of the Chinese body and on other populations in the rest of the world.

Second, the method by which SizeChina data have been collected and converted into anthropometric tools helps to define new standards for 3-D digital data collection and processing.

Conclusion

In seeking to convert their anthropometric data into data tools suitable for use by designers, SizeChina staff faced the need to create tools that suited designers' needs for visual interfaces, intuitive operation, and integration with existing practice. The data tools also needed to take into consideration international standards. SizeChina has created two sets of products: the first set of physical Chinese headforms, to enable designers to design products that fit the Chinese head; and a database of 3-D scans that will enable designers to work with Chinese head and face shapes within the 3-D virtual reality of design software.

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