

16 – WHEEL BUILDING AND RIM REPLACEMENT

ABOUT THIS CHAPTER

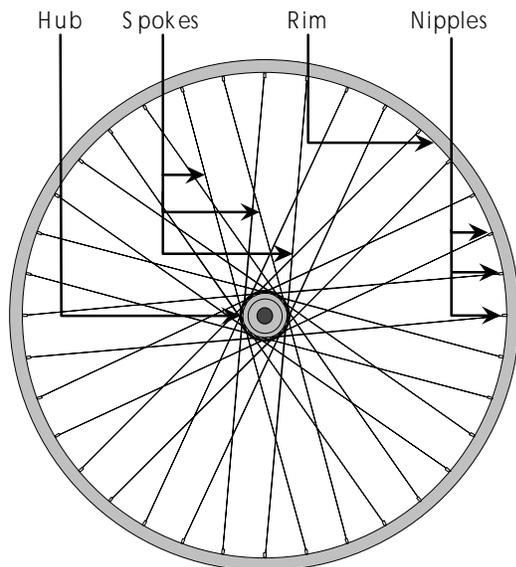
This chapter is about rebuilding wheels. It covers designing the wheel, determining the spoke length, assembling the spokes to the hub and rim (lacing the wheel), and getting the wheel ready for truing. Additional information is included about replacing rims and re-using old spokes. This chapter does not include anything about truing the wheels, but refers to the **WHEEL TRUING AND REPAIR** chapter (page 17-6) for that purpose.

The information in this chapter can be used for rebuilding a damaged wheel (saving the hub and using a new rim), or building a new wheel with all new components; however, it is written as though a wheel is being rebuilt. If building a new wheel with new components, merely substitute the word “build” for the word “rebuild.”

GENERAL INFORMATION

TERMINOLOGY

Wheel: The structure consisting of the hub, spokes, nipples, and rim.



16.1 Parts of a wheel.

Rim: The metal hoop at the outer end of the spokes that the rubber tire attaches to. The word *rim* is sometimes misused to apply to the wheel.

Spoke hole: The hole in the rim where the nipple comes out, although it would be better called the “nipple hole.” In regard to the hub, the term refers to the hole in the hub flange that the spoke goes through.

Eyelet: A separate metal reinforcement that goes in the spoke-nipple hole in the rim.

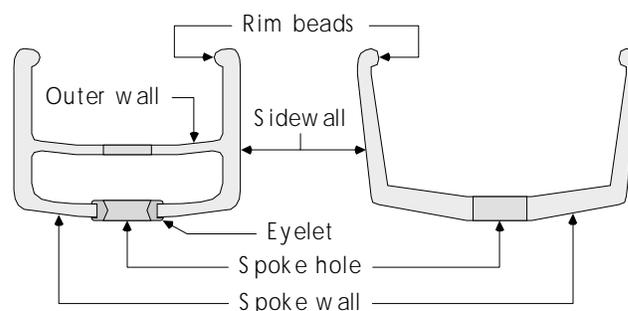
Valve hole: The hole in the rim that the tire-inflation valve inserts through.

Spoke wall: The wall of the rim that the spokes attach to.

Outer wall: The wall of the rim that faces the tube and tire. This wall only exists on modular-style clincher rims and tubular rims.

Sidewall: The vertical face of the rim where brake pads contact. There are rim sidewalls and tire sidewalls; in regard to a tire, *sidewall* refers to the portions of the tire between the rim bead and the tire tread.

Rim bead: The edge of the rim where the tire attaches.



16.2 Parts of a rim.

Hub: The mechanism at the center of the wheel that an axle rotates inside of and the spokes attach to.

Hub flange: The disc on either end of the hub that the spokes attach to.

Spokes: The wires that go from the hub to the rim.

Spoke elbow: The end of a spoke that makes a 90° bend where the spoke goes through the hole in the hub flange.

Spoke head: The flattened disc at the end of the spoke elbow that keeps the spoke from pulling through the holes in the hub flange.

Nipple: The elongated nut that threads onto the end of the spoke and attaches the spoke to the rim.

Nipple head: The fat portion at one end of the nipple (usually round).

Nipple slot: A slot in the nipple head that fits a slotted screwdriver.

Cross pattern: The pattern created by two sets of spokes in a hub flange that radiate in opposite directions as the spokes go out to the rim. If a clockwise-radiating spoke crosses three counterclockwise-radiating spokes from the same hub flange, then the wheel is said to be a “three-cross pattern.” Cross patterns are described symbolically. A three-cross pattern is usually just written “3X.”

Interlace: When a spoke leaves the hub, it crosses over other spokes; if it switches to crossing under at the last spoke it crosses on way to the rim, then this pattern is called an interlace.

Dish: The centering of the rim to the hub locknuts. Because the flanges of a rear hub may not be equidistant from the locknuts, a rim centered to the locknuts is not necessarily centered to the hub flanges. Viewed from the wheel’s edge, this makes the wheel appear like a dish viewed from its edge.

PREREQUISITES

Wheel removal and installation

Before rebuilding a wheel, the wheel must be removed from the bike. See the **WHEEL REMOVAL, REPLACEMENT, AND INSTALLATION** chapter (page 18-6) if unsure about wheel removal and installation.

Tire removal and installation

Before rebuilding a wheel, the tire must be removed from the wheel. See the **TIRES AND TUBES** chapter (page 19-3) if unsure about tire removal and installation.

Freewheel removal and installation

To rebuild a wheel, it is necessary to remove the freewheel or freehub cogs. See the chapter **FREEHUB MECHANISMS AND THREAD-ON FREEWHEELS** for freewheel removal (page 25-9) and freehub-cog removal (page 25-16).

Hub adjustment

Before building a wheel, the hub must be adjusted to have no free play when out of the bike. See the appropriate chapter on hub adjustment.

INDICATIONS

Symptoms indicating the need for rim replacement or wheel rebuilding

During wheel repair, or even before, symptoms may be experienced that indicate wheel replacement or wheel rebuilding is desired. These symptoms are:

Multiple broken spokes, either all at once or one at a time, over the last few hundred miles.

Multiple corroded nipples that won’t turn.

Multiple damaged nipples (rounded-off wrench flats).

Dents or bends in the rim that cannot be adequately straightened by normal spoke adjustment and unbending techniques.

Cracks in the rim.

Severe rim-sidewall wear, evidenced by a concave rim sidewall, or by rim beads that have become wider apart than they were originally.

Whenever these symptoms are specific to the spokes and nipples, decide whether to keep the rim or replace it. The dilemma is that if the problem with the spokes or nipples is bad enough to prevent truing the wheel, then there is no good way to tell if the rim is in good shape. If the rim is reused, the damage may not be discovered until most of the work of truing has been done. As a rule, replace the rim when the set of spokes needs to be replaced.

TOOL CHOICES

The most important tool for building a wheel is the spoke-length system that will be used to determine the correct spoke length. There are many systems on the market, and all will determine the length correctly most of the time; however, there is no ideal system. Each has its own compromise. Short reviews of several of the systems are included. In the section of this chapter on determining spoke length, there are tips for some of these systems and complete instructions for a few of them. The systems are basically sound, but the instructions that come with them are over-simplified, making each system appear simple and easy-to-use. Because the systems come with over-simplified instructions, this chapter includes very detailed instructions that will enable you to get better results out of any of these systems than you would get by just using the manufacturer’s over-simplified instructions.

The spoke-length-calculation systems are either manual, or electronic. The electronic ones require a computer or a special scientific calculator. The manual

ones require the use of written tables for looking up factors, and leave the math up to the user. Most systems provide hub and rim data for existing equipment to simplify calculations, but inevitably wheels need to be built with components that are not listed. Consequently, the system's provisions for dealing with unlisted equipment are more critical than the lists of existing equipment.

Sutherland's Handbook for Bicycle Mechanics. This book covers much more than spoke length, but its spoke-length system is one of its most important features. The database on existing rims and hubs is good when an edition is first published, but becomes seriously out of date between editions. The book provides a system for determining data for rims not listed, but the instructions for measuring and calculating rim data are vague. This manual includes instructions for *Sutherland's* fifth and sixth editions for no other reason than these editions are the one most widely used at the time of this writing.

Spoke Calc by DT. This is a wall poster full of data tables and measuring devices for hubs and rims. The data tables are based on dimensions, rather than models, so they never go out of date. On the other hand, no model information means that every rim and hub needs to be measured, instead of just looked up. The built-in measuring systems are primitive and a likely source of error. In this chapter, full instructions for use of *Spoke Calc* (with more accurate methods for measuring components) are provided.

Wheelsmith Spoke Length Calculator. This scientific calculator, programmed specifically for spoke-length calculation, is simple and quick. The accompanying book has a reasonable range of existing component data, and the system comes with a good device for measuring rims. The system for measuring hubs is less precise, but this chapter provides more accurate hub-measurement techniques.

Blue Pig Industries Wheel Calculator. This PC-based computer program is accurate, has a comprehensive database, allows adding and editing data, and has many extra features. It requires hub and rim measurements for unlisted equipment. Procedures for making these measurements are included in this chapter.

SpokeMaster (BOD). SpokeMaster is a component of the BOD bicycle-product database. This program (based on the *Sutherland's* book) is easy to use but is severely limited by the complete lack of any way to deal with rims or hubs that are not listed in its database. It is difficult to confirm whether a hub or rim matches a listing due to lack of dimensional and descriptive information about the hubs and rims. *This program is not recommended!*

SpokeMaster for Windows by Two-Bit Software. This is a completely different program than SpokeMaster (BOD). The name is likely to change because of trademark infringement, so look for a spoke-length program for Windows by Two-Bit Software. It has a database, and allows custom entries for hubs and rims. The descriptions of how to measure hubs and rims are inadequate, so use procedures recommended later in this chapter. The program is inexpensive and easy to use, but forces the user to complete the process for both sides of rear wheels, resulting in inconsistent differentials between the left and right sides (inconsistent differential values are the result of the program's use of a simple geometrical model of the wheel, rather than a more realistic one based on physics). Use the recommended left-side length and calculate the right-side length differential by methods recommended later in this chapter.

Tool choices and useful supplies are listed in table 16-1 (page 16-4). The preferred tools or supplies in table 16-1 are shown in **bold** face. If there are several tools for the same purpose that are shown in **bold** type, the choice is strictly a matter of personal preference or price.

TIME AND DIFFICULTY RATING

Lacing new spokes into a wheel is a 8–12 minute job of little difficulty. This time is based on starting with a bare hub. This does not include calculating spoke length (which varies from 2–10 minutes depending on the system used), or truing.

COMPLICATIONS

Removing spokes before removing the freewheel from hub

On the freehub-type rear hubs that are most common today, it is not a big concern if the cogs are not removed from the hub before the spokes are cut or unthreaded. Making this mistake on a traditional hub with thread-on freewheel can be disastrous because the rim is an indispensable part of the freewheel-removal procedure, and because the freewheel blocks access to the spoke holes in most cases. See the chapter **FREEHUB MECHANISMS AND THREAD-ON FREEWHEELS** (page 25-13)

for methods for removing freewheels once the rim has been detached. Usually, a choice must be made between sacrificing the freewheel or sacrificing the hub.

Knowing whether to reuse a rim

When spokes start breaking repeatedly, then it makes more sense to replace them all at once, rather than one at a time. It might also be desirable to replace a set of spokes because of corroded nipples, rounded nipple-wrench flats, or spokes mangled from a chain over-shift. For reasons of economy, a decision is often made to reuse the rim.

If the problems with the spokes make it impossible or impractical to true the wheel precisely before rebuilding it, then there is no way to know whether the rebuilt wheel will end up true with good uniform spoke tension. It can turn out to be very false economy to reuse a rim. Unless it is possible to true the wheel and evaluate spoke-tension uniformity before unbuilding the wheel, it is recommended to use a new rim when the spokes need to be replaced.

WHEEL-LACING AND BUILDING TOOLS (table 16-1)

Tool	Fits and considerations
Blue Pig Wheel Calculator	PC computer program. See preceding review of spoke-length systems.
DT Spoke Calc	Wall chart or PC computer program. See preceding review of spoke-length systems.
SpokeMaster (BOD)	Not recommended — see preceding review of spoke-length systems.
SpokeMaster for Windows by Two-Bit Software	Name for this is likely to change due to trademark conflict. Make sure program is by Two-Bit Software. See preceding review of spoke-length systems.
Sutherland's Handbook	Book, includes spoke-length system. See preceding review of spoke length systems.
Wheelsmith Spoke Length Calculator	Programmed scientific calculator. See preceding review of spoke-length systems.
Bicycle Research ND-1	Offset screwdriver for speed-threading of nipples.
VAR 265	Special nipple driver for electric drills. Only useful for production runs of identical wheels.
Hozan C915	Relatively inexpensive spoke-threading machine, impractical for more than 2–3 spokes at a time. Valuable for creating replacement spokes in unusual sizes for wheels that just need a few spokes replaced.
Phil Wood Spoke Threading Machine	Cuts and threads spokes, difficult to cost-justify, difficult to create consistent length of threading (makes truing more difficult).
DT Spoke Ruler	Inexpensive spoke ruler, aluminum gauge-notches loose accuracy quickly.
Park SBC-1	Inexpensive spoke ruler, no gauge-notches
Phil Wood Spoke Length Gauge	Expensive, precise, and durable. Superior variety of gauge-notches that retain accuracy.
Wheelsmith Spoke Ruler	Precise and durable. Limited variety of gauge-notches.
Eldi 2620	Heavy duty spoke cutter for cutting out old spokes.
DT Spoke Freeze	Thread preparation compound reduces corrosion and vibration loosening.
Wheelsmith Spoke Prep	Thread preparation compound reduces corrosion and vibration loosening.
Sanford Sharpie Fine Point permanent marker	Used for marking on hub and rim to keep track of where spokes will go.
1/2" masking tape	Used for tagging a spoke in order to keep track of it.

Knowing whether to reuse the spokes

When a rim is damaged, it may seem to make sense to replace the rim, but reuse the spokes. This can be another false economy. There is no way to tell what life is left in old spokes. They may all be on the verge of fatigue failure. It is strongly recommended to always use new spokes when installing a new rim.

Calculating inaccurate spoke lengths

Determining the correct spoke length can depend on taking numerous measurements precisely, looking up numbers accurately from complex tables without error, and performing a number of mathematical procedures without error. Manual systems have all these potential problems. Electronic systems can reduce some of them, but usually not all. Until a mechanic has calculated spoke length for a large number of wheels without error, it is a mistake not to double-check all spoke-length calculations — recalculation is far less time-consuming than building a wheel twice.

Correct spoke length(s) unavailable

It is not unusual to calculate the correct spoke length, only to find that it is not on hand or readily available from a supplier. For most wheels there is an ideal length, and a range of acceptable lengths of at least plus or minus 1mm from the ideal.

If deviating slightly from the ideal does not solve the problem, then consider switching to another gauge or another cross pattern. Most wheels are built as a three-cross, but a four-cross pattern is practically identical in function. On front wheels only, a two-cross pattern might be an option.

Wrong spokes in box

One of the most common situations in a bike shop is for spokes in a container to be mixed, or all the spokes different from the label on the box (due to lids getting switched). Another problem is that gauges of spokes or nipples are wrong or mixed.

It is always easier to measure length and gauge of the spokes before lacing the wheel, than it is to unlace a wheel and start over again. Measuring every time is the *only* way to prevent this common problem.

Building with wrong-length spokes

For each wheel there is a range of spoke lengths that will not cause problems. Beyond this range, there are lengths that are too long or too short, but can be lived with. Spokes that are too long or too short cannot be used.

When spokes are too long, they protrude past the nipple into the tire area. If the nipple is in a recessed socket and the protrusion 1mm or less, this is not a problem. If the nipple is not in a socket, the protruding spokes will need filing, which is time-consuming and awkward.

When spokes are too short, they will show thread outside the nipple. Up to 1mm of exposed thread is nothing more than a cosmetic flaw. More than this raises concerns that there may be inadequate thread engagement between the nipple and the spoke.

Poor fit of spokes to hub flange

Spokes may seem to be too tight or too loose in the spoke holes.

Some high performance hubs are made with 1.8mm spokes in mind. The 2.0mm size usually fits, but is difficult to install and causes the spokes to come out of the flange at an awkward angle. The lacing procedure recommended here effectively deals with the problem of the tight spokes coming out of the flanges awkwardly.

Sometimes a flange seems too thin for the elbow of the spoke. Traditionally, it has been recommended to use washers between the spoke head and hub flange in this case, however these washers are virtually impossible to find. Structurally it makes little difference.

Light gauge spokes, such as 1.8mm, sometimes seem loose inside the spoke hole in the hub flange. As long as the spoke is a harder metal than the hub flange, then the spoke under load will always create its own ideal bed of support in the hub flange.

Special hub configurations

There are numerous special hub configurations, and between the time this manual is being written and the time that a new edition comes out, there will undoubtedly be more.

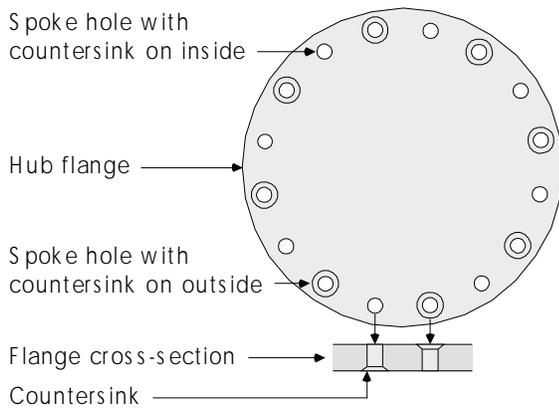
The rage at the time of this writing is “direct pull” hubs that use spokes that have no elbow. The only certain thing is that this rage will be replaced by another before this edition of the manual gets old.

This chapter only applies to the tried-and-true drilled-flange hubs and elbowed-spoke designs.

Even with this traditional design there are variations that create complications. The simplest variation is one in which every other spoke hole is countersunk on the outer face of the flange, and all the other holes are countersunk in the inside face of the flange. The countersinks are designed to accommodate the elbow of the spoke (highly debatable — see ***Countersunk or chamfered spoke holes*** on page 16-9), so

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dealing with this design is simply a matter of choosing the first hole correctly so that the head of the spoke ends up on the opposite side of the flange from the countersink.



16.3 *Cross-section of a hub flange with alternately-countersunk spoke holes.*

Some hubs are designed so that all the spokes have their heads on the inside of the flange. To accomplish this, there are usually two “levels” to the outer face of the flange. The “upper level” is the normal outer face of the flange. The “lower level” is usually a “V-shaped” notch in the outer face of the flange that allows a spoke to come out of the hole (in the notch) and pass under the spokes in the “upper lever.” This design causes two problems: 1) when selecting the spoke length, it is important to know if the V-notches limit the cross pattern (3-cross or less is typical) so that you may select a pattern and the appropriate length accordingly; 2) when lacing, it is necessary to feed all spokes into the flange from the inside, and install the spokes (to the rim) in the “lower level” before attaching any spokes from the “upper level.”

Special rim configurations

Special rim configurations present several types of challenges.

Not all rims have the same spoke-drilling style. There are three drilling styles; furthermore, the manufacturers and distributors tend to ignore the issue entirely, so it is up to the mechanic to determine the drilling style. There are no commonly accepted terms for different styles, so the following terms are unique to this book. Depending on how the rim is oriented when being examined, a drilling style can appear two exactly opposite ways.

Hold the rim horizontal with the valve hole on the opposite side of the wheel from your body. Look at the two spoke holes to the *right* of the valve hole to see which of the following styles a rim matches:

Staggered down/up: This is the most common pattern, and the first hole to the right of the valve hole is staggered down.

Staggered up/down: This is a less common pattern, and the first hole to the right of the valve hole is staggered up.

Unstaggered: This pattern is usually found on aerodynamic-profile rims, and all spoke holes are directly in line with each other.

Deep cross-section rims have awkward access when putting a nipple down into its hole. Although tools have been made for this process, nothing works better than putting the nipple on a square-shaft toothpick.

Some aerodynamic-rim designs keep the nipple entirely inside the rim. Special tools may be required to install and adjust the nipples.

Different cross patterns on each side of the wheel

The rules change on how to lace a wheel when the lacing pattern is not the same on both sides of the wheel. Be sure to read about the special technique required whenever building something like a wheel with 3-cross on one side and 2-cross on the other side.

Lacing errors

The complexity of lacing a wheel makes it inevitable that errors will occur. The lacing method in this chapter is designed to reduce error, but more importantly it includes periodic checks as the wheel develops stage-by-stage, so that the errors will be discovered early. *Always perform the checks!*

Scratching the rim while lacing the wheel

Rims can be very expensive, and maintaining the cosmetic finish in good condition is an important part of building a wheel. Don't hesitate to bow spokes when installing them in order to get the tips to clear the rim — just avoid kinking them.

ABOUT THE REST OF THIS CHAPTER

The rest of this chapter is divided into four parts. The first part is about wheel design. This section helps determine which hub, rim, spoke, and lacing pattern will be best for any particular reason. The second section is about how to determine spoke length. The third section is about how to lace the spokes into the hub

and rim from scratch. The fourth section is about replacing a damaged rim while reusing the spokes and keeping them in place. This should only be done when a new wheel is damaged and it is known that the spokes are not damaged and have not yet begun to fatigue.

WHEEL DESIGN

When designing a wheel, the designer should keep in mind the three types of load that the wheel experiences, and the performance and reliability criteria that suit the user.

Wheels experience three types of load; radial load, lateral load, and torsional load.

Radial load is the load that is experienced in a straight line between the hub and the rim. Radial loads result from the weight on the wheel, and from hitting bumps and dips in the riding surface.

Lateral load is load experienced at the rim that is at right angles to the plane of the wheel. Normal lateral loads are relatively slight, and occur when the wheel is leaning over, but the rider is not (for example, when rocking the bike side to side while climbing out of the saddle). Extreme lateral loads are experienced when control is lost and the wheel receives impact from the side.

Torsional load is experienced on all rear wheels, and on any wheel that has a hub-mounted brake (disc brakes, drum brakes, and coaster brakes). Torsional load is experienced when drive forces cause the hub to rotate, which then causes the rim to rotate by means of the spokes. Hub brakes cause torsional load because the momentum of the vehicle is causing the rim to rotate, and the brake at the hub is resisting the rotation. Rim brakes do not cause torsional load on the wheel structure because the resistance to the rim's rotation is at the rim, not at the hub.

In addition to designing a wheel to withstand these loads, the wheel designer must consider the performance expectations of the user. Wheel weight and aerodynamic resistance are the primary considerations that affect performance. In regard to wheel weight, rim weight is most important, spoke weight is less important, and hub weight is the least important. These differences are because of the relative speed of rotation of each wheel component. The faster the speed of rotation is, the more significant a weight difference will be. Rim shape and spoke shape are the most significant factors affecting aerodynamics.

The reliability of the wheel is one more consideration in the design of a wheel. A wheel that will withstand high radial load is more reliable for the type of user that will subject the wheel to extreme levels of off-road use. Heavier riders are also concerned with a wheel's ability to withstand high radial loads. Rim weight and shape would be important considerations for this user. A wheel that will last many thousands of miles without spoke breakage is more reliable for the type of user that rides many miles of smooth road. For this user, spoke gauge and spoke number choices might be most significant.

The rest of this section on wheel design discusses the specifics of how rim shape, rim weight, rim materials, lacing patterns, spoke gauges, spoke quantity, and hub choices affect how a wheel will hold up, and meet the user's expectations of performance and reliability.

RIM CHOICES

Materials

Materials used for rims include steel, aluminum, carbon fiber, and titanium. Steel is economical, but otherwise undesirable. Aluminum has a superior strength-to-weight ratio and superior braking performance and is the only choice for most applications. Titanium rims of a reasonably low weight have extremely thin wall thickness, so their use is limited to the track. Carbon-fiber rims can either be full carbon fiber, or a carbon-fiber "fairing" on the inner diameter of an aluminum rim. A full carbon-fiber rim is prone to catastrophic failure and provides an inferior surface for braking. Aluminum/carbon-fiber combinations have neither of the disadvantage of plain carbon fiber.

Because of its combination of desirable properties, aluminum remains the material of choice for most bicycle rims.

Shapes

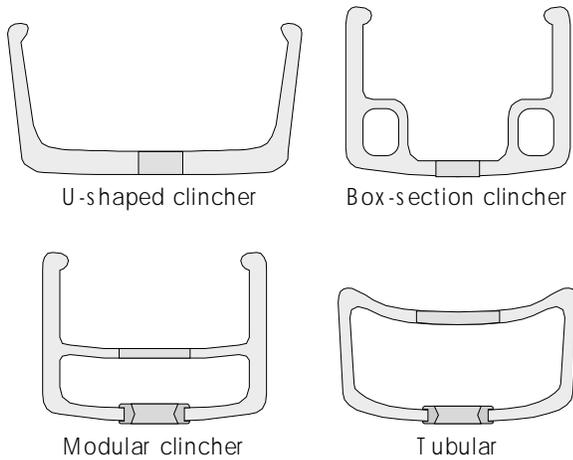
The cross-sectional shape of a rim and the thickness of its walls are the primary things affecting rim strength. Rims are of either of two categories, tubular (tires are glued on) or clincher (conventional tires).

Tubular rims have a cross-section shaped like a modified tube. This is the best shape for strength-to-weight ratio, but only sew-up tires that are glued onto a rim can be mounted on these rims, so tubular rims are therefore impractical for the average cyclist.

Clincher rims are either U-shaped, box section, or modular. U-shaped rims for clincher tires have no hollow to their cross-section and have the least strength for their weight. Box-section rims have a hollow box

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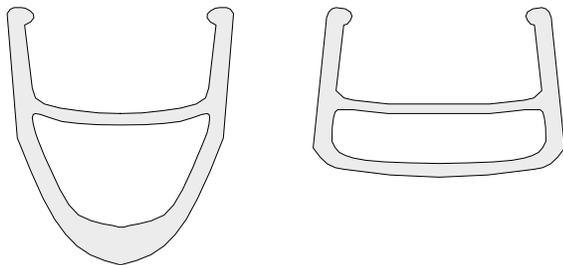
section at each corner of the rim cross-section and have an improved strength-to-weight ratio. Modular rims have a tubular cross-section with rim flanges attached for mounting a clincher tire. This design features the best strength-to-weight ratio for clincher rims.



16.4 Common rim cross-sections.

Aerodynamic rims can be tubular or clinchers with box or modular cross-section. They are generally heavier than their non-aerodynamic counterparts, weaker laterally and stronger radially. Aerodynamic rim shapes are compatible with sidepull brakes, but are not very suitable for cantilever brakes (touring and mountain bikes).

The best shape for a rim to be used with cantilever brakes is sort of a reverse-aerodynamic shape, narrower at the outer perimeter than at the inner perimeter of the sidewall. Straight-wall (no slope) rims are almost as suitable for use with cantilever brakes. Any rim that is wider at the point where it meets the tire is a poor choice for use with cantilever brakes, or brakes that mount on cantilever braze-ons.



16.5 The aero' rim type on the left is unsuitable for use with cantilever brakes; the rim in the right has the ideal slope to the sidewalls for use with cantilever brakes.

In conclusion, shape is important because it determines whether a rim gets the most out of the amount of material that is used.

Eyelets (hole reinforcements)

Rims may be eyeleted to reinforce the rim at the spoke hole. Single eyelets reinforce the rim only at the spoke wall. Double eyelets form a socket that distributes the spoke load between the spoke wall and outer wall of a tubular or modular-clincher rim. Eyelets also reduce friction between the nipples and the rim, and are critical for this reason when using aluminum nipples.

Eyelets are a desirable, but not critical, feature.

Anodized rims

Anodized aluminum rims have been chemically treated to make the surface more corrosion resistant. The anodization could be a variety of colors including clear, gray, silver, gold, blue, red or black. This results in a rim that keeps its appearance better; however, the anodization wears off the braking surface rapidly.

Hard-anodized rims have been chemically treated to create an anodized layer that not only resists corrosion, but is more abrasion resistant than plain-anodized rims. The process incidentally improves the strength of the rim insignificantly. These rims will be dark in color, such as smoky gray, brownish gray, dark gray, dark blue-gray or black. The result is that the hard anodization remains on the braking surface longer, but it seems to detract from braking performance.

In conclusion, anodization of all types is an insignificant consideration in wheel design.

Heat-treating and work hardening

A variety of alloys and hardening processes (heat treating) are used in manufacturing rims. These alloy choices and hardening processes cannot be described as having any special significance without also considering the rim weight and design. There is a very narrow range of hardness that is suitable to a bicycle rim. Too hard and the rim is brittle and tends to crack around the spoke holes, and elsewhere. Too soft and it bends to easily. Whether a manufacturer uses "heat treating," "work hardening," or some other exotic-sounding hardening process, the end results must be very close to the same or the rim will be too brittle or too soft.

In conclusion, the use of different materials and hardening processes mean more to the rim designer than they do to the end user. Marketing people look for every little tidbit to make their products sound superior. Do not let these marketing concepts have too much influence on rim choice.

Ceramic coating

Ceramic coatings are put on rim sidewalls to improve brake performance. They have no effect on overall rim strength, other than to reduce rim wear from the brake pads (an important consideration for many mountain bikers). These ceramic coatings are effective for the purpose of improving braking.

In conclusion, ceramic coatings are an expensive plus.

Rimweight

Rim weight is a significant factor in determining wheel strength and the bicycle's acceleration and braking performance. Weight is a function of the overall dimensions of the rim, the cross-sectional design, and the wall thickness. It is most useful when comparing two rims of similar cross-section design (both modular, for example) and similar dimensions (both 19mm wide and 14mm deep, for example). If one rim weighed 10% more than the other, the likely reason would be that the heavier rim would have thicker rim walls at some point. Thicker means stronger. If the extra thickness is uniform throughout, then it means that the rim is overall stronger. If the sidewalls only are thicker, it means that the rim is stronger radially. If the spoke wall is thicker, it means that the rim is less likely to fail at the spoke holes, and it has greater lateral strength. Whether the extra thickness would be uniform throughout is unknown, unless you have access to the manufacturer's specifications or have a rim cross-section to measure.

Clincher rims of the 27" and 700C sizes range in weight from more than 800 grams to as little as 400 grams. Less than 475 grams is generally considered to be in a range where strength is significantly compromised for the advantage of low weight. Manufacturers of 26" narrow triathlon rims claim weight savings ranging from 0 to 40 grams for a 26" rim compared to the 700C size of the same model; general weight guidelines for these 26" rims should not be considered different. Tubular rims (700C) range in weight from 480 grams to as little as 280 grams. Less than 375 grams is generally considered to be in a range where strength is significantly compromised for the advantage of low weight. Mountain bike rims (26") range in weight from 750 grams to as little as 390 grams. Less than 450 grams is generally considered to be in a range where strength is significantly compromised for the advantage of low weight.

In conclusion, rim weight is a significant factor in wheel design, but rim shape determines whether two rims of comparable weight have comparable strength and stiffness.

HUB CHOICES

Small-versus large-flange hubs

Large-flange hubs were traditionally thought to increase a wheel's lateral, radial and torsional stiffness. Of these, only torsional stiffness has been scientifically verified, but the increase in torsional stiffness reduces spoke fatigue by an insignificant degree.

Small-flange hubs have been traditionally described as having less radial stiffness (making them more comfortable), less lateral stiffness (making them less stable in cornering) and less torsional stiffness, which is true, but of low significance (see above). The assumptions about comfort and lateral stiffness with either flange type are false and the difference in torsional stiffness is not significant, so flange diameter should not be a major consideration in designing a wheel. This is also true for mixed-flange designs (small flange on one side and large flange on the other side).

In conclusion, flange-diameter considerations are relatively insignificant with regard to wheel properties.

Five-, six-, seven-, or eight-speed capacity

Providing more space for a greater number of sprockets increases the offset of the right flange to the left, which in turn significantly increases the wheel's vulnerability to failure when exposed to high lateral loads (generally only experienced during crashes or other forms of losing control of the bike). In some cases, this is compensated for by adding space to the left side of the hub. A standard seven-speed hub might have 130mm overall spacing, but be available in a 135mm "dishless" (actually not dishless, just less dish) option.

In conclusion, giving up a needed gear or spreading a frame to accept a wide version of a hub to prevent wheel failure during crashes is a questionable priority choice. Build wheels with no consideration to how the number of gears affects lateral strength.

Countersunk or chamfered spoke holes

Countersinking is done to improve the mating of the spoke elbow to the flange to reduce fatigue. Aluminum flanges are softer than spokes, so the edges of non-countersunk holes will easily conform (shape) to the shape of the spoke. This "shaping" of non-countersunk spoke holes is superior to the "shaping" that occurs if the spoke holes are countersunk.

For this reason, ignore the countersinking pattern if it interferes with lacing the wheel in the way desired.

Hub-core diameter

The advent of front suspensions has led to front-suspension hubs. These hubs often have a larger diameter core, which has been reputed to increase stiffness. Research has shown that front-suspension hubs that do reduce separate fork-leg action do so because of changes in axle design. Larger hub cores alone are irrelevant to wheel strength.

Suspension-hub considerations

Special front hubs are made for use on bikes with front suspensions. These hub features may include large diameter hub cores, oversized axles, oversized skewers, and oversized locknut faces. All these features (except larger diameter hub cores) reduce independent leg action on front forks. It cannot be designed into the hub, but nothing reduces independent fork-leg action more than maximizing the security of the hub in the fork. Wheel performance is unaffected by all these factors, which work by reducing flex in the axle and motion between the axle and the fork leg.

Direct-pull flange designs

Direct-pull flange designs use a spoke that has no elbow. This is a poor design that attempts to solve a problem that does not exist. It has been reinvented and abandoned numerous times in the history of bicycles. The rationale is that since spokes break at the elbow, the elbow should be eliminated. Spokes do not break at the elbow because it is an elbow, but because it is the anchor-point of the spoke.

The dynamics of a rear wheel require that the hub rotate under torque-loads slightly before the rim responds. The traditional elbowed spoke compensates for this by allowing the spoke to rotate in the hole in the flange, which, in itself, adds no stress to the spoke. Direct-pull designs allow the hub to wind up before the rim only by flexing the spoke, which does add additional stress to the spoke.

The direct-pull design complicates determination of spoke length, reduces cross-pattern options, increases spoke inventory, reduces choice of spoke brands and gauge options, and in some cases makes it more difficult to tighten nipples because of a tendency of the spoke to spin in the flange hole.

Avoid recommending this hub type to customers, and inform those who request it of the disadvantages.

SPOKE CHOICES

Materials

Carbon-steel spokes (most common, called chrome plated, galvanized, zinc plated) are inexpensive. Stainless-steel spokes are corrosion resistant and are usually made with superior manufacturing techniques, making them a generally more reliable choice. Stainless-steel spokes can be identified by the fact that they are not magnetic, or very mildly magnetic, whereas carbon-steel spokes are fully attracted to magnets.

There are exotic material choices, as well. Both titanium and carbon-fiber spokes are available in limited lengths and gauges at extremely high prices.

Titanium spokes are only available in thicker gauges that make them no lighter than the thinnest gauge steel spokes. Thin-gauge titanium spokes are not possible because of the greater elasticity of the material.

Carbon-fiber spokes are quite thick and may be a serious aerodynamic disadvantage. Carbon-fiber spokes are very susceptible to failure due to nicks. The carbon-fiber spokes are aerodynamically shaped, but due to their great thickness, they create more drag than thin round steel spokes.

Neither carbon-fiber or titanium spokes allow use of conventional tension meters, resulting in having to guess about the most critical factor in wheel building — correct spoke tension.

Stick with stainless-steel spokes for a proven combination of reliability, low weight potential, selection, and vital compatibility with tension meters.

Gauge choices

The most common gauge is English 14g, or ISO (and Japanese) 2mm. Note that English gauge numbers increase as the spoke diameter decreases, so that a 15g spoke is thinner than a 14g spoke.

Plain-gauge spokes are spokes that are uniform gauge over their entire length (except the thread). Common plain-gauge spokes are 2mm (14g) and 1.8mm (15g). Plain-gauge spokes are economical. Plain-gauge 2mm spokes are the easiest to build with because they wind up the least as nipples are tightened. For this reason, most machine-built-wheel spokes are 2mm. If a spoke breaks, a wheel built with 2mm spokes will go out of true less than a wheel with thinner spokes, because the spokes are less elastic.

Butted spokes are spokes that are thicker at the ends than they are in the middle. Common butted spokes are 2mm/1.8mm/2mm, 2mm/1.6mm/2mm,

1.8mm/1.6mm/1.8mm, and 1.8mm/1.5mm/1.8mm. Differentials of up to 3 gauges are now being seen. Butted spokes have the advantage of resisting fatigue by virtue of their thickness at the ends where fatigue occurs, and of enhancing wheel strength by making it more elastic, allowing a wheel to flex under load without bending. Butted spokes are more difficult to build with than plain 2mm spokes because they wind up more as the nipples are tightened. Butted spokes can save several ounces of weight per wheel compared to plain 2mm spokes, and their smaller diameter creates less aerodynamic drag.

Aerodynamic spokes are spokes that do not have a round cross-section. They may be bladed (flattened), elliptical (oval), or airfoil (best aerodynamics) cross-section. These shapes reduce the frontal area exposed to the air as the wheel moves through the air. The aerodynamic benefit is clear when riding in windless conditions, or directly in line with the wind, but in cross winds even greater turbulence (and drag) may be encountered with aerodynamic spokes than would be encountered with round-section spokes. With many aerodynamic spokes, there is a potential that there will be a compatibility problem with a tension meter.

Bladed spokes are usually 2mm spokes that have been flattened. Their weight is comparable to plain 2mm spokes. If bladed spokes have conventional spoke heads, the holes in the hub flange must be slotted with a special tool, which voids any manufacturer's warranty. Spokes with an oval or airfoil cross-section are usually 1.8mm spokes and have a weight comparable to butted 1.8mm spokes. The aerodynamic shape of oval or airfoil spokes is generally superior to bladed spokes, and they usually do not require modification of the hub flange.

The best overall spoke choice is a butted 2mm, and the best overall choice when performance is a greater priority than durability is a butted 1.8mm spoke. In addition, extra-light rims should always be built with light-gauge spokes.

NUMBER OF SPOKES

Conventional full-size wheels almost always use 36 or 32 spokes per wheel. Racing wheels usually use at most 32 spokes per wheel, but sometimes are built with 28 or 24 spokes per wheel. Touring bikes and tandems usually use 40 or 48 spokes.

Spoke quantity, weight, and true tolerances

When the number of spokes is reduced, weight is saved, but more importantly, aerodynamic resistance is reduced. When the number of spokes is reduced, the wheel structure is slightly more elastic and resistant to bending. When the number of spokes is reduced, each spoke is asked to control the true of a longer section of rim, which may lead to a worsening of the lateral-true and radial-true tolerances that can be achieved, particularly with lightweight rims. This loss of control over true is particularly troublesome with light-weight rims and less than 32 spokes.

Spoke quantity and fatigue life

The fatigue life of a spoke is directly proportional to the number of spokes. Consequently, 28 spoke wheels will start breaking spokes at 78% of the life of the same wheel built with 36 spokes. This statistic is even more significant in regards to tandem wheels. It is reasonable to assume that a tandem experiences approximately twice the load per wheel as a single bike. If both bikes had the same wheels with 36 spokes each, the life of the spokes in the tandem wheel would be 50% of the life of the spokes in the single wheel. To get equal spoke life, the tandem wheel would need 72 spokes. Increasing from 36 to 48 spokes only makes a 33% improvement in the life expectancy of the spokes on a tandem.

On the other hand, extra-spoke wheels on touring bikes are probably more trouble than they are worth. If the average rider is about 160 pounds and the average touring bike is about 30 pounds, the average 45-pound load of touring gear only increases the load on the spokes by 24%. More importantly, the total vehicle load (235 pounds) is only about 4% more than what would be considered a normal but heavy rider and bike (225 pounds). Although 40-spoke wheels would have 11% greater spoke life than 36-spoke wheels, the trade off is that replacement rims and spokes are much harder to find.

Extra spokes and rim/spoke availability

At drillings above 36 holes, the selection of rims becomes very limited. Also, every bike shop in the country is likely to have 36-hole replacement rims and the appropriate length spokes, but probably less than 5% of the shops in the country have 40- or 48-hole rims, or the unusual spoke lengths sometimes needed for such wheels. Since a tourist can't carry spare rims, the trade-off is not worth it.

NIPPLE CHOICES

Nipple length

Long nipples are designed to protrude further through thicker rim walls, or to provide a greater length for the wrench to engage. Long and short nipples of the same brand usually have the same depth of thread engagement, so use of long nipples does not usually allow the use of shorter spokes.

Nipple materials

Most nipples are made of brass and are plated with chrome or a similar plating. Aluminum nipples are used to save weight, and more significantly, in conditions where the spokes may snag on obstacles, aluminum nipples are more likely to fail than pull through the rim. The weight saved is less than 1 ounce per wheel. Aluminum nipples have a high coefficient of friction on non-eyeteled aluminum rims and may be more difficult to tighten.

SPOKING PATTERNS

A cross pattern, such as three cross (3X), gets its name from the number of times a spoke radiating one direction from a flange crosses the path of spokes radiating the opposite direction from the same flange. Most wheels are either built with a 3X or 4X pattern.

Cross-pattern voodoo

The discussion of cross pattern in regard to wheel-performance characteristics is the source of a great deal of “voodoo mechanics.” Countless unsubstantiated theories based on subjective experience abound. Suffice it to say that wheel builders have been experimenting with cross patterns for as long as there have been spoked wheels. Decades ago the bulk of wheel designers settled on the virtually indistinguishable 3X and 4X patterns as the reliable ones. Scientific studies have verified these patterns to be the best and roughly comparable. All other cross patterns are voodoo, not science.

Three-cross and four-cross patterns

Traditionally, 3X patterns were thought to create a wheel with greater lateral, radial and torsional stiffness, and 4X wheels were thought to have all the opposite characteristics. All of these opinions have been scientifically disproved. On the contrary, the only measurable difference in strength between 3X and 4X is that 4X patterns have an insignificantly greater torsional stiffness. In a more practical sense, 3X has an

advantage over 4X in that the hub does not need to wind up as far when installing the third set of spokes, so that 3X is less awkward to build with.

On wheels with less than 36 spokes, 4X spoking is not compatible.

Pick between these patterns on the basis of spoke-length availability, and build 3X when lengths for both are available.

Radial, one-cross, and two-cross patterns

Cross patterns with fewer crosses than 3X are best used on very small wheels (less than 20") and are used to reduce congestion of spokes at the hub.

Performance advocates sometimes suggest using 2X, 1X, or radial spoke patterns to save weight (through use of a shorter spoke) or reduce aerodynamic resistance (only in regards to radial spoking, and in this case the logic is false). Since spoke lengths get shorter when crosses get fewer and shorter lengths are more rare, using 2X, 1X, or radial patterns often means not getting your choice of spoke gauges in order to build the lesser-cross wheel. To build a radial-spoked wheel with 14g spokes would be heavier and have more aerodynamic drag than to build the same wheel 3X with butted-1.8mm spokes.

The weight loss of radial spoking compared to 3X is 4%, or as little as 7 grams per wheel. One- and two-cross patterns are an even lesser weight savings compared to 3X. Aerodynamic resistance is not a factor, because, at the top of the wheel where the spokes are moving the fastest in relation to the air mass, changing the cross pattern does not change the face the spokes present to the air. Radial spoking (and to a lesser degree 1X and 2X) does put stresses on the hub flange in directions that they are not designed to withstand, and may lead to sudden, complete wheel failure.

Radial spoking, 1X, or 2X have inadequate torsional stiffness to support the wheel under high hub torque loads from pedaling (rear wheels) or hub-mounted brakes (such as disc brakes on either wheel). For this reason, radial spoking should not be used on any rear hub, or any front hub with a disc brake.

Traditionally, radial spoking is thought to increase the radial and lateral stiffness of the wheel. These characteristics have not been proven through testing. Radial spoking does reduce the torsional stiffness of the wheel (proven), and for this reason should not be used on rear wheels, even if just on the left flange (which does do part of the job of transferring torque to the rim from the hub).

Five-cross pattern

If 4X is better than 3X (debatable) then 5X is even better, right? No. Even if 4X were better, it would be better because it achieves an ideal 90° relationship between the spoke and the radius of the hub. The 5X pattern deviates just as much above the ideal of 90° as the 3X pattern deviates below. Furthermore, the 5X pattern causes the spokes to interfere with each other in a way that cause them to become kinked or bent.

Mixing cross patterns

Mixing cross patterns on rear wheels is sometimes suggested as a way to save weight or improve aerodynamics. A typical mix might be 3X on the right side and radial on the left. The weight savings by using radial on the left would typically be about 3 grams. The aerodynamic savings would be none.

Another reason given for mixing cross patterns on the two sides of a rear wheel is to minimize the tension difference between left and right-side spokes. Think of a wheel like a tug-of-war game in which the objective is to *keep* the flag on the middle of the rope over the center line. The rim is the flag on the rope. The spokes on each flange are like the two tug-of-war teams. The balance of tension on each side of the flag *must never change* if the flag (rim) is to stay centered. The positions of each member of the team on one side of the rope can be rearranged countless ways, but it will not change the net force they must pull with to keep the flag centered. Pretty much the only way to change the average amount of force required from each team member is to change the number of team members (number of spokes).

When cross patterns are mixed on a rear wheel, the only real difference between cross patterns becomes more significant. That difference is torsional stiffness. If the right-side spokes are a higher cross pattern than the left-side spokes, then the right side will have greater torsional stiffness. This means that load on the right-side spokes will start the rim moving before the left-side of the hub will have wound up enough to generate torsional load to the rim. In other words, on a mixed-cross wheel, only the spokes on the side with the higher cross pattern will do the work of transmitting load from the hub to the rim. Because there are no significant advantages, and because fewer spokes will be supporting the torsional load, mixing cross patterns is not recommended.

Pulling spokes heads-in or heads-out

The argument has been made that pulling spokes should be installed with the heads on the inside of the flange because the spoke is better supported when installed in this fashion. Research has shown that pulling spokes (counterclockwise radiating, viewed from the bike's right side) are no more inclined to fail from fatigue than the pushing spokes. This negates the argument; furthermore, the argument is based on the assumption that the spoke touching the flange after it leaves the spoke hole somehow gives the spoke more support. Since the primary loads in the spoke are in the shear direction, there is no way that this additional contact could provide more support.

The other argument about which way the pulling-spoke heads should face has to do with what will happen when the chain over-shifts the innermost cog and goes into the spokes. When the pulling-spoke heads are inside the flange, then the chain has a greater tendency to jam in the spokes *if pedaling pressure is maintained on the chain*; in this case, the pulling spokes act like guides that catch the chain and force it closer to the center of the wheel. What is often overlooked is that when the pulling-spoke heads are outside the flange, then the chain has a greater tendency to jam in the spokes *if the rider resists the continued rotation of the chain by keeping the cranks stationary after the over-shift occurs*; in this case, the non-pulling spokes act like guides that catch the chain and force it closer to the center of the wheel. It is impossible to predict what the rider's behavior will be in this situation, so there is no real value to build one way instead of the other.

The procedure in this chapter creates a wheel that has the pulling spokes in the flanges with the heads facing out. Because no real difference exists, there are not detailed instructions on how to build a wheel the opposite way. The least confusing way to get the opposite result is to put each set of spokes into the opposite face of the flange than the instructions indicate.

Conclusion

Stick with 3X and 4X patterns for all types of wheels except those smaller than 20".

TYING AND SOLDERING SPOKES

Tying and soldering is a technique used to restrain the spokes in case they should break. Although it has been credited with increasing the strength and stiffness of the wheel, this has been scientifically disproved. Any process that alters the metallurgy of the spoke by exposing it to high heat should be avoided.

DETERMINING SPOKE LENGTH

USING THIS SECTION

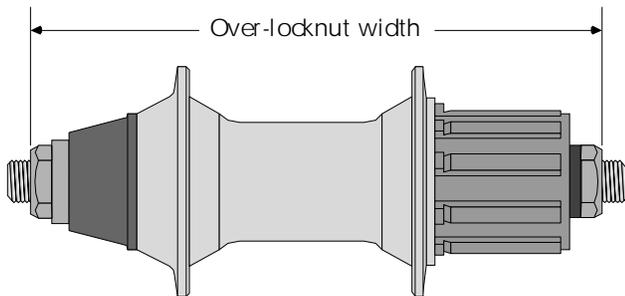
This section includes complete instructions for using *Spoke Calc* by BPP, *Wheelsmith Spoke Length Calculator*, and *Sutherland's Handbook for Bicycle Mechanics* (fifth and sixth editions). The process for several of these systems requires common measurements of the hub and rim. Before any specific system is covered, there are procedures described for making these common measurements.

In addition to complete instructions for these three systems, there are guidelines for using three computer programs. These programs are Blue Pig Wheel Calculator, PC Quick Spoke, and SpokeMaster for Windows.

COMMON HUB MEASUREMENTS AND FACTORS

Over-locknut width

As seen in the illustration below, over-locknut width is the distance from the face of one locknut to the face of the other locknut. Some cartridge-bearing hubs do not use locknuts. In this case, measure to the surfaces that butt against the inside faces of the dropouts.

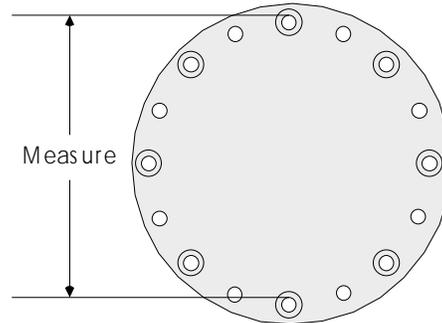


1. [] Measure Over-locknut width (_____ is O_w)

Hub-flange diameter

Hub-flange diameter is not actually a measurement of the flange diameter, but a measurement of the diameter of the circle that goes through the center of all the spoke holes in a flange. Depending on the length system being used, it will be called *hub-flange diameter*, *flange diameter*, *actual hub diameter*, *spoke-hole-*

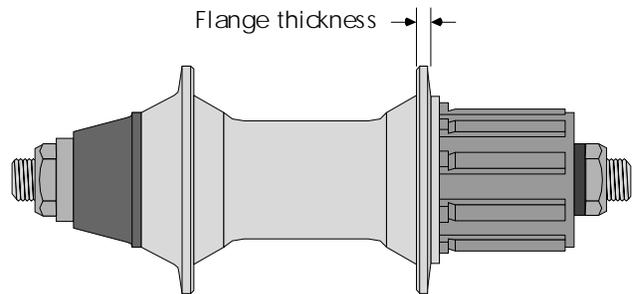
circle diameter, or *hole diameter*. It is easiest to measure from the inside edge of one hole to the outside edge of the opposite hole.



1. [] Measure Hub-Flange diameter to nearest millimeter. (_____ is HF_D)

Center-to-flange dimension

The center-to-flange dimension is the distance from the center of a flange to the centerpoint between the two locknuts. It is easy to describe and easy to diagram, but not so easy to measure accurately because of the large offset between the edge of the flange and the face of the locknut. For this reason, a series of measurements and calculations are required.



1. [] Measure Flange thickness (_____ is F_T)
2. [] Record Over-locknut width (_____ is O_w)

Flange thickness and over-locknut width are used in the following formula:

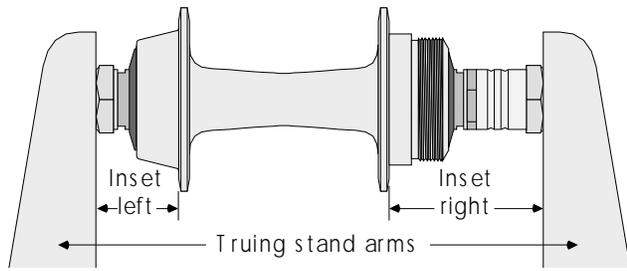
$$(O_w - F_T) \div 2 = C_{WF}$$

In the following steps, formulas are not written in their correct mathematical form, but as a series of calculator entries. In the blanks under each letter code, fill in the correct measurements. Then enter the values and calculator function keys as indicated, to get the result.

3. [] Center-width factor of hub (C_{WF}) Calculator entries (round result to whole millimeter):

$$O_w \quad F_T$$

$$\text{_____} \text{ [-] } \text{_____} \text{ [\div] } 2 \text{ [=] } (\text{_____} \text{ is } C_{WF})$$



4. [] Measure Inset left (_____ is I_L)
5. [] Measure Inset right (skip for front hub):
(_____ is I_R)

The formula for calculating the center-to-flange (left) dimension is: $C_{WF} - I_L = CF_L$. The following step shows the calculator entries, not the mathematical formula.

6. [] Center-to-Flange left (CF_L) Calculator entries (round result to whole millimeter):

$$C_{WF} \quad I_L$$

$$\text{_____} - \text{_____} = \text{_____} \text{ (_____ is } CF_L \text{)}$$

The formula for calculating the center-to-flange (right) dimension is: $C_{WF} - I_R = CF_R$. The following step shows the calculator entries, not the mathematical formula.

7. [] Center-to-Flange right (CF_R) Calculator entries (skip for front hub):

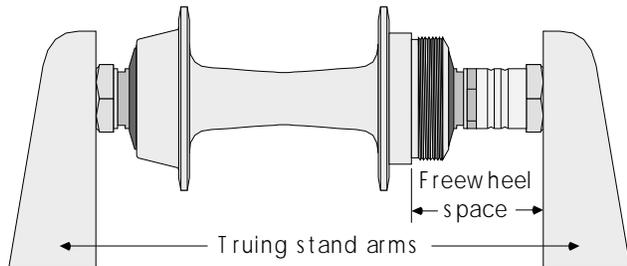
$$C_{WF} \quad I_R$$

$$\text{_____} - \text{_____} = \text{_____} \text{ (_____ is } CF_R \text{)}$$

Freewheel/freehub space

NOTE: Step 1 is for conventional hubs that a freewheel threads on to.

1. [] Measure freewheel space (freewheel shoulder to locknut face): _____ mm



16.10 Measuring freewheel space with the hub in a truing stand.

NOTE: Step 2 is for freehubs only.

2. [] Count and record the number of cogs that fit on the freehub and record here:
Number of cogs on freehub is: _____.

Rear-wheel-spoke-length differential factor

Many spoke-length-calculation systems create different lengths for the left and right sides of the rear hub by repeating all the calculations separately for both sides. Others may use a simplified mathematical calculation that determines the difference between the left and right sides. Most systems create an acceptable (but less than ideal) difference, because they rely on a simple geometrical model for determining the length differential; the simple geometrical model does not account for additional stretch that occurs on the tighter right-side spokes. The numbers in the table 16-2 are based on experience (not calculation), and should provide more consistently satisfactory length differentials than differentials that are determined by geometric calculation.

The table 16-2 shows the correct length differential for most wheel types. By looking up the intersection of the over-locknut width and the freehub space (or number of freehub cogs), the correct differential is determined. This difference can be subtracted from the calculated left-side length to determine the correct right-side length, or it can be added to the calculated right-side length to determine the correct left-side length.

REAR-WHEEL-SPOKE-LENGTH DIFFERENTIAL FACTORS (table 16-2)

Freewheel space or # of freehub cogs	Over-locknut-width measurement in millimeters				
	90-119.5	119.6-124.5	124.6-128.5	128.6-131	131.1-136
none, or less than 29mm	0mm	N/A	N/A	N/A	N/A
29-34mm	N/A	1mm	0mm	N/A	N/A
35-38mm, or 6- or 7-speed freehub	N/A	N/A	2mm	1mm	0mm
8-speed freehub	N/A	N/A	N/A	2mm	1mm

1. [] Record over-locknut width: _____ mm.
2. [] Record freewheel space or number of freehub cogs: _____ cogs.
3. [] Look up in table 16-2 at intersection of over-locknut width and freewheel-space/no.-of-freehub-cogs value for rear-wheel-spoke-length differential factor and record here: _____ mm (rear-wheel-spoke-length differential)

COMMON RIM MEASUREMENTS

Rim size

Rim size is often marked directly on the rim. If not, one measurement needs to be taken and then the rim size can be looked up in table 19-1 (page 19-16) in the **TIRES AND TUBES** chapter.

1. [] Use tape measure to measure outside diameter of rim.
2. [] Look up outside diameter in *Approximate rim O.D. column of TIRE AND RIM SIZES table 19-1 (page 19-16) and record equivalent rim size from the Nominal size column here:*
 _____ rim size.

Making a rim-measurement tool

For most spoke-length systems, a dimension called *effective rim diameter* or *spoke end diameter* is required. To get this dimension, an accurate inside diameter of the rim is needed (except if using the Wheelsmith Spoke Length Calculator). To get the inside diameter dimension, a tool must be made. This will be called a *rim ruler*.

The tool is made by modifying two metal metric yardsticks (available at hardware stores). One of the yard sticks needs to be cut off once so that it goes from 0–350mm. The other needs to be cut twice, so that it goes from 350–700mm. Because material is lost when the ruler is cut, it is not possible to use one yardstick to get both pieces.

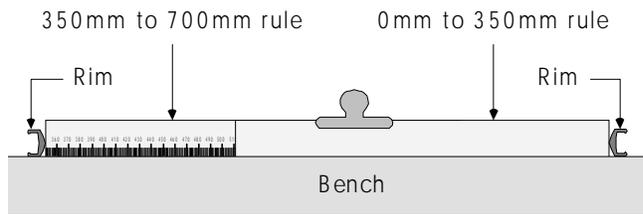
When cutting the piece that must start at 350mm, use a hacksaw to cut 1–2mm before the 350mm mark (between 348 and 349) and then use a file to carefully remove the excess to the midpoint in the thickness of the 350mm mark. Make sure that the end is square (perpendicular to the top and bottom edges of the ruler). If too much material is removed, it can be compensated for by leaving that much extra on the second piece. Cut the other end at 700mm. Precision is not important for this cut.

The second ruler must be cut so that its actual length ends up exactly equal to the starting dimension of the first ruler. If the first ruler ended up cut precisely at 350, then the second ruler needs to be 350mm long. If the first ruler ended up cut between the 350 and 351mm marks, then the second ruler needs to end up as close as possible to 350.5mm long. Make sure that all cut ends are square. *Remember, if the first piece ends up with too much cut off at the 350 millimeter mark, leave the second piece long by the amount of the error.*

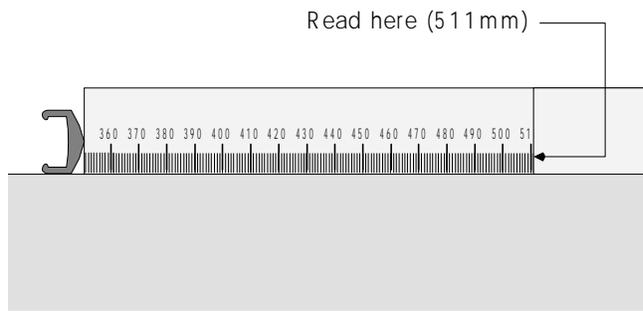
Rim diameter

Rim diameter is the diameter at the end of the spokes in the rim. It is not a measurement of the rim, but of the spokes. Other names for this are *spoke end diameter*, *actual rim diameter*, and *rim inner diameter*.

When measuring the rim, the rim should be lying on a flat surface. The rim rulers stand on their edges on the same surface, inside the rim, overlapping each other. Set the rulers up so that the 350–700mm ruler faces you with the 350mm mark on the left. The second piece will overlap in front and on the right, with the backside of the ruler facing you (no ruler markings visible). The left edge of the right piece is the point at which the reading is taken. If the end of the right piece is touching the 511mm mark, the reading is 511mm. If it clears the 511mm but does not expose the 512mm mark, then call it 511.5mm. Always read the ruler to the nearest half millimeter.



16.11 Setting up the rim rulers.



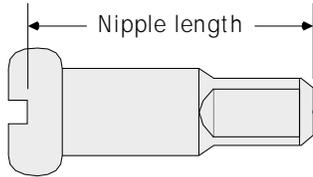
16.12 Reading the rim rulers.

To take readings, place one end of the rim-sizing rulers adjacent to the second hole past the valve hole, and the other end adjacent to the hole half the number of holes in the rim away from the second hole past the valve hole. Do not put the rulers against reinforcements of the nipple holes, but against the main body of the rim. For additional measurements, move each end of the rulers four-holes clockwise. Take four measurements and average, to account for imperfections in the rim.

1. [] Measure rim Inside Diameter at four equally-spaced points and record:

- (_____ = ID₁)
- (_____ = ID₂)
- (_____ = ID₃)
- (_____ = ID₄)

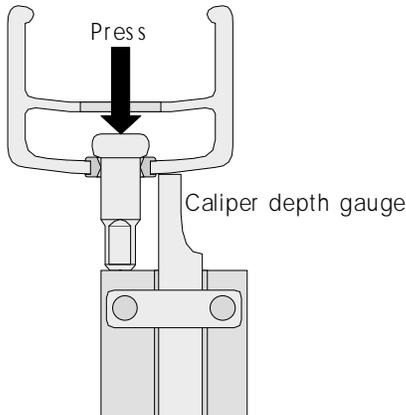
In the next step, measure the nipple length with a caliper. In this and all other steps involving caliper measurements (unless noted otherwise), read the caliper to the nearest tenth millimeter.



16.13 Measure the nipple length by putting one caliper jaw in the slot in the nipple head and the other against the other end of the nipple.

2. [] Measure and record Nipple length (N_L) from bottom of slot to tip of nipple: (_____ is N_L)

In the next step, insert the nipple in the rim, then measure the amount of nipple that protrudes from the rim. Use the depth gauge on the caliper to measure with, and make sure the nipple is held firmly in place while measuring.



16.14 Measure nipple drop by placing the butt of the caliper against a nipple and extending the depth gauge of the caliper until it meets the rim (not nipple hole eyelets).

3. [] Measure and record Nipple drop (N_D) from rim to nipple tip: (_____ is N_D)

The next step is a calculation. The step is written as a series of entries into a calculator, not as a mathematical equation. Treating it as a mathematical formula will result in error. Round all calculator results to the nearest whole millimeter. For this step the process is expressed twice. The first time shows the letter codes for the variable data that must be entered and symbols for the function keys that must be pressed in be-

tween each item of data. The second time (directly below), substitutes blanks that must be filled in; for example, in step #4 (in the blank below ID₁), fill in the value recorded for ID₁ in step #1. When all the blanks have been filled in, then enter the values and the key functions as shown. After pressing the equals key, round the answer to the nearest whole and enter this in the last blank.

Step #4 calculates something called *rim diameter*. It is not actually a measurement of the rim but of the diameter at the bottom of the slots in the nipple heads when all the nipples are in the rim. This is the point that the spoke should stop, so this calculation determines the *spoke end diameter*. By adding in the nipple length and subtracting the nipple drop, the actual distance from the inner perimeter of the rim to the bottom of the slot in the nipple head is calculated. This distance must be added at both ends of the rim inside diameter, so that is why length and drop are included twice in the calculator entries.

4. [] Rim diameter (R_D) Calculator entries (round result to whole millimeter):

ID ₁	ID ₂	ID ₃	ID ₄
_____	_____	_____	_____
[+]	[+]	[+]	
	N _L	N _L	N _D
[÷] 4	[+]	[+]	[−]
	N _D		
[−]	[=]	(_____ is R _D)	

If not using a calculator, the formula for this calculation is:
 $((ID_1 + ID_2 + ID_3 + ID_4) \div 4) + 2(N_L - N_D) = R_D$

SPOKE-CALC BY DT

The Spoke-Calc system is a wall poster that has graphics on which the hub and rim are placed to determine dimensions, and tables in which numbers are looked up based on the dimensions. The table contain good data, but experimentation has shown that the method for determining rim dimensions is too subjective, with different people getting results varying by up to 4mm for the same rim.

The following information needs to be measured and looked up to use Spoke-Calc:

- Over-locknut width
- Hub-Flange diameter
- Center-to-flange dimension (left side)
- Freewheel/freehub space (rear wheels only)
- Rear-wheel-spoke-length differential

16 – WHEEL BUILDING AND RIM REPLACEMENT

Rim diameter

Differential-length factor

The following instructions use Spoke-Calc for data, but rely on the hub and rim measurement systems detailed earlier in this chapter. The data in the portions of the Spoke-Calc tables that are represented here has been altered because the tables are provided only as an illustration of how the system works. *Do not use the data in these partial tables to determine spoke length!*

Determine Table A factor

NOTE: All tables in following procedure are small simulated portions of SPOKE-CALC TABLE A from SPOKE-CALC by BPP and DT.

Steps #1, #2, and #4 require information that is common to many spoke-length-calculation systems. The instructions for measuring and calculating these pieces of information are earlier in this chapter under the headings **COMMON HUB MEASUREMENTS AND FACTORS** and **COMMON RIM MEASUREMENTS**.

1. [] Calculate Hub Center-To-Flange Dimension for left flange and record here: _____ mm.
2. [] Calculate Rim Diameter and record result here: _____ mm.

The following table is a simulated segment of Table A on the Spoke-Calc poster. The information is deliberately altered and cannot be used. It is provided to help recognize which table to use.

SPOKE-CALC TABLE A (segment)

		HUB CENTER-TO-FLANGE DIMENSION									
		18	19	20	21	22	23	24	25	26	
R	535	269	269	269	269	269	269	270	270	270	535
I	536	270	270	270	270	270	270	270	270	270	536
M	537	270	270	270	270	270	270	271	271	271	537
	538	271	271	271	271	271	271	271	271	271	538
D	539	271	271	271	271	271	271	272	272	272	539
I	540	272	272	272	272	272	272	272	272	272	540
A	541	272	272	272	272	272	272	273	273	273	541
M	542	273	273	273	273	273	273	273	273	273	542
E	543	273	273	273	273	273	273	274	274	274	543
T	544	274	274	274	274	274	274	274	274	274	544
E	545	274	274	274	274	274	274	275	275	275	545
R	546	275	275	275	275	275	275	275	275	275	546

3. [] Table A factor (TA_F). Look up in Table A for intersection of:
Rim diameter (R_D) row and
Center-to-Flange dimension (CF_L) column:
(_____ is TA_F)

Determine Table B factor

4. [] Measure and record Hub-flange Diameter here: _____ mm.
5. [] Count number of holes in one flange, double, and record here:
(_____ is holes in hub)

In the next step, a lacing pattern must be chosen. Discussion of the merits of different lacing patterns occurs earlier in this chapter under the heading **SPOKING PATTERNS**.

6. [] Decide on lacing (cross) pattern and enter here: (_____ is lacing pattern)

NOTE: SPOKE-CALC TABLE B has factors for combinations of lacing patterns and numbers of holes in the hub that can't be built (because spokes would interfere with each other). The most common of these unbuildable combinations are 4-cross lacing on hubs with 32 or fewer holes, and 3-cross lacing on hubs with 24 or fewer holes. A small portion of SPOKE-CALC TABLE B from SPOKE-CALC by BPP and DT has been reproduced here.

SPOKE-CALC TABLE B (segment)

		HUB DRILLING AND LACING PATTERN									
		32 HOLE HUBS					36 HOLE HUBS				
		0	1x	2x	3x	4x	0	1x	2x	3x	
H	41	21	19	14	8	1	21	20	16	11	
U	42	21	19	15	8	1	21	20	16	11	
B	43	22	20	15	8	1	22	20	17	11	
	44	22	20	15	8	1	22	21	17	11	
F	45	23	21	16	8	1	23	21	17	11	
L	46	23	21	16	9	1	23	22	18	12	
A	47	24	21	16	9	1	24	22	18	12	
N	48	24	22	17	9	0	24	23	19	12	
G	49	25	22	17	9	0	25	23	19	12	
E	50	25	23	17	9	0	25	24	19	13	
	51	26	23	18	9	0	26	24	19	13	
D	52	26	24	18	9	0	26	25	20	13	
I	53	26	24	18	10	0	27	25	20	13	
A	54	27	25	19	10	0	27	26	20	13	
M	55	27	25	19	10	0	28	26	21	14	
E	56	28	26	19	10	0	28	27	21	14	
T	57	28	26	20	10	0	29	27	21	14	
E	58	29	26	20	10	0	29	27	22	14	
R	59	29	27	20	11	+1	30	28	22	15	
		0	1x	2x	3x	4x	0	1x	2x	3x	

7. [] Table B factor (TB_F). Look up in correct # Hole Hubs column of Table B for intersection of:
HF_D row and Lacing Pattern column
(_____ is TB_F)

Determine Base-Spoke length

In step #8 Base-Spoke length is calculated. Correct front length, correct right-rear length, correct left-rear length, and correct non-differential rear length are all based on Base-Spoke length.

8. [] Base-Spoke length Calculator entries (round result to whole millimeter):

TA_F TB_F
 _____ _____ _____ is BS_L.

Front-wheel-spoke length**NOTE: Skip to step 10 or 14 for rear wheels.**9. [] Front spoke length equals BS_L .

FRONT spoke length is: _____mm

Rear-wheel differential-spoke lengths

The dish of a typical rear wheel creates a situation where the distance from the left flange to the rim is greater than the distance from the right flange to the rim. Therefore, different spoke lengths should be used to ensure equal thread engagement on all the nipples and to reduce the likelihood of spokes protruding through nipples or leaving thread exposed at the top of the nipples.

There are drawbacks to using two spoke lengths. When two sizes are needed, it is more likely that at least one is out of stock. When lacing the wheel, it complicates things to work with two lengths and make sure that they do not get mixed up.

10. [] Record BS_L here: _____mm

11. [] Record Differential Factor here: – _____mm

12. [] REAR RIGHT length is: = _____mm

13. [] Rear left length is same as BS_L (step 8)
REAR LEFT length is: _____mm***Rear-wheel non-differential-spoke lengths***

Non-differential rear length is a compromise. It usually means that the right-side spokes will be a little longer than ideal, and the left-side spokes will be a little shorter than ideal. This sometimes results in a little thread showing at the left-side nipples. Non-differential-spoke length is particularly useful when the correct lengths for differential spoking are not available. It is also useful for beginners because there is no complication of keeping track of different spokes for the right and left sides while lacing the wheel.

When using one spoke length, it is almost never acceptable to just use the Base-Spoke length for both sides. This will usually result in right-side spokes protruding all the way through the nipples. It is also unacceptable to just use the right-side length for both sides in many cases. If the correct right-side length were to be used on the left side, then it is likely that the thread engagement to the nipples would be compromised too much.

NOTE: Next step is optional and is only used for rear wheels, when needing (or preferring) to build with one spoke length.

14. [] Record BS_L (step 8) here: _____mm
– 1mm

NON-DIFFERENTIAL REAR = _____mm

WHEELSMITH SPOKE LENGTH CALCULATOR

In addition to the calculator and rim measuring rods that come with the system, a metric caliper is needed. Common measurements and factors needed (from the earlier section of this chapter **COMMON HUB MEASUREMENTS AND FACTORS** and **COMMON RIM DIMENSIONS**) include:

Over-locknut width

Hub-flange diameter

Center-to-Flange dimension (left side only for rear wheels)

Freewheel/Freehub space (rear wheels only)

Rear-wheel-spoke-length differential factor (rear wheels only)

Rim diameter

Differential-length factor

The following instructions assume that the WheelSmith System, with the HP 332SII, is being used.

Preliminary measurements and calculations

1. [] Record Rim Diameter here: _____mm.
2. [] Record Hub-flange diameter here: _____mm.
3. [] Calculate and record left-side Center-to-Flange dimension here: _____mm.
4. [] Count number of holes in hub and record here: _____spokes.
5. [] Decide on a cross pattern and record cross pattern number here: _____X.
6. [] For rear wheels only look up *Rear-wheel-spoke-length differential factor* and record here: _____mm.

WheelSmith calculator entries

NOTE: "C" restarts calculation, key with back-space arrow clears entry.

7. [] Press ON key (marked "C") to turn calculator on.
8. [] Press XEQ key.
9. [] Press 9 key. R? appears.
10. [] Enter Rim Diameter on keypad and press R/S key. F? appears.
11. [] Enter Hub-flange diameter on keypad and press R/S key. C? appears.
12. [] Enter Center-to-Flange dimension on keypad and press R/S key. N? appears.
13. [] Enter number of holes in hub on keypad and press R/S key. X? appears.
14. [] Enter cross pattern number on keypad and press R/S key.
15. [] Round value on display screen to nearest whole number and record here:
Base-spoke length (BS_L) equals _____mm.

Front-wheel-spoke length

NOTE: Skip to step 17 or 21 for rear wheels.

16. [] Front spoke length equals BS_L .

FRONT spoke length is: _____mm

Rear-wheel differential-spoke lengths

The dish of a typical rear wheel creates a situation where the distance from the left flange to the rim is greater than the distance from the right flange to the rim; therefore, different spoke lengths should be used to ensure equal thread engagement on all nipples, and to reduce the likelihood of spokes protruding through nipples or leaving thread exposed at the top of the nipples.

There are drawbacks to using two spoke lengths. When two sizes are needed, it is more likely that at least one is out of stock. When lacing the wheel, it complicates things to work with two lengths while making sure that they do not get mixed up.

17. [] Record BS_L (step 16) here: _____mm

18. [] Enter Differential Factor here: - _____mm

19. [] REAR RIGHT length is: = _____mm

20. [] Rear left length is same as BS_L (step 16).

REAR LEFT length is: _____mm

Rear-wheel non-differential-spoke lengths

Non-differential rear length is a compromise. It usually means that the right-side spokes will be a little longer than ideal, and the left-side spokes will be a little shorter than ideal. This sometimes results in a little thread showing at the left-side nipples. Non-differential-spoke length is particularly useful when the correct lengths for differential spoking are not available. It is also useful for beginners because there is no complication of keeping track of different spokes for the right and left sides.

When using one spoke length, it is almost never acceptable to just use the Base-Spoke length for both sides. This will usually result in right-side spokes protruding all the way through the nipples. It is also unacceptable to just use the right-side length for both sides in many cases. If the correct right-side length were to be used on the left side, then it is likely that the thread engagement to the nipples would be compromised too much.

NOTE: Next step is optional and is only used for rear wheels, when needing (or preferring) to build with one spoke length.

21. [] Record BS_L (step 15) here: _____mm

- 1mm

NON-DIFFERENTIAL REAR = _____mm

SUTHERLAND'S HANDBOOK FOR BICYCLE MECHANICS

The following instructions can be used for determining spoke length using either the fifth or sixth edition of *Sutherland's*. Note that although the procedures are the same, tables occur on different page numbers for each edition. When the instructions refer to *Sutherland's*, there is a fifth edition page number, then a sixth edition page number.

Several of the first steps require information that is determined by procedures in the earlier sections in this chapter **COMMON HUB MEASUREMENTS AND FACTORS** and **COMMON RIM MEASUREMENTS**.

Determine hub-diameter category

1. [] Determine Hub-flange diameter and record here: _____mm.

Sutherland's groups similarly-sized hub flanges into groups called hub-diameter categories. The following procedure recommends measuring the Hub-flange diameter (previous step) and from that determining the category.

If the hub is not on hand, it may be possible to determine the hub-diameter category by looking up the brand and model in *Sutherland's* (fifth edition 11–5 through 11–13, or sixth edition 11–2 through 11–35). Look in the lists below each category heading for the make/model that corresponds to the hub in question to determine the category into which it fits.

HUB-FLANGE-DIAMETER CATEGORIES

(table 16-3)

Spoke-hole-circle-diameter range	Hub-diameter category
30–32mm	31mm
33–36mm	34mm
37–42mm	40mm
43–46mm	44.5mm
47–52mm	48mm
53–60mm	58mm
61–64mm	63mm
65–69mm	67mm
80–90mm	90mm
102.5–112mm	102.5mm

2. [] Determine hub-diameter category by finding range in table 16-3 that includes result from step 1, then look up corresponding Hub-diameter category. Hub-diameter category is: _____mm

Determine theoretical spoke length

In the next step, the rim size must be determined. Usually, this can be done by looking on the rim for size markings (such as 26 × 1.75). In the absence of markings, the outside diameter of the rim should be measured and the rim size looked up in the **TIRE AND RIM SIZES** table 19-1 in **TIRES AND TUBES** (page 19-16).

3. [] Record rim size here: _____.
4. [] Count number of spoke holes in hub and rim, make sure they match, and record here: _____ Number of spokes.
5. [] Decide on a cross pattern and record cross pattern number here: _____ X
6. [] Turn to correct *Sutherland's* page for rim size determined in step 3 according to table 16-4:

LOCATIONS OF SUTHERLAND'S THEORETICAL SPOKE-LENGTH TABLES

(table 16-4)

Rimsize	fifthedition	sixthedition
27" & 28" rims	11-15	11-39
700C rims	11-15	11-47
26" MIB rims	11-31	11-63
26" (other), 700D, & 650 rims	11-31	11-73
24", 22", 600 & 550 rims	11-41	11-83
20" & 500 rims	11-51	11-93
18" & 17" rims	11-58	11-99
16" & 400 rims	11-60	11-101
14" rims	11-62	11-104
12" rims	11-64	11-106
10" rims	11-65	11-107

7. [] On page determined in step 6, find table for hub-diameter category determined in step 2.
8. [] Look at intersection of *cross pattern column* and *number of spokes row* to find theoretical spoke length and record here: _____ mm.

Looking up rim-correction factors

NOTE: If exact brand and model of rim are not found in step 11, it will be necessary to measure the rim and calculate rim-correction factor starting at step 12.

9. [] Find correct *Sutherland's* correction-factor table. Use table 16-5 to find correct page.

LOCATIONS OF SUTHERLAND'S RIM-CORRECTION-FACTOR TABLES

(table 16-5)

Rimsize	5thedition	6thedition
28 × 1-1/2	11-16	11-40
27 × 1-1/4, 27 × 1-1/8, 27 × 1	11-16 thru 11-19	11-40 thru 11-44
700C, 28 × 1-5/8 × 1-3/8	11-20 thru 11-25	11-48 thru 11-55
700C sew-ups (Tubulars)	11-26 thru 11-29	11-56 thru 11-60
26 × 1-1/4 EA1	11-32	11-74
26 × 1-3/8 EA3 and 650A	11-33	11-75 thru 11-76
650B and 26 × 1-1/2	11-34	11-76
700D	11-34	11-76
26 × 1-3/4 and 650C	11-34	11-77
26 × 1.5, 26 × 1.75, 26 × 2.125	11-35 thru 11-38	11-64 thru 11-70
26 and 650 SEW-UPS (TUBULARS)	11-39	11-78 thru 11-79
24 × 1-1/4	11-42	11-84 thru 11-85
24 × 1.25 and 24 × 1.375	11-43	11-84
600A	11-43	11-85
24 × 1-3/8	11-44	11-86
24 × 1-3/4	11-45	11-86
24 × 1-1/8	none	11-87
24 × 1.5, 24 × 1.75, 24 × 2.125	11-46 thru 11-47	11-87 thru 11-88
22 × 1-3/8	11-48	11-90
550A	11-48	11-91
22 × 1.5, 22 × 1.75, 22 × 2.125	11-48	11-91
25", 24", 22", 600 SEW-UPS	11-49	11-89 thru 11-90
20 × 1-3/8, 20 × 1-1/4 20 × 1-1/8	11-52 thru 11-53	11-94 thru 11-95
500A	11-53	11-95
20 × 1.5, 20 × 1.75, 20 × 2.125	11-54 thru 11-55	11-96 thru 11-98
20 × 1-3/4	11-55	11-96
20 × 2 and 20" sew-ups	11-56	11-98
18" and 17"	11-59	11-100
16" and 400	11-61	11-102
14"	11-63	11-105
12"	11-64	11-106
10"	11-65	11-107

10. [] Starting on page determined in step 9, located rim brand.
11. [] Under rim brand, locate exact rim model and record corresponding correction factor here. Rim-correction factor is: _____ mm (Skip this step and proceed to step 12 if exact model was not found in table.)

Calculating rim correction factors

NOTE: Steps 12–17 should be skipped if correction factor was found in tables using step 11.

12. [] Determine Sutherland’s constant from following table based on rim size determined in step 3 and record constant here: _____.

SUTHERLAND’S RIM CONSTANTS

(table 16-6)

Rim size	Sutherland’s rim constant
28", 27", 700C, & 700C tubulars	315
26"	300
24"	270
20"	225
18"	200
16"	175
14"	150
12"	125
10"	100

13. [] Measure and calculate Rim Diameter by method described in COMMON RIM MEASUREMENTS section of this chapter and record Rim Diameter here: _____ mm

14. [] Divide by 2 ÷ 2

15. [] Rim radius equals: = _____ mm

16. [] Subtract Sutherland’s constant: – _____ mm

17. [] Rim-correction factor is: = _____ mm

Determine Base-Spoke length

18. [] Record theoretical spoke length from step 8 here: _____ mm

19. [] Correction factor from step 11 or step 17 + _____ mm

20. [] Base-Spoke length (BS_L) is: = _____ mm

NOTE: When adding a negative number (the rim-correction factor), simply subtract it as though it were a positive number.

Front-wheel-spoke length

NOTE: Skip to step 22 or 25 for rear wheels.

21. [] Front spoke length equals BS_L.
FRONT spoke length is: _____ mm

Rear-wheel differential-spoke lengths

The dish of a typical rear wheel creates a situation where the distance from the left flange to the rim is greater than the distance from the right flange to the rim; therefore, different spoke lengths should be used to ensure equal thread engagement on all the nipples and to reduce the likelihood of spokes protruding through nipples or leaving thread exposed at the top of the nipples.

There are drawbacks to using two spoke lengths. When two sizes are needed, it is more likely that at least one is out of stock. When lacing the wheel, it complicates things to work with two lengths, and make sure that they do not get mixed up.

22. [] Record BS_L (step 20) here: _____ mm

23. [] Enter Differential Factor here: – _____ mm

24. [] REAR RIGHT length is: = _____ mm

25. [] Rear left length is same as BS_L (step 20).

REAR LEFT length is: _____ mm

Rear-wheel non-differential-spoke lengths

Non-differential rear length is a compromise. It usually means that the right-side spokes will be a little longer than ideal, and the left-side spokes will be a little shorter than ideal. This sometimes results in a little thread showing at the left-side nipples. Non-differential-spoke length is particularly useful when the correct lengths for differential spoking are not available. It is also useful for beginners because there is no complication of keeping track of different spokes for the right and left sides.

When using one spoke length, it is almost never acceptable to just use the Base-Spoke length for both sides. This will usually result in right-side spokes protruding all the way through the nipples. It is also unacceptable to just use the right-side length for both sides in many cases. If the correct right-side length were to be used on the left side, then it is likely that the thread engagement to the nipples would be compromised too much.

NOTE: Next step is optional and is only used for rear wheels, when needing (or preferring) to build with one spoke length.

26. [] Record BS_L (step 16) here: _____ mm
– 1mm

NON-DIFFERENTIAL REAR = _____ mm

BLUE PIG WHEEL CALCULATOR

Blue Pig Wheel Calculator is a DOS program for IBM-compatible computers. Use the operator’s manual to learn how to use the program. For unlisted hubs or rims, the program will require input on several hub and rim measurements that are the same as some of the common hub and rim measurements described earlier in this chapter.

Blue Pig references to “Actual Rim Diameter” or “Average Rim Diameter” are the same as Rim Diameter as described in this chapter (page 16-16).

Blue Pig references to “Hub Diameter” or “Actual Hub Diameter” are the same as Hub-flange Diameter as described in this chapter (page 16-14).

To get the value Blue Pig calls “Dish,” subtract the left flange inset from the right flange inset and divide by 2.

Blue Pig references to “Lock nut- Lock nut” are the same as Over-locknut width as described in this chapter (page 16-14).

SPOKEMASTER FOR WINDOWS

SpokeMaster for Windows is a Windows-based program for IBM-compatible computers equipped with the Windows operating system. Hubs and rims may be selected from lists, or new hubs and rims can be added to the lists.

When entering a new rim, a dimension must be listed in an empty box underneath the label “inner (mm).” Use Rim Diameter as described earlier in this chapter. An empty box labeled “outer(mm)” should also be filled in with the approximate outside diameter of the rim. Although this second number is not used for calculating anything, the program will not continue the process without some value in this box that is larger than “inner (mm).”

When entering a new hub, a dialog box appears with four unlabeled empty entry boxes. The upper left one is the left-side Center-to-Flange dimension. The upper right one is the right-side Center-to-Flange dimension. The lower left one is the left Hub-flange Diameter. The lower right one is the right Hub-flange Diameter. All of these dimensions are described in the section of this chapter **COMMON HUB DIMENSIONS AND FACTORS** (page 16-14).

Although the program forces the user to calculate both sides of a rear hub, only the left-side information should be used; the right-side length information is based on a faulty geometry-only approach that fails to take spoke stretch into account. Use this chapter’s *rear-hub differential-length factor* to determine how much shorter the right side should be than the left.

LACING WHEELS

NOTE: If building a new wheel from scratch, start with step 1.

PREPARING AN EXISTING WHEEL FOR REBUILD

If re-using an old rim, there is a chance that rim damage will be discovered *after* it has been laced and partially trued. If reusing an existing rim, it is important to loosen all the spokes before cutting them out. Cutting spokes under full tension can damage the rim.

A common beginner mistake with disastrous consequences is to cut out or unthread the spokes on a rear hub *before* removing the freewheel. Since normal freewheel removal requires the presence of the rim, this will mean either sacrificing the hub or the freewheel. Once the rim has been removed, there is no guaranteed way to save and reuse both the hub and freewheel.

0a. [] Remove wheel from bike.

0b. [] Remove tire, tube, and rim strip.

0c. [] Remove thread-on freewheel or freehub cogset, if any.

0d. [] If saving rim, loosen all spokes until slack.

0e. [] Cut out all spokes.

PREPARING THE RIM AND HUB

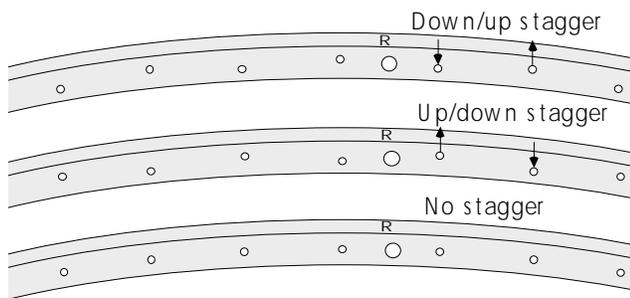
The steps in this group are the most critical to the entire process. All thinking and decisions that need to be made are made here. If these steps are done correctly, the rest of wheel lacing is little more than connect-the-dots. The general concept here is to prepare the rim by giving every spoke hole in the rim a unique name. These names will be based on names that will be given to each spoke. Like names for people, each of these names will have two parts, indicating the family the spoke belongs to and the name for the individual as well. In the case of wheels, there are always four families. The spokes are divided into two obvious groups, the left side and right side of the wheel. Look at a wheel from either side. See that on each side of the wheel there is a set of spokes that radiate out from the hub in a clockwise direction and a set of spokes that radiate counterclockwise from the hub.

Two sides with two directions on each side creates four families of spokes. The family names are A, B, C, and D. In a 36-spoke wheel there are nine spokes in each set, so each family of spokes (and corresponding holes) will be numbered A1–A9, B1–B9, C1–C9, and D1–D9. When building the wheel, the process will alternate from right side to left side, so the A and C spokes will be on the right side of the wheel and the B and D spokes will be on the left side. Once this system of marking the rim has become familiar, it will suffice to simply mark the first spoke hole for each family.

- 1. [] Lay rim on a surface, rotate in order to look directly at valve hole in inner face of rim, and observe that spoke holes are staggered so that every other hole is up and every other hole is down. There are some cases when there is no obvious stagger.**

16 – WHEEL BUILDING AND RIM REPLACEMENT

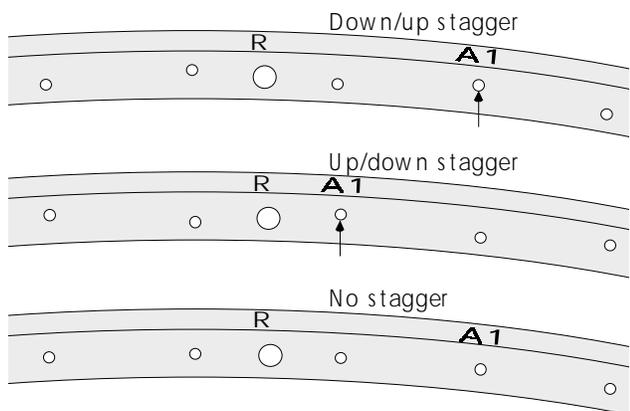
2. [] Put an “R” at valve hole on side of rim facing up with marker or tape to indicate right side of rim.



16.15 Mark an “R” on the rim at the valve hole. Note that on some rims the spoke holes are staggered so that when the rim is on its side the holes alternate up and down, on other rims the spoke holes are staggered the opposite, and that on some rims there is no spoke-hole stagger.

In the next step, the first up-hole to the right of the valve hole is marked A1. Rims are drilled three different ways (going right/clockwise from the valve hole): spoke holes staggered down/up, spoke holes staggered up/down, and without any stagger to the spoke holes. On most rims, the first up-hole clockwise from the valve hole is the second hole. On a few models, the first up-hole is also the first hole clockwise from the valve hole. With the rare rims that have no stagger to the spoke holes, the remainder of the procedure will be easier to follow if you pretend that such a rim is a staggered-hole rim of the more common variety (first up-hole is the second hole clockwise/right of the valve hole).

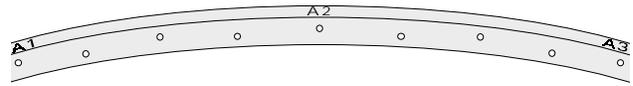
3. [] Mark first up-hole to right (clockwise) of valve hole to be A1. In cases where there is no obvious stagger, mark second hole clockwise of valve hole to be A1.



16.16 Mark the first up-hole to right of valve hole to be A1.

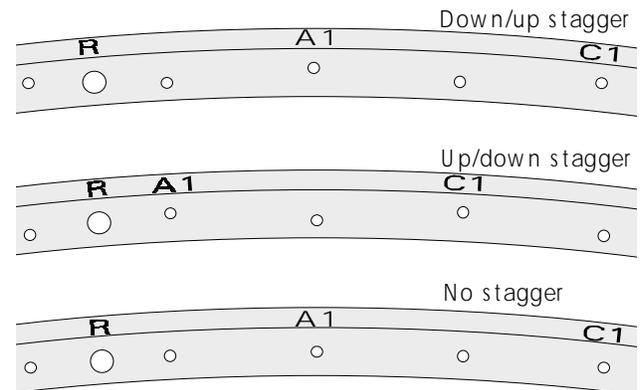
The following step #4 is useful the first few times a wheel is built, but after the lacing process becomes familiar, it is a good step to skip.

4. [] Continue clockwise around rim marking every fourth hole A2, A3, A4, etc., until back to A1. There should be three holes in-between each pair of “A” holes. The last mark should be A7 for 28-hole rims, A8 for 32-hole rims, A9 for 36-hole rims, etc.



16.17 Working to the right (clockwise) mark every fourth hole A2, A3, etc.

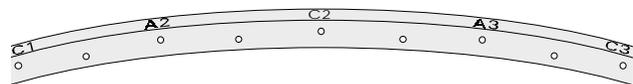
5. [] With right side of rim still up, mark hole that is two holes to right (clockwise) of A1 to be C1. This hole will always be halfway between A1 and A2.



16.18 Mark the first up-hole to right of A1 to be C1.

The following step #6 is useful the first few times a wheel is built, but after the lacing process becomes familiar, it is a good step to skip.

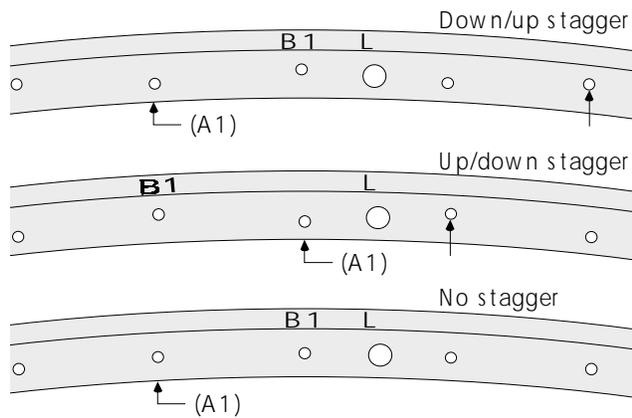
6. [] Continue clockwise around rim marking every fourth hole C2, C3, C4, etc., until back to C1. The last mark will be C7 for 28-hole rims, C8 for 32-hole rims, C9 for 36-hole rims, etc.



16.19 Starting four holes to the right (clockwise) from C1, mark every fourth hole C2, C3, C4, etc.

7. [] Turn rim over, rotate rim to look directly at valve hole in inner face of rim, and put an “L” at valve hole.

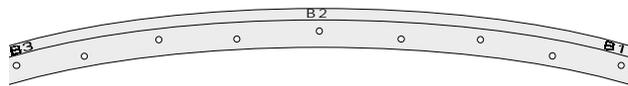
8. [] Mark first up-hole *counterclockwise* (left) of valve hole to be B1. In cases where there is no obvious stagger, mark *first* hole counterclockwise of valve hole to be B1.



16.20 Mark the first up-hole counterclockwise of the valve hole to be B1.

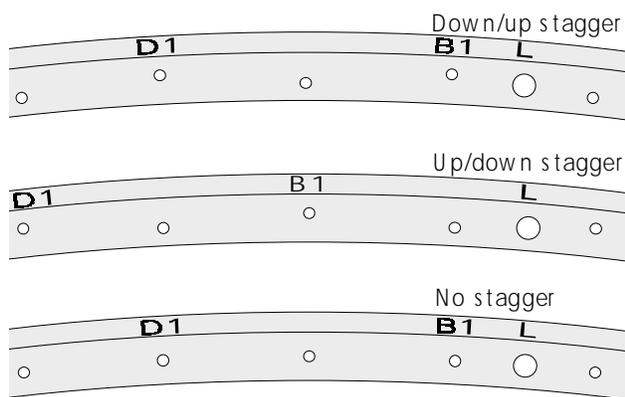
The following step #9 is useful the first few times a wheel is built, but after the lacing process becomes familiar, it is a good step to skip.

9. [] Continue *counterclockwise* (left) around rim marking every fourth hole from B1 to be B2, B3, B4, etc., until back to B1. The last mark will be B7 for 28-hole rims, B8 for 32-hole rims, B9 for 36-hole rims, etc.



16.21 Working to the left (counterclockwise) mark every fourth hole B2, B3, etc.

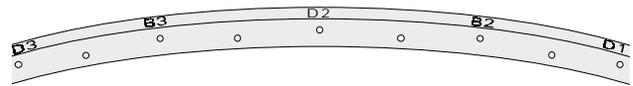
10. [] With left side of rim still up, mark second hole *counterclockwise* (left) of B1 to be D1. This hole will always be halfway between B1 and B2.



16.22 Mark the first up-hole to left of B1 to be D1.

The following step #11 is useful the first few times a wheel is built, but after the lacing process becomes familiar, it is a good step to skip.

11. [] Continue *counterclockwise* (left) around rim marking every fourth hole D2, D3, D4, etc., until back to D1. The last mark will be D7 for 28-hole rims, D8 for 32-hole rims, D9 for 36-hole rims, etc.



16.23 Starting four holes to the left (counterclockwise) from D1, mark every fourth hole D2, D3, D4, etc.

Steps #12 and #13 establish a starting hole in the right flange for spokes of the “A” set. On the rear hub, the freewheel-mounting threads or freehub body clearly distinguish the right side. There is no true right to a front hub, but it is necessary to create one in order to follow the lacing procedure. An easy way to do this is to wrap a rubber band around the axle set to mark the right side.

12. [] Front hubs only, mark one side of hub to indicate an arbitrary right side.

In the following step, any hole in the right flange may be marked. If alternating holes are countersunk, it is optional (but unnecessary) to select a hole that is not countersunk. The merits (or lack of them) to countersinking holes is discussed in the earlier section *Countersunk or chamfered spoke holes* (page 16-9).

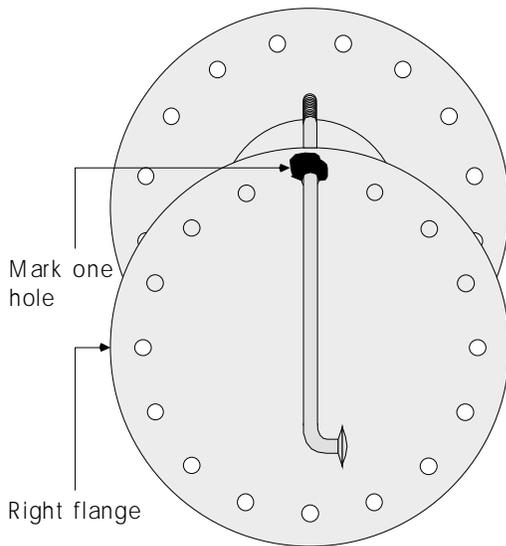
13. [] Use marker to mark any spoke hole in right-side hub flange on both faces of flange. If holes are alternately countersunk, it is optional to mark a hole that is not countersunk.

Step #14 is very straightforward, unless the rim is one of the rare models that have no apparent spoke-hole stagger. In this case, as it was in step #3, it is important to pretend that there is a stagger to the spoke holes, so that the instructions will be consistent for staggered and unstaggered rims.

14. [] With either side of rim up, observe whether first hole to right (*clockwise*) of valve hole is: *up* or *down* (circle one). (If, in step 3, second hole clockwise from valve hole was marked to be A1 because there was no obvious hole stagger, circle *down* for this step.)

16 – WHEEL BUILDING AND RIM REPLACEMENT

15. [] From outside of flange, temporarily insert a spoke several inches into marked hole in right flange.



16.24 Mark any hole in the right flange and insert a spoke as shown.

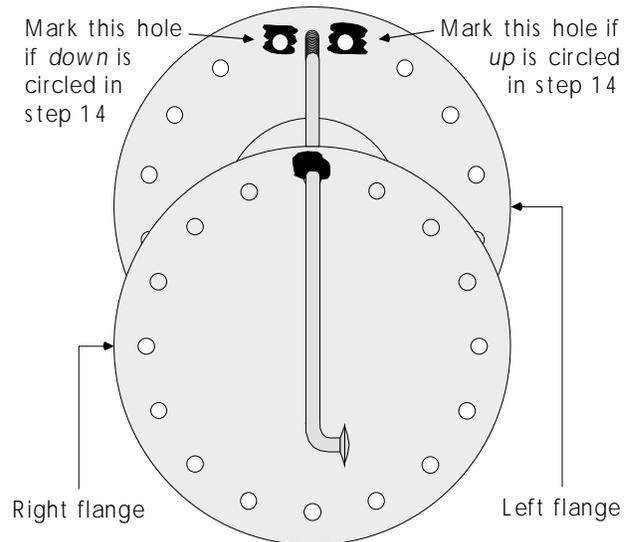
Step #16 is a critical step that selects the correct hole in the left flange for the first spoke of the “B” set. Insert a spoke from into the right flange (from the outside), keep it parallel to the axle, and stop it against the backside of the left flange between two spoke holes. The design of hubs is such that there is *never* a spoke hole in the left flange that is directly opposite a spoke hole in the right flange, so pick a space between two holes in the left flange to stop the spoke. If not sure the spoke is in the right space between holes, try one space to the right and one space to the left. It should be easy to see *obvious* differences in whether the spoke remains parallel to the axle.

With the left flange away and the right flange close, mark a hole in the left flange to the left or right side of the spoke that is inserted through a spoke hole in the right flange. Whether to mark the hole to the left or to the right depends on whether the first spoke hole to the left of the valve hole in the rim is *up* or *down*, an observation made in step #14. There is no benefit to having the first hole to the left of the valve hole up or down; manufacturers do it different ways as a matter of preference. *However, when building the wheel, ignoring this difference will result in half the spokes ending up much tighter than the others, and the wheel must be rebuilt!* The explanation for why this would happen would only create confusion; simply take care to mark the hole in the left flange correctly. When marking the hole in the left flange, mark it so that the mark can be seen from the outside face of the flange.

The following procedure only applies to wheels that use the same cross pattern on the left and right sides. There is no detailed procedure elsewhere on how to build a mixed-cross pattern (design is not recommended). Marking the hole in which to install the first B spoke is where the change occurs when building mixed-cross wheels; for example, in step 16, assuming a 4X pattern is being built on the right side, to build a 3X on the left side, mark the second hole instead of the first hole to the left. For a 2X it would be the third hole, and for 1X it would be the fourth hole, and for radial it would be the fifth hole. Always mark on additional hole away for each reduction in cross number.

- 16. Hold hub to face right end of axle (left end of axle is pointing away), and the hole with spoke in it is at 12 o'clock. Keeping spoke in line with the axle, push spoke through until it bumps into back side of left flange between two spoke holes. If spoke is straight, end of spoke should end up between two holes in left flange (holes in left and right flange are staggered to each other and do not line up).**

- [] **Mark first hole (both faces of flange) in left flange to left of spoke if down was circled in step 14.**
- [] **Mark first hole (both faces of flange) in left flange to right of spoke if up was circled in step 14.**



16.25 With the spoke held parallel to the axle, mark the appropriate hole in the left flange to be the first hole of the “B” set.

PREPARING THE SPOKES

17. [] Divide total number of spokes by 4 to determine number of spokes to be in each set of four. Spokes per set is: _____

Nothing is more exasperating than getting a wheel laced up and mostly trued and then discovering that the spokes are the wrong length. Either they all are wrong, or they are mixed up. Step #18 and #19 are critical to prevent this, so they are well worth the effort. In step #18, if using two lengths of spokes for a rear wheel, it is critical to get the correct length on each side of the wheel. Start by putting the short spokes on the right side of the bench and long spokes on the left side of the bench. When selecting a spoke set to install in the right flange, choose a set from the right side of the bench; when selecting a spoke set to install in the left flange, choose a set from the left side of the bench.

In step #19, use a spoke ruler to make sure that all the spokes in a group are the same length, and that all are the correct length. To use a spoke ruler, hang the bend of the spoke in the hole at the “0” end of the ruler and read the length at the end of the thread. If the end of the spoke ends up between two marks, use the higher value. If using a regular ruler, measure from the inside of the bend to the end of the thread.

18. [] Put two sets of spokes on bench to right of rim and two sets to left of rim. If building rear wheel with shorter spokes on right side, be sure shorter spokes are on bench on right side of wheel!

19. [] Arrange all spokes in each set so that thread ends are together. Stand each set up on thread ends and make sure all spokes are same length. Measure one spoke from each set to make sure it is correct length.

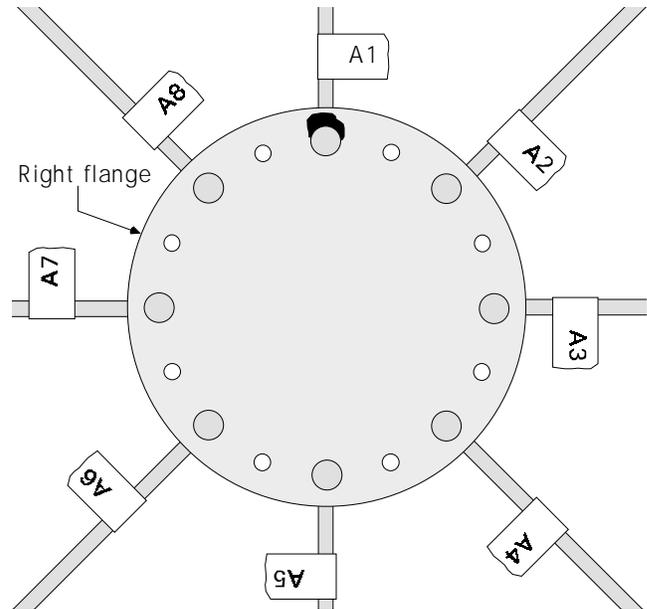
Prepping the threads with either oil or a special spoke-prep compound is vital. Oil will provide reasonable protection from corrosion, but it needs to be renewed periodically. Spoke-prep compounds last longer (in terms of corrosion prevention) and also act as a mild Loctite to keep nipples from unthreading if they loose tension.

20. [] Prep all threads with spoke-prep compound or oil.

LACING THE “A” SET

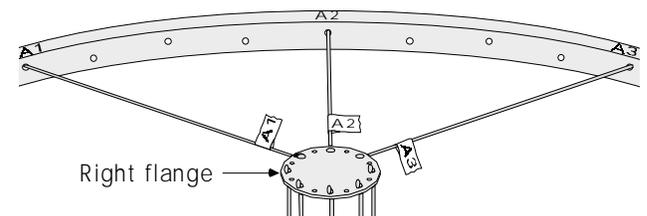
21. [] Insert spoke from one right-side set into marked hole in right flange so that spoke head ends up on outside of flange and tag this spoke with masking tape and mark it A1.

22. [] Insert second spoke from same right-side set in similar fashion into second hole clockwise from marked hole. Continue working clockwise filling every other hole until right flange has every other hole filled with spokes, all with heads facing out.



16.26 Insert spoke in marked hole and mark it A1. Insert spokes in every other hole and mark them A2, A3, etc.

23. [] With right side of rim and right end of hub facing up, attach marked spoke to A1 hole in rim, covering approximately half of thread length with nipple. Continue clockwise around hub and rim, inserting each next clockwise spoke to fourth hole clockwise in rim from last spoke and threading each nipple halfway on.



16.27 Attach the spokes to their correspondingly-marked holes.

Step #24 is a set of inspections to confirm everything is done correctly so far. It becomes a real nightmare to find out in a later set that something was wrong from early on, so be thorough about these inspections.

24. With right side of rim facing up rotate rim to look at valve hole in inner face of rim and inspect for following:

[] Right side of axle should be pointing up.

16 – WHEEL BUILDING AND RIM REPLACEMENT

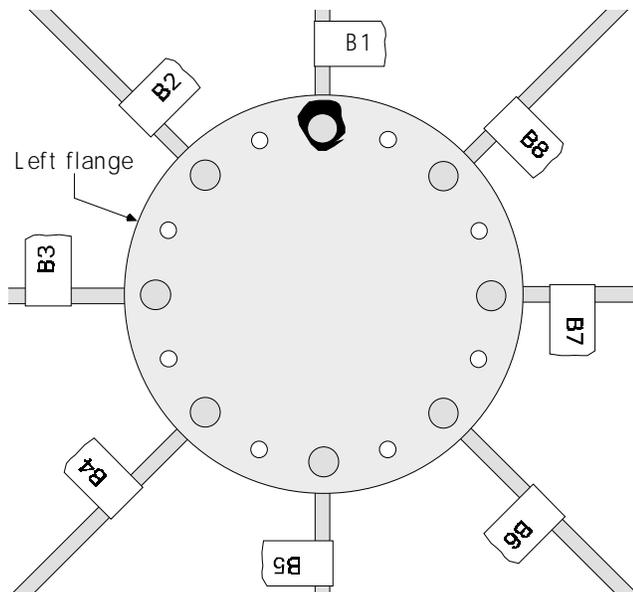
- [] If building a rear wheel with two different spoke lengths, two sets of spokes should be left on bench on left side of wheel.
- [] A spoke should be in first up-hole clockwise from valve hole.
- [] Three empty holes should be between every filled spoke hole in rim.
- [] Every other hole in right hub flange is filled.
- [] All spoke heads are on outside face of flange.

25. [] If any of inspections in step 24 are failed, remove all spokes and repeat **LACING THE "A" SET**.

LACING THE "B" SET

The "B" set is the mirror image of the "A" set, just on the other side of the wheel. The most important parts of doing the "B" set are already done, step #8 and step #16, when the starting holes for the "B" set in the rim and in the left flange were marked. Because the wheel is turned over, and because the "A" and "B" sets are a mirror image, work counterclockwise in this set, instead of clockwise.

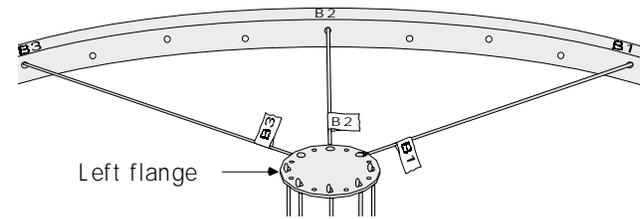
26. [] Turn wheel over so left side of hub and rim are up and rotate rim to look directly at valve hole in inner face of rim.
27. [] Insert spoke from one left-side spoke set into marked hole in left flange, so that spoke head ends up on outside of flange and tag this spoke with masking tape and mark it B1.



16.28 Spoke B1 is put in the hole marked in the left flange in step #16.

28. [] In similar fashion, insert second spoke from same left-side set into hub, in second hole counterclockwise from marked hole. Continue working counterclockwise, filling every other hole until left flange has every other hole filled with spokes, all with heads facing out.

29. [] With left side of rim and left end of hub facing up, attach marked spoke to B1 hole in rim, covering approximately half of thread length with nipple. Continue counterclockwise around hub and rim, inserting each next counterclockwise spoke to fourth hole counterclockwise in rim from last spoke and threading each nipple halfway on.



16.29 Attach the B1 spoke to the B1 hole, and all other B set spokes in every fourth hole counterclockwise from B1. "A" set spokes are in place at this time, but are not shown.

Step #30 is a series of inspections. Just as with the "A" set, if anything is left wrong with the "B" set, it can be extremely difficult to figure out what went wrong with the "C" set. When something goes wrong putting in the "C" set, the tendency will be to think the problem is with the "C" set, instead of with the "B" set. Perform these inspections religiously. Then, if anything goes wrong with the "C" set it will be known that the problem is limited to the spokes just put in.

30. With left side of rim facing up, rotate rim to look at valve hole in inner face of rim and inspect for following:

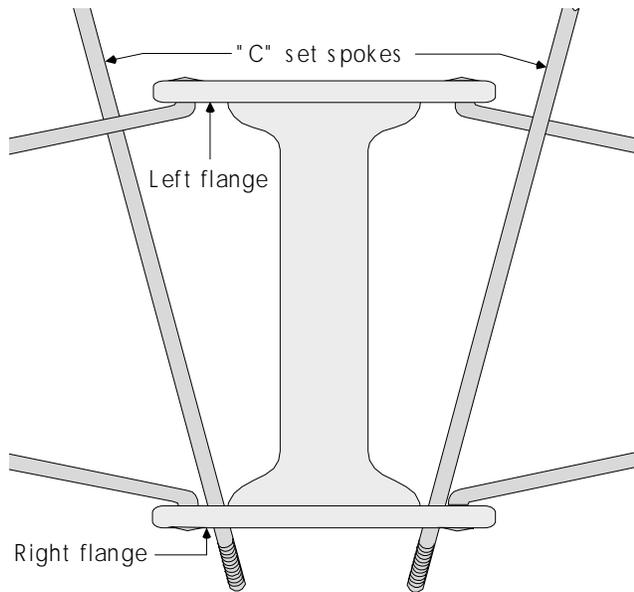
- [] If building a rear wheel with two different spoke lengths, one set of spokes should be left on bench on each side of wheel.
- [] A spoke should be in first up-hole counterclockwise of valve hole.
- [] Two empty holes should be between every pair of filled spoke holes in rim.
- [] Every other hole in left hub flange is filled.
- [] All spoke heads are on outside face of flange.

31. [] If any of inspections in step 30 are failed, remove all B spokes and repeat **LACING THE "B" SET**.

LACING THE “C” SET

32. [] Cross-pattern wheel only: With left side of wheel still facing up, insert remaining set of right-side spokes down into right flange so that spokes end up with heads on inside of right flange.

Radial wheel only: With right side of wheel facing up, insert remaining set of right-side spokes down into right flange so that spokes end up with heads on outside of right flange.



16.30 Insert the remaining spokes from the right side of the bench in the right flange in this fashion.

The cross pattern is established in the “C” set. Rather than counting crosses to determine where the spokes need to go, the spokes are installed by rote, and then the cross is counted to verify what happened. The “C” set is going in the right flange. The “A” set was the other set in the right flange, and its spokes had the heads to the outside of the flange. Just as sets are alternating from right flange to left flange and back to right flange, sets in the same flange will alternate so that the spoke heads alternate head-out (“A” set) and head-in (“C” set). To do this, the spokes are fed into the right flange from the left side of the hub. Then the wheel is turned over so that the right flange is up.

A key step here is finding the right spoke to mark to be C1. Because the location of C1 will change with each cross pattern, it is necessary to count a different number of spokes (for each different cross pattern) counterclockwise from the marked hole in the right flange (marked in step #13 and now containing spoke A1) to find the correct spoke to mark C1. The exception to this is with radial spoking, in which case

the C1 spoke will be the first “C” set spoke clockwise of the marked hole. For 1X pattern, the C1 spoke will be the first “C” spoke counterclockwise of the marked hole in the right flange. For 2X pattern, the C1 spoke will be the second “C” spoke counterclockwise of the marked hole in the right flange. For 3X pattern, the C1 spoke will be the third “C” spoke counterclockwise of the marked hole in the right flange. For 4X pattern, the C1 spoke will be the fourth “C” spoke counterclockwise of the marked hole in the right flange. With the exception of radial spoking, the number of “C” spokes counted counterclockwise from the marked hole to find C1 always equals the number of the cross pattern.

After finding C1, the rest of the spokes are numbered C2, C3, C4, etc. clockwise from C1.

33. [] Turn wheel over so that right flange faces up.

In the following step, if comfortable with the procedure it is OK to just mark the C1 spoke and skip marking the additional spokes of the C set.

34. Do one of next five options depending on spoke cross pattern being used (see figure 16.31 on following page):

4X SPOKE PATTERN:

[] Mark “C” set spoke that is fourth spoke counterclockwise of only marked hole in right flange, C1.

[] Going clockwise from C1, mark remaining spokes C2, C3, C4, etc.

3X SPOKE PATTERN:

[] Mark “C” set spoke that is third spoke counterclockwise of only marked hole in right flange, C1.

[] Going clockwise from C1, mark remaining spokes C2, C3, C4, etc.

2X SPOKE PATTERN:

[] Mark “C” set spoke that is second spoke counterclockwise of only marked hole in right flange, C1.

[] Going clockwise from C1, mark remaining spokes C2, C3, C4, etc.

1X SPOKE PATTERN:

[] Mark the “C” set spoke that is counterclockwise of the only marked hole in the right flange, C1.

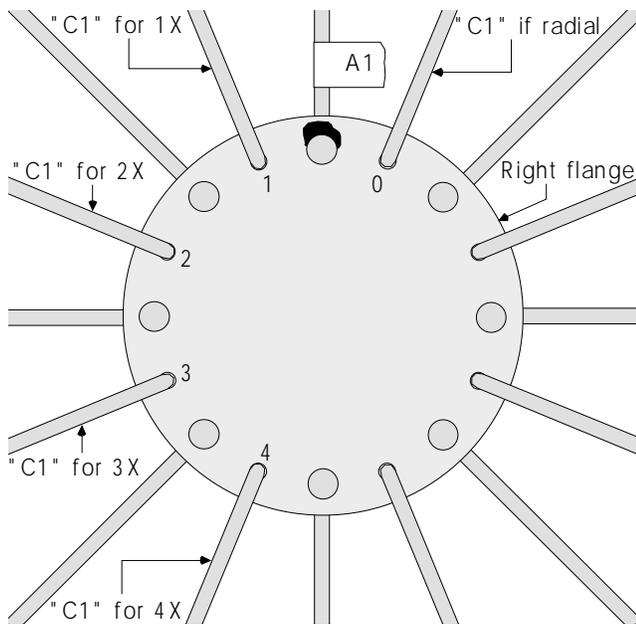
[] Going clockwise from C1, mark remaining spokes C2, C3, C4, etc.

RADIAL SPOKE PATTERN:

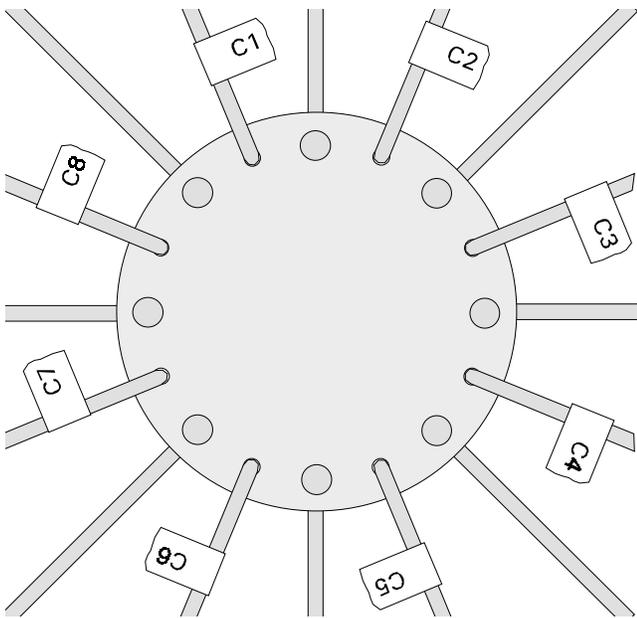
[] Mark the “C” set spoke that is clockwise of the only marked hole in the right flange, C1.

[] Going clockwise, mark remaining spokes in “C” set C2, C3, C4, etc.

16 – WHEEL BUILDING AND RIM REPLACEMENT



16.31 Depending on the cross pattern, different spokes will be marked C1.



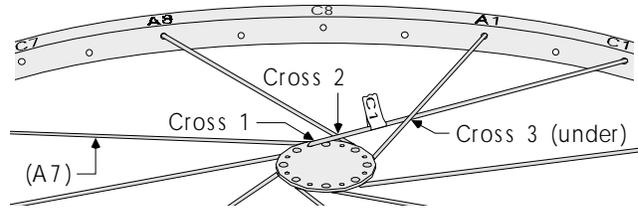
16.32 Mark the remaining "C" set spokes clockwise from C1 to be C2, C3, etc.

35. [] Holding rim stationary, rotate hub clockwise as far as it comfortably can.

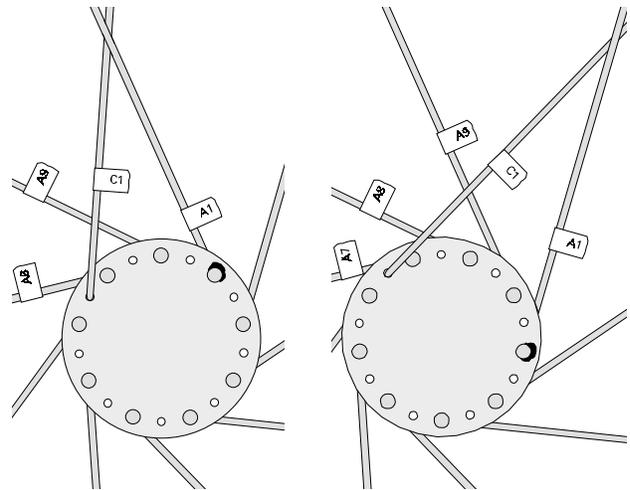
In the next step, create the cross pattern. After attaching spoke C1 to the rim at hole C1, trace the path of spoke C1 back from the rim to the hub flange. It will be found that it crosses the same number of "A" set spokes as the name of the cross pattern. After building a 3X and 36 spoke wheel, it will be found

that C1 crossed A1, A9, and A8. For a 3X and 32 spoke wheel, it will be found that C1 crossed A1, A8, and A7.

"B" spokes in place, but not shown
C2, C3, etc. in flange, but not shown



16.33 In this 3X-32° example, C1 crosses over A7 and A8, then under A1. See figure 16.34 for 3X-36° and 4X-36° examples.



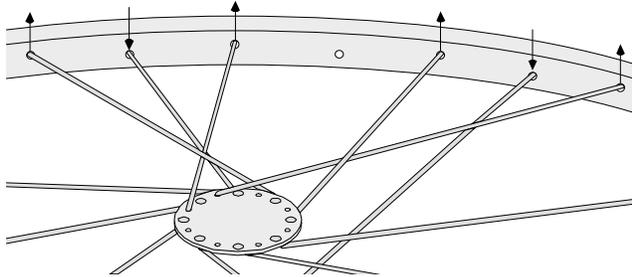
16.34 The left example is a 3X-36° wheel, and the right example is a 4X-36° wheel.

36. [] Move spoke C1 until it points to hole C1. Flex it slightly, in order to pass tip of spoke C1 under spoke A1, then insert spoke C1 into hole C1, covering approximately half of spoke-thread length with nipple.

37. [] Repeat previous step for spoke C2, C3, C4, etc., consecutively. Each spoke will attach to rim exactly four holes after last spoke and will always cross under last A spoke before reaching rim.

The next three steps are inspection steps. As with the previous spoke sets, do not let confidence encourage skipping these steps before doing the “D” set.

38. [] Inspect at rim for each set of three filled spoke holes separated by one empty spoke hole.



16.35 Each set of three spokes separated by an empty hole should consist of one up spoke, a down spoke in the middle, and another up spoke.

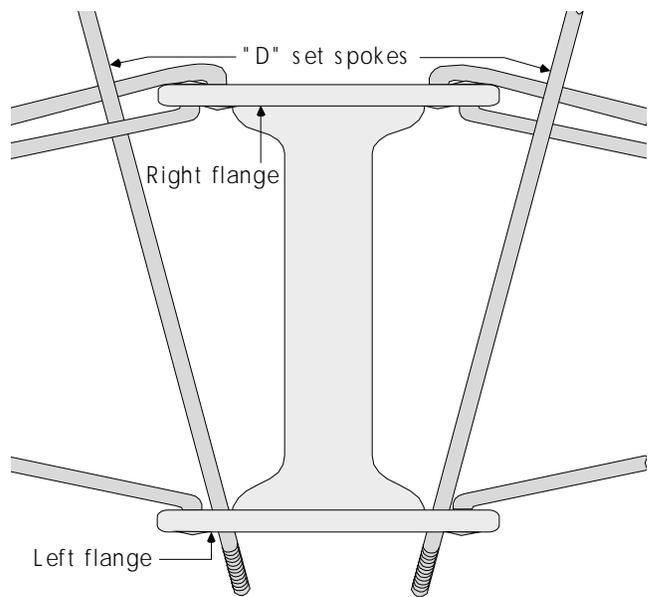
39. [] Inspect one set of three consecutive spokes at rim for whether set consists of, in order, one right (up) flange spoke, one left (down) flange spoke, then one right (up) flange spoke.

40. [] Inspect that each “C” spoke crosses under a “A” spoke just before reaching rim. Correct any spokes that don’t cross under.

41. [] If any of inspections in steps 38 through 39 are failed, or if remaining group of spokes on bench is on right (if building a rear wheel with two spoke lengths), remove all C spokes and repeat LACING THE “C” SET.

LACING THE “D” SET

The “B” set is the first set in the left flange, and its spokes have the heads to the outside of the flange. Just as the insertion of spoke sets has alternated from right flange to left flange and back to right flange, spokes sets in the same flange will alternate so that the spoke heads alternate head-out (“B” set) and head-in (“D” set). To do this, the spokes are fed into the left flange from the right side of the hub. After the spokes have been inserted, the wheel is turned over so that the left flange is up (see figure 16.36).



16.36 Insert the remaining spokes from the left side of the bench in the left flange in this fashion.

42. [] Cross-pattern wheel only: With right side of wheel still facing up, insert remaining set of left-side spokes down into left flange so that spokes end up with heads on inside of left flange.

Radial wheel only: With left side of wheel facing up, insert remaining set of left-side spokes down into left flange so that spokes end up with heads on outside of left flange.

43. [] Turn wheel over so that left flange faces up.

A key step here is finding the right spoke to mark to be D1. Because the location of D1 will change with each cross pattern, it is necessary to count a different number of spokes clockwise from the marked hole in the left flange to find the correct spoke to mark D1 (for each different cross pattern). The exception to this is with radial spoking, in which case the D1 spoke will be the first “D” set spoke *counterclockwise* of the marked hole. For a 1X pattern, the D1 spoke will be the first “D” spoke clockwise of the marked hole in the left flange. For a 2X pattern, the D1 spoke will be the second “D” spoke clockwise of the marked hole in the left flange. For a 3X pattern, the D1 spoke will be the third “D” spoke clockwise of the marked hole in the left flange. For a 4X pattern, the D1 spoke will be the fourth “D” spoke clockwise of the marked hole in the left flange. With the exception of radial spoking, the number of “D” spokes counted clockwise from the marked hole to find D1, always equals the number of the cross pattern.

After finding D1, the rest of the spokes are numbered D2, D3, D4, etc. counterclockwise from D1.

16 – WHEEL BUILDING AND RIM REPLACEMENT

In the following step, if comfortable with the procedure, it is OK to just mark the D1 spoke and skip marking the additional spokes of the D set.

44. Do one of next five options depending on spoke cross pattern being used (see figure 16.37):

4X SPOKE PATTERN:

- [] Mark "D" set spoke that is fourth spoke clockwise of only marked hole in left flange, D1.
- [] Going *counterclockwise* from D1, mark remaining spokes D2, D3, D4, etc.

3X SPOKE PATTERN:

- [] Mark "D" set spoke that is third spoke clockwise of only marked hole in left flange, D1.
- [] Going *counterclockwise* from D1, mark remaining spokes D2, D3, D4, etc.

2X SPOKE PATTERN:

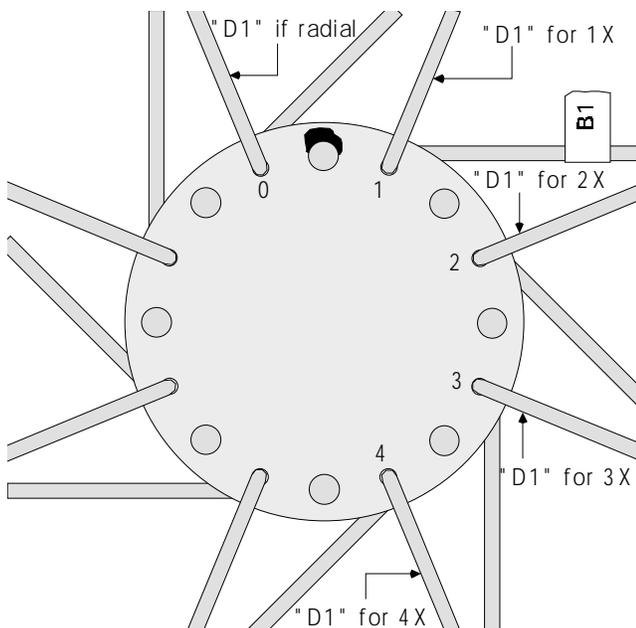
- [] Mark "D" set spoke that is second spoke clockwise of only marked hole in left flange, D1.
- [] Going *counterclockwise* from D1, mark remaining spokes D2, D3, D4, etc.

1X SPOKE PATTERN:

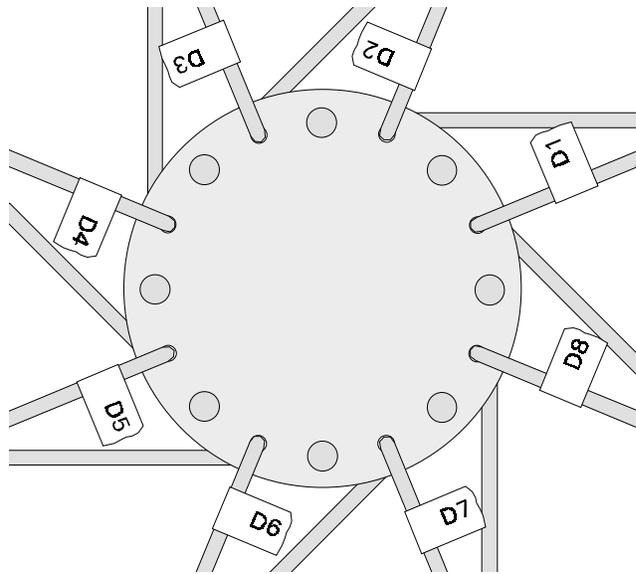
- [] Mark the "D" set spoke that is clockwise of the only marked hole in the left flange, D1.
- [] Going *counterclockwise* from D1, mark remaining spokes D2, D3, D4, etc.

RADIAL SPOKE PATTERN:

- [] Mark the "D" set spoke that is *counterclockwise* of the only marked hole in the left flange, D1.
- [] Going *counterclockwise*, mark remaining spokes in "D" set D2, D3, D4, etc.



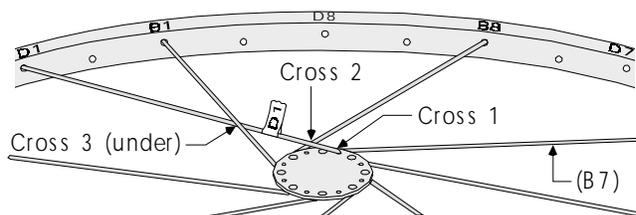
16.37 Depending on the cross pattern, different spokes will be marked D1.



16.38 Working counterclockwise from D1, mark the remaining spokes D2, D3, D4, etc.

45. [] Move spoke D1 until it points to hole D1. Flex it slightly, in order to pass tip of spoke D1 under spoke B1, then insert spoke D1 into hole D1, covering approximately half of spoke-thread length with nipple.

"A" and "B" spokes in place, but not shown
D2, D3, etc. in flange, but not shown



16.39 In this 3X-32° example, D1 crosses over B7 and B8, then under B1.

- 46. [] Repeat previous step for spoke D2, D3, etc.**
- 47. [] Inspect that each "D" spoke crosses under a "B" spoke just before reaching rim. Correct any spokes that don't cross under.**

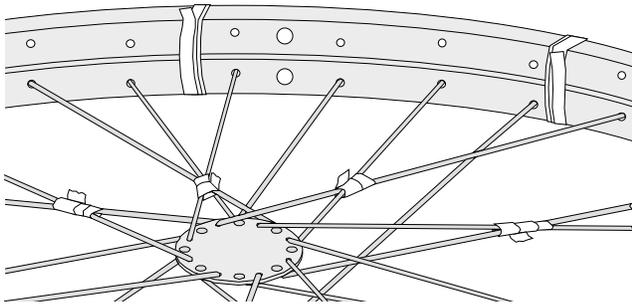
REPLACING RIM AND REUSING OLD SPOKES

Reusing old spokes is strongly recommended against. Spoke fatigue is impossible to detect by inspection. Building a new rim onto an existing wheel, only to have to rebuild the wheel because of fatigued spokes, is a terrible waste of time and money; further-

more, two rims of the same size do not necessarily take the same-size spokes, so unless the replacement rim is identical, the old spokes may not work.

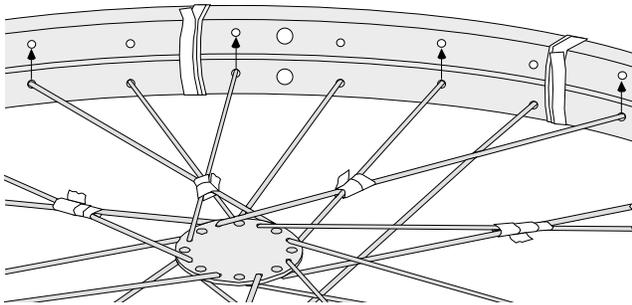
Only if the customer has smashed a virtually new rim and an identical replacement is available, then it would it make sense to reuse the old spokes.

1. [] Lay replacement rim on top of damaged rim (right-side up) with valve holes lined up and fix rims together with tape.



16.40 Tape new rim on top of right side of old rim in this fashion, then tape the outermost spoke crosses on the upper set of spokes together.

2. [] Wrap tape securely around each pair of spokes where they cross each other the last time before reaching rim.
3. [] Unthread all nipples on spokes coming from right-side flange.
4. [] Re-attach all right-side spokes to new rim in holes directly adjacent to holes that spokes have been removed from.



16.41 Transfer spokes to new rim.

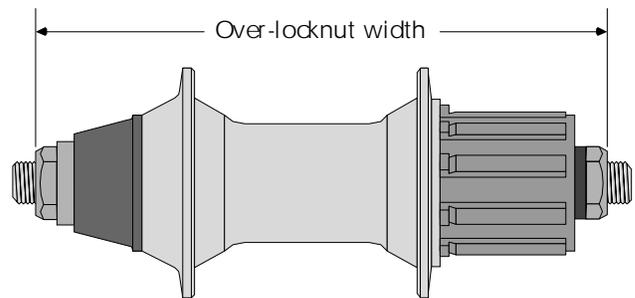
5. [] Turn wheel over so left side is up and new rim is on bottom.
6. [] Unthread all nipples on spokes coming from left-side flange.
7. [] Re-attach all left-side spokes to new rim in holes directly adjacent to holes that spokes have been removed from.
8. [] Remove tape from spoke crosses and remove tape holding rims together.

PREPARING WHEEL FOR TRUING

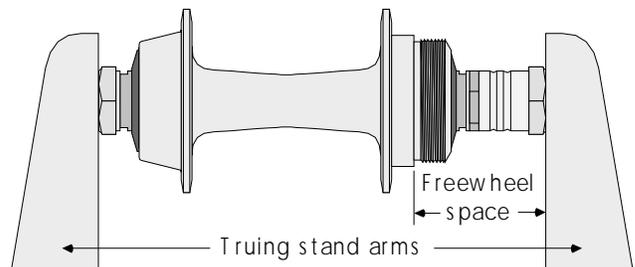
1. [] Put wheel securely in truing stand so that right end of axle is on your right and secure fully.
2. Do one of next two options depending on whether wheel is front wheel, rear wheel with two different spoke lengths, or rear multi-sprocket wheel with one spoke length:
 - [] If building a front wheel or a rear wheel with two spoke lengths, tighten all nipples until 1mm of thread (or two whole threads) is exposed above nipple.
 - [] If building a multi-cog rear wheel with one spoke length, tighten all nipples until 2mm of thread (or 4 whole threads) is exposed above nipple.

NOTE: If building a front wheel, skip to step 4.

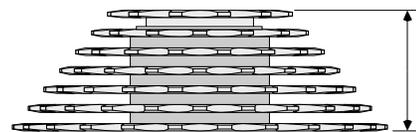
Establishing initial dish:



16.42 Measure over-locknut width in this fashion.



16.43 Measure freewheel space in this fashion.



16.44 Measure cogset width in this fashion.

16 – WHEEL BUILDING AND RIM REPLACEMENT

The following recommended dish corrections are just ball park estimates of what it will take to get the dish adjustment close to ideal. Further dish correction will be likely for many wheels.

3. Do one of the following options depending on width of cogset, over-locknut width, and amount of spoke-length differential used between left and right side of rear wheel:

EIGHT-SPEED COGSET, WIDE-WIDTH HUBS
(over-locknut width is 131.1–136.0mm)

- [] If one spoke length was used, tighten all right-side nipples three full turns.
- [] If 1mm shorter spokes were used on right side, tighten all right-side nipples two full turns.
- [] If 2mm shorter spokes were used on right side, skip to step 4.

EIGHT-SPEED COGSET, NARROW-WIDTH HUBS
(over-locknut width is 127.6–131.0mm)

- [] If one spoke length was used, tighten all right-side nipples four full turns.
- [] If 1mm shorter spokes were used on right side, tighten all right-side nipples three full turns.
- [] If 2mm shorter spokes were used on right side, tighten all right-side nipples one full turn.

NORMAL SIX- OR SEVEN-SPEED COGSET AND WIDE-WIDTH HUB

(cogset width is 29-32.5mm or freewheel space of 35.0-38.0mm, over-locknut width is 131.1–136.0mm)

- [] If one spoke length was used, tighten all right-side nipples two full turns.
- [] If 1mm shorter spokes were used on right side, skip to step 4.

NORMAL SIX- OR SEVEN-SPEED COGSET AND MEDIUM-WIDTH HUB

(cogset width is 29-32.5mm or freewheel space of 35.0-38.0mm, over-locknut width is 127.6–131mm)

- [] If one spoke length was used, tighten all right-side nipples three full turns.
- [] If 1mm shorter spokes were used on right side, tighten all right-side nipples one full turn.

NORMAL SIX- OR SEVEN-SPEED COGSET AND NARROW-WIDTH HUB

(cogset width is 29-32.5mm or freewheel space of 35.0-38.0mm, over-locknut width is 124.6–127.5mm)

- [] If one spoke length was used, tighten all right-side nipples four full turns.
- [] If 1mm shorter spokes were used on right side, tighten all right-side nipples two full turns.
- [] If 2mm shorter spokes were used on right side, skip to step 4.

FIVE- OR NARROW SIX-SPEED COGSET AND WIDE-WIDTH HUB

(cogset width is less than 27.5mm or free-wheel space of 30–34mm, over-locknut width is 124.6–127.5mm)

- [] If one spoke length was used, tighten all right-side nipples one full turn.

FIVE- OR NARROW SIX-SPEED COGSET AND WIDE-WIDTH HUB

(cogset width is less than 27.5mm or free-wheel space of 30–34mm, over-locknut width is 119.6–124.5mm)

- [] If 1mm shorter spokes were used on right side, tighten all right-side nipples 1 full turn.
- [] If one spoke length was used, tighten all right-side nipples three full turns.

Establish working tension:

4. Jiggle rim at bottom vigorously side-to-side and observe amount nipples move up and down in rim, then:

- [] If nipples move up and down >2mm, tighten all nipples 3 full turns and check again.
- [] If nipples move up and down 1–2mm, tighten all nipples 2 full turns and check again.
- [] If nipples move up and down <1mm, tighten all nipples 1 whole turn and check again.
- [] If nipples do not move up and down, skip to step 5.

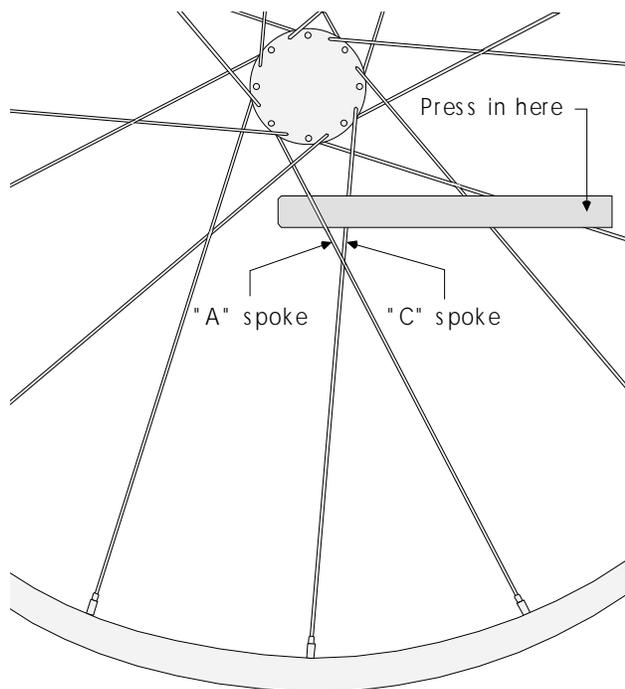
5. [] Pluck numerous spokes on right side of wheel and feel and hear for resonance in rim. If no resonance is felt or heard, tighten all nipples ½ turn.

Pre-set spoke bands

(skip to step 11 if reusing old spokes):

As can be observed, spokes do not naturally take a straight line from the hub flange to the rim. They tend to arc on their way out of the flange, although they will straighten up when tensioned. Once the tension is gone, they will go back to being bowed. When a wheel is in use, the spokes are constantly getting tighter and looser. If they are also bowing and straightening when riding, then they will fatigue much faster. The following group of steps is designed to get the spokes to follow a straight line from the hub to the nipple, even when the spokes are relaxed, so that as they loosen and tighten under use, they will not be bowing and straightening as well.

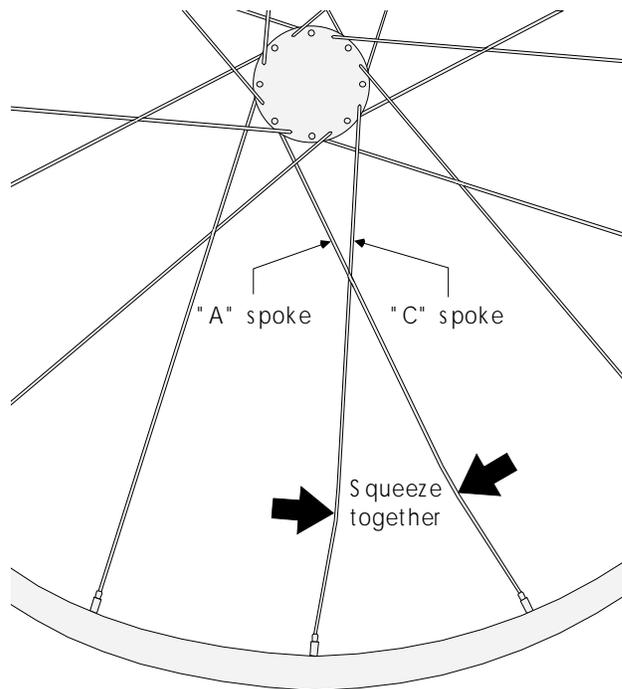
6. [] On right side of wheel, insert broad flat tool (such as a cone wrench or large combination wrench) between cross of spokes A1 and C1 and the right hub flange, then apply leverage in direction that forces A1 away from central plane of wheel and C1 toward central plane of wheel. Repeat for A2 and C2 pair, A3 and C3 pair, etc.



16.45 Just inside of the point where they cross each other, lever each A-C pair with the same number so that the A spoke is moved out and the C spoke is moved in to preset the spoke bends where the spokes come out of the flange.

7. [] On left side of wheel, insert broad flat tool (such as cone wrench or large combination wrench) between cross of spokes B1 and D1 and the left hub flange, then apply leverage in direction that forces B1 away from central plane of wheel and D1 toward central plane of wheel. Repeat for B2 and D2 pair, B3 and D3 pair, etc.

8. [] On right side of wheel, grab spoke pair A1 and C1 close to rim and squeeze pair together firmly. Repeat for pairs A2 and C2, A3 and C3, etc.



16.46 Squeeze each A-C pair with the same number, and then each B-D pair with the same number firmly together just above the nipples to preset the bend where the spokes come out of the nipples.

9. [] On left side of wheel, grab spoke pair B1 and D1 close to rim and squeeze pair together firmly. Repeat for pairs B2 and D2, B3 and D3, etc.
10. [] Repeat steps 4 and 5 as necessary.

WHEEL TRUING

11. [] Jiggle rim side-to-side to check hub for play (Remove wheel and adjust hub to eliminate play if hub is loose. Reinstall wheel in stand when done).
12. [] Put a drop of oil where each nipple enters rim.
13. Use procedure *TRUING WHEELS WITH UNDAMAGED RIMS, SPOKES, AND NIPPLES* (page 17-11) from step 13 to complete truing.

