Introduction

This Excel workbook was originally constructed to assess the fit of production frames with respect to a desired riding position. Its purpose was to determine component dimensions such as the required stem and seatpost lengths, the saddle position on its adjustment rails, and steerer tube spacer height. Published dimensions and geometry inputs describing the frame, crank, saddle, and handlebar were used to produce a plot showing the desired saddle and handlebar locations on the specified frame and wheels, creating a visual display of the frame fit. Additionally, the frame and fork geometry and the key dimensions of the crank, pedal, and shoe were used to check for possible interference between the rider’s shoe toe and the front tire while pedaling. Finally, a longitudinal center of gravity (CG) calculation was developed, to determine the weight distribution between the front and rear wheels for the rider in his desired position on the frame under consideration.

Further detail has been added so that it will be useful as a geometry definition and design tool for made-to-measure frames. Methods for estimating crank length, top tube, and seat tube lengths, and the saddle and handlebar positions using anatomical measurements have been included. These are similar to the procedures found in the bicycle fitting literature, but modified so that wherever possible the actual contact points that form the interface between the rider and the bicycle are used as reference points. Inputs describing the tube lengths beyond the intersections, tube diameters, and fork crown details allow calculations of clearances for the wheels and the required front brake reach.

For the design of a new frame to meet the requirements of a specified riding position, a novel automated design method is described. This involves using Excel’s Solver utility to manipulate twelve geometric variables in the frame design to satisfy constraints of desired riding position, specified steering geometry, top tube slope, top tube-down tube interference at the head tube, steerer tube spacer height, stem length, tire clearances, toe clearance, stand-over height, and weight distribution, while minimizing wheelbase. This method is customizable to accommodate virtually any design requirements.

Several additional pages have been created to calculate the cut tube lengths and miter details for a given frame geometry and to display two views of the assembled frame. Using the tube dimensions and a description of the rear dropout, a plot showing an elevation view of the assembled frame is drawn, with the chain stays and seat stays in their exact positions. Rear tire, crankset, and rear cassette descriptive dimensions are used to construct another plot showing a layout of the rear tire and drive components as seen in the plane of the chain stay axes. Clearances between the drive components and the frame can be checked in this view.

To record design data, a library worksheet is used as a database to record some or all of the inputs for a frame design. Each design record can be tagged with identifiers for sorting and recalling selected rider measurements, component dimensions, geometry, or design features. The complete record or portions of previous work can be reloaded into
the active input cells as a starting point for a new design, and this process has been automated using Visual Basic macros.

To facilitate cutting and mitering the frame tubes, a separate plot shows a larger view of each tube in its finished form, with key length dimensions displayed. For marking the tubes to be mitered, a utility calculation has been created that describes the line of intersection of two round tubes of specified diameters and angle of intersection. When printed at full scale, a plot of this data produces a template for marking and cutting tube miters. To produce a template for the lower end of the down tube, an optional third tube, perpendicular to the others, can be included to represent the bottom bracket shell.

Since the geometry inputs are arranged such that a progressive level of detail is addressed, the spreadsheet still works very well for its original purpose of assessing frame fit. If a particular frame’s suitability to a particular rider is all that is desired, only the rider position and basic frame geometry data are needed.
The Frame Geometry Worksheet

**Project Title and Design Summary**

The Project Title is the first input to BG101, and is used to identify the current design case specified by all of the other inputs. This title appears on the various plots created by the program, and is used as the record identifier for designs stored on the Design Library Worksheet.

The Design Summary is a condensed set of specifications for the current design case. This summary is also written onto the Position Plot and Frame Plot. Some of the values in the summary are inputs and others are calculated outputs. The values are gathered from elsewhere on the Frame geometry Worksheet, so there are no user inputs in this block.

**Rider measurements**

The rider measurements used to estimate frame dimensions and the saddle and handlebar positions are shown in Figure 1. These can be obtained quickly with the aid of a steel tape measure, a carpenter’s framing square, a chair, and a convenient wall.

For the inseam, the rider stands with his or her back to the wall, without shoes on. One side of the framing square is placed vertically against the wall between the rider’s legs and raised tightly into the crotch (against the *pubic symphysis*). The inseam measurement is taken from the top of the horizontal side of the square to the floor.

For the sternal notch measurement, the rider stands facing the wall. One side of the square is placed vertically against the wall and positioned it so that the end of the other side rests in the rider’s sternal notch. The measurement is then taken from that edge of the square to the floor.

Arm length is measured from the apex of the head of the humerus at the outside of the shoulder (the *greater tubercle*) to the second knuckle of the thumb (the one closest to the crotch).

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**Fig. 1 - Rider Measurements**
formed by the thumb and first finger). The arm is held straight with the palm facing in, ten centimeters or so away from the hip. Measure both arms and average the results.

For the femur length, the rider sits on a chair so that the left and right femurs are approximately parallel to the floor and to each other. The inside edge of the short side of the square is placed against the front of the knees, and the long side is positioned such that it passes over the head of a femur (the greater trochanter). The distance from the inside corner of the square to the apex of the head of the femur is the femur length. The square will likely have graduations, which will directly indicate the desired length. Measure both femur lengths and average the results.

Foot length is measured by standing with the back of the heel against a wall, and measuring the distance from the wall to the end of the longest toe. Measure both feet and use the longer dimension.

**Calculated rider measurements**

From the measurements described above, a torso length is calculated as the difference between the sternal notch and the inseam. This dimension and the arm length are used to compute a “right-angle reach,” which is the length of the hypotenuse of a right triangle whose other two sides are the torso and arm lengths. This method comes from the notion that the angle between the arms and upper body should not be more than ninety degrees when riding.

The foot length is used to estimate the horizontal distance from the pedal axle to shoe toe, which is later used to check for interference between the rider’s shoes and the front tire. The foot length is multiplied by a factor of about 35% to estimate the length of the shoe in front of the pedal axle.
**Estimated contact points and frame dimensions**

A series of proportionality constants and calculations are used in conjunction with the rider measurements to estimate the location of the contact points and the frame dimensions necessary to meet them. Between the frame and the contact points are the pedals, cranks, saddle, seatpost, handlebars, stem, and the steerer “stack” between the head tube and the stem. Estimates and allowances must also be made for the dimensions of these parts.

The method described here locates the saddle and handlebars by referencing the actual contact points. Saddle and handlebar dimensions vary significantly, and this system takes these variations into account. For most of the estimates, an “override” input is available to substitute a known value or enter an alternate equation. If the value of the override cell is anything other than zero, then that value will be used for the subsequent calculations in the design case. Note that none of these estimated values are automatically factored into the frame design; so they may be used or not, as desired.

An annotated version of the Position Plot showing these and other descriptive dimensions is shown in Figure 2, with those pertaining to the contact points shown in red. The calculations are described here and are visible in the equations within cells. These may or may not work well for a wide range of body types. In any case, the proportionality constants are all available as inputs so that they can be adjusted as needed, and any alternate value or calculation can be entered into the override cells.
Estimating crank arm length, pedal stack height, and shoe toe arc

Crank arm length is estimated using a linear function of the inseam length. The coefficients chosen will produce crank arm lengths that are typical and available for most riders.

From a biomechanical standpoint, it would seem that crank length should be directly proportional to leg length. However, the range of inseam lengths encountered seems to be larger than the range of crank lengths in common use, and there is some controversy over this issue. Considerations such as pedal ground clearance and the ability to maintain a suitably high cadence are often cited as reasons to limit crank arm length for taller riders, and the length may also be limited by availability. Multiplying inseam length by a constant factor of about 21.5% can be used to make an estimate of crank length, and this will work reasonably well for riders with shorter to average length inseams. For taller riders, the resulting length will only be available from specialty manufacturers. With the upper end of standard crank lengths being around 180 mm, tall riders may have to accept cranks that are as small as 19% of inseam length or even less. In any case, use judgment or past experience when possible.

Pedal stack height, which is the distance from the pedal axle to the insole of the shoe, is around 30mm for current “clip-less” pedals. The best accuracy will result from measuring the actual components since these dimensions vary from one manufacturer to another.

The shoe toe arc is the radial distance from the pedal spindle to the extreme of the rider’s shoe. An estimate of the forefoot length was made in the Calculated Rider Measurements section, and this is combined with the pedal stack height input to estimate the radius of the shoe toe arc. This length is used to check for adequate clearance between the rider’s toe and the front tire. Again, the best accuracy will result from measuring the actual components since the exact shape of the shoe last will vary from one manufacturer to another.

Estimating saddle height

Saddle height (from bottom bracket center to saddle top) is estimated using the inseam measurement, plus the crank length and pedal stack height inputs. The distance from the bottom of the foot to the saddle top is first found by multiplying the inseam by a factor of about 104.5%, and then this dimension is reduced by crank length minus pedal stack to arrive at the bottom bracket center-to-saddle top dimension (pedal stack is the distance from the pedal axle center to the insole of the shoe). An auxiliary calculation is provided which compares the bottom bracket center-to-saddle top dimension to the inseam measurement as a percentage.

Estimating saddle contact point horizontal position

The positioning of the rider relative to the pedal cranks is estimated as a horizontal distance from the bottom bracket center to the saddle contact points, where the sit bones (ischial tuberosities) are located. A linear combination of femur length and inseam is used to estimate this dimension, with the intention of placing the front of the knee approximately over the pedal axle with the cranks horizontal. In practice, it is ultimately best to determine the saddle horizontal position for a given rider.
experimentally, or from past experience. Besides the proportions of the leg, the crank length used and the rotation angle of the pelvis (which is influenced by the rider’s upper body position) may affect the position of the saddle required to achieve this relationship.

**Estimating handlebar position**

For the handlebar position, a “reach” distance, defined as the diagonal distance from the saddle contact point to the extreme of the handlebar centerline, at the height of the bar clamp, is used. A great deal of time is spent with the hands on the brake hoods, and the extreme reaching position is encountered when the hands are on the drops. Both of these riding positions place the hands at the front of the bars. A factor of about 98% is applied to the calculated right-angle reach to account for the torso and arm lengths being less than as measured when riding in a crouched position.

A handlebar reach dimension, defined as the distance from the bar clamp center to the extreme of the handlebar bend centerline, is also estimated at about 12% of the right-angle reach. This will be used in conjunction with the estimated reach and stem length to estimate the virtual seat tube length and horizontal top tube length.

The vertical drop from the top of the saddle to the stem’s bar clamp center is estimated using the calculated reach dimension described above and an angle specifying the slope of the diagonal reach line. This angle will typically vary from zero to about -7 degrees.

**Verifying rider position**

It is always advisable to verify the proposed rider position using an existing bicycle mounted in a stationary trainer, or an adjustable fitting apparatus. A device that permits testing of the proposed position while pedaling under load is preferred so that the rider’s feedback can be obtained, and his pedaling mechanics can be observed.

**Estimating Stem Length**

The stem length used will affect the frame dimensions required to support a given riding position, and it will also influence the handling feel of the bicycle. The stem length is estimated at about 13% of the right-angle reach.

**Estimating Frame dimensions**

From the inseam measurement alone, an estimate of the frame’s actual seat tube length can be made. This will be the same as the virtual seat tube length for standard horizontal top tube geometry. A figure of 65% of the inseam measurement is often used, and this will primarily insure adequate stand-over clearance, assuming a typical bottom bracket height.

Saddle type and the offset of the seatpost clamp from the seat tube axis will affect the seat tube angle required to center the saddle on its adjustment rails when it is in the desired location, and therefore the horizontal top tube length as well. The offset of the sit bone location from the point where the seat tube axis would pierce the saddle top is specified for the horizontal top tube and seat tube angle estimates. An offset dimension of 60mm is typical.
The virtual seat tube length can be estimated using the reach and handlebar position estimates and the stem length, plus an assumption regarding the distance from the bar clamp center to the intersection of the top tube and head tube and the stem angle. A value of 80-85mm will typically be required to accommodate the head tube extension (about 30mm), the upper headset stack height (about 20mm), half of the stem’s steerer clamp height (about 15mm) and 15-20mm of spacers on the steerer. Stem angles typically range from 80 to 84 degrees in the normal (low) position, or 106 to 110 degrees inverted. If the virtual seat tube length is greater than the actual seat tube length, a sloping top tube may be required to position the handlebars as required while maintaining acceptable stand-over height. Alternatively, more steerer spacers or an inverted stem can be used.

The rotational position of the handlebar will vary due to personal preference and the bend of the particular bar in use. Ten to fifteen degrees (positive) is a typical angle for the bar end.

**Position Inputs**

These values are used to specify the desired location of the saddle, stem, and handlebars relative to the bottom bracket. The BG101-estimated values, using the sit bone location and the handlebar extreme reference points, or other known values are entered here. However they are determined, the saddle height, horizontal distance from the bottom bracket center to the saddle reference point, desired reach, stem drop, and handlebar rotation, plus the saddle and stem dimensions, will locate the saddle exactly, and position the stem and handlebar vertically on the steerer axis. Note that the handlebars are only located vertically through these inputs. The top tube length and/or the stem length inputs must be varied to bring the calculated reach dimension in line with the desired reach. Perhaps the best way to develop an understanding of the function of these inputs is to vary each one in turn and observe the effect on the Position Plot.

**Saddle height**

Saddle height is specified as the distance from the bottom bracket center to the top of the saddle, measured along the seat tube axis. The saddle is located at this height regardless of its fore-aft position.

**Saddle reference point horizontal position**

The horizontal distance from the bottom bracket center to the saddle reference point is used to locate the saddle on the Position Plot. Note that the location of the saddle reference point on the saddle, be it at the sit bone location or otherwise, is controlled by the “Location of Saddle Reference Point” input as shown in Figure 3 and described below under Frame Geometry Inputs.

**Desired reach**

The desired reach is a specified distance from the chosen saddle reference point. This value only affects the center location and radius of the desired reach arc shown on the position plot. The disparity between the desired reach and the calculated reach can be observed both numerically, by examining the calculated reach outputs, and graphically on
the position plot. The desired reach input must be appropriate for the specified saddle reference point, and compared against the appropriate calculated reach (handlebar extreme or bar clamp center reference point).

**Stem position**

Stem position refers to the vertical distance from the saddle top to the center of the handlebar clamp. This dimension determines the location of the specified stem on the steerer axis.

**Rotation of handlebar**

A handlebar rotational position input is also required, where the rotation of the handlebar is specified relative to a position where the bar ends are horizontal. Rotation of the handlebar affects the first of the calculated reach dimensions.

**Mass and CG data inputs**

The rider weight and center of gravity (CG) inputs, along with the estimated bicycle weight and weight distribution allows a calculation of weight distribution on the frame being considered. The weight and position of touring gear may be included here as part of bicycle weight and weight distribution, if desired. Details of how to find rider and bicycle CG are included on the CG Calculator Worksheet.

**Frame Geometry Inputs**

**Basic frame geometry inputs**

The basic frame geometry inputs should be self-explanatory, but the variables that control the position of the top tube may benefit from some explanation. The forward end of the top tube is positioned by the specification of the virtual seat tube length, since this input defines the height of the horizontal top tube centerline, and therefore its intersection point with the steerer axis. This point is common to the horizontal and actual top tube centerlines, and independent of the head tube length. For a given virtual seat tube length, the head tube length must be adjusted to achieve the desired free length above the top tube, or vice-versa. The aft end of the actual top tube is positioned by the intersection of its centerline with the seat tube axis, which is determined by the actual seat tube length center-to-center input. The seat tube extension is adjusted to achieve the necessary free length of the seat tube above the top tube.

For the tire radii, a table is provided on the Component Geometry tab showing the radius for various sizes of tires. These are derived from the effective (loaded) circumference of the tire, and so some additional allowance should be made if precise clearance calculations are required. Front and rear tires of different sizes may be specified. If this is the case, the axle height reference will be that of the rear tire.
Detail for reach, saddle height, and seatpost length

The next group of geometry inputs describes the saddle, stem, crank, and pedal component dimensions (see the illustrations for details). These are needed for the reach, saddle height, and seatpost length calculations.

If a saddle reference point other than the sit bone location is desired, an alternate saddle reference point can be specified using the appropriate value for the “Location of saddle reference point” input in the saddle geometry description. Saddle reference point definitions are shown in Figure 3. Since this input is the distance from the saddle nose to the reference point divided by the saddle length, an input of zero will place the reference at the nose of the saddle, and a value of one will place it at the tail.

Handlebar style and position are significant variables in riding position. A detailed description of the handlebar shape is entered in a table below the four horizontal rows of frame geometry inputs on the Frame Geometry Worksheet. A few handlebar geometry descriptions have been included on the Component Geometry Worksheet. Replacing the default handlebar description should be self-evident; copy and paste in the values for the desired shape.

Detail for steerer stack height calculation

The next five frame geometry inputs, including fork length, head tube length, headset stack, and the stem’s steerer clamp height dimension are necessary if a precise calculation of the steerer tube stack height (and required spacers) is needed. For this it is assumed that the frame angles are correct relative to horizontal, meaning that the fork length and headset lower stack height match the frame’s design. The head tube will be positioned on the steerer axis so that its lower end is above the fork crown race seat a distance equal to the headset lower stack height. With the stem positioned according to the specified drop from the saddle top, the steerer tube spacer required is the distance remaining after allowing for the headset upper stack height and half the height of the stem’s steerer clamp. This calculation will work even if only the total headset stack height is known. Enter the total headset stack height as either the upper or lower height, and zero for the

Fig. 3 - Saddle & Seatpost Geometry
Typical lengths of manufactured forks are provided on the component geometry worksheet.

**Detail for toe clearance calculation**

The dimensions describing the shoe-pedal combination and crankset are used to assess the potential for interference between the shoe toe and the front tire. The required inputs are the radius of an arc with its center on the pedal axle that defines the extreme of the shoe toe; the distance that the center of the shoe toe is located from the centerline of the frame when the shoe is clipped into the pedal (the shoe semi-tread); and the radius of the shoe toe itself, as seen in a plan view. Using the specified frame geometry and tire radius, the path of the front tire and the distance between the shoe toe and the tire are calculated as the steerer is turned through a range of angles. The results are shown on the Toe Clearance Plot, Figure 4. In this view the path described by the tire radius as the steerer is turned is plotted at its nearest possible proximity to the shoe toe. The minimum calculated clearance is captured and displayed in the calculated outputs on the Frame Geometry Worksheet. The calculated clearance is an absolute distance to the circle described by the shoe toe radius. A simple projected overlap of the front wheel and shoe toe, as seen from the side, is also calculated.
Detail for tube lengths and clearance calculations

The final frame geometry inputs, including the head tube lower extension (distance from the intersection of head tube and down tube centerlines to the lower end of the head tube), seat tube extension, and tube diameters allow the down tube centerline to be drawn, and calculation of tube clearances and the free lengths of the head tube and seat tube. Definitions of these dimensions are shown in Figure 5. The calculated clearance between the front tire and the down tube is made conservatively, assuming that the lower surface of the down tube is tangent to the bottom bracket shell.

Fork crown and front brake dimensions

Fork crown details and front rim braking surface average radius are included so that the clearance between the front tire and the inside of the fork crown and the required front brake reach, including the effects of fork offset and brake offset can be determined. The required dimensions and definitions are shown in Figures 6 and 6a. Note that the front tire to fork crown clearance calculation is made along a radial line from the front axle to the point identified by the crown height and crown front depth inputs. The minimum clearance will typically be at the front inside corner at the center of the crown, but can vary with crown type. For clincher tires, the braking surface average radius can be approximated as half the
bead seat diameter of the tire.

The required front brake reach and the front axle to brake center bolt distance are calculated for two cases. The first is for curved fork blades, where the brake center bolt is perpendicular to the steerer axis and the brake reach and front axle to brake center bolt distances are measured parallel to the steerer axis. In this case brake offset is the distance from the steerer axis to the center of the brake pad, measured in the central plane of the fork. The second case is for fork crowns and manufactured forks using straight blades, where the brake center bolt hole is perpendicular to the fork blade axis, and the brake reach and front axle to brake center bolt distances are measured parallel to the fork blade axis. The line connecting the center of the crown race seat and the center of the front axle defines the fork blade axis and the fork blade length. In this case, brake offset is the distance from the fork blade axis to the center of the brake pad. The schematic representations of the front brake in the Position Plot and the Frame Plot (described below) are drawn assuming the curved blade case.

If a manufactured fork is used, its length and the distance from the crown race seat to the brake center bolt are fixed. These dimensions are specified directly by input, with the required brake reach being a calculated output. Manufactured forks using cantilever brakes can be accommodated by using the distance from the crown race seat to the cantilever pivots as the brake center bolt input, with the resulting calculated brake reach being negative. For curved fork blades, this is equal to the fork length minus the axle to brake pivot length. For straight blades it will be the blade length minus the axle to brake pivot length. Excel’s Goal Seek function (select Tools -> Goal Seek on the top menu bar) can be used to vary the brake center bolt input so the axle to brake pivot length dimension of the fork is matched.

A specially built fork using a cast crown will have only the brake center bolt distance fixed, and so the fork length input may be varied to achieve a particular tire
clearance or brake reach dimension. A specially built fork using cantilever brakes is not constrained in length or brake center bolt distance. The length can be chosen to get the desired tire clearance and the brake center bolt distance may be varied to achieve any desired brake reach dimension, with the appropriate calculated axle to brake center bolt dimension being used to locate the brake pivots for either curved or straight blades.

**Calculated Outputs**

Calculated frame dimensions appear below the input section on the Frame Geometry Worksheet. Using the frame geometry inputs, the principal dimensions of the frame are determined in the following sequence:

First, the radius of the rear wheel establishes a horizontal datum above the ground. The bottom bracket drop dimension then locates the bottom bracket center vertically. The chain stay length then locates the rear axle center on the horizontal datum relative to the bottom bracket center. Seat tube angle and virtual seat tube length are used to locate the seat tube-horizontal top tube intersection, and horizontal top tube length locates the top tube-head tube intersection point. A line passing through the top tube-head tube intersection at the specified head tube angle then defines the steerer axis. Finally, the front axle center is located at a distance equal to the front wheel radius above the ground and a distance equal to the specified fork offset from the steerer axis. At this point, bottom bracket height above ground, wheelbase, front center, and trail have all been fixed, and their dimensions are calculated. Figure 5 shows the nomenclature used for the frame angles, and the height, extension, and free length of the tubes.

Two calculated reach dimensions are included in the output section: The first is the diagonal distance from the reference location on the saddle to a point defined at handlebar clamp center height and at the horizontal distance of the farthest extreme of the handlebar centerline with the bars positioned (rotated) as specified. The other calculated reach is the diagonal distance from the saddle reference point to the stem’s handlebar clamp center.

Additional calculations of interest may be added if desired. Any of the outputs can be quickly driven to any desired value using Excel’s Goal Seek (single independent variable) or Solver (multiple independent variables) functions to vary the appropriate input(s). Excel’s Auditing functions can be used to trace dependencies.
Comparing A Production Frame to a Desired Rider Position

An existing frame design can be compared against a specified rider position with a relatively limited set of inputs, all of which are on the Frame Geometry Worksheet.

The first requirement is to specify rider position using the saddle height, the horizontal distance from the bottom bracket center to the saddle reference point, the desired reach and stem position (handlebar drop), and the handlebar rotation. These are in the block titled Position Inputs. Mass and CG data may be included, if known.

The next 28 inputs on the Frame Geometry Worksheet (“Basic Frame Geometry Inputs” through “Detail for Toe Clearance”) plus the handlebar description will define all of the overall frame dimensions and angles, and all of the component dimensions that affect fit (the pedal stack height input is actually used only to estimate the saddle height and shoe toe arc dimensions).

Frame manufacturers commonly provide most or all of the basic frame geometry, but not necessarily in the right form. Bottom bracket height from the ground might be specified instead of the drop from the wheel axle center height, for example, or a center-to-top dimension may be given for the seat tube length instead of center-to-center. Usually a simple calculation is all that is required to get the data in the right form. Alternatively, iteration may be performed to obtain missing inputs. For example, if trail and head tube angle are given but not the fork offset, Excel’s Goal Seek function can be used to determine the offset which results in the calculated trail matching the specification. Choosing Tools -> Goal Seek from the top menu bar accesses The Goal Seek function. To verify that the geometry has been accurately modeled, the calculated wheelbase, front center, etc. can be checked against the specification values.

Next are the details for the specific stem, crank, and saddle that will be used, and then the details that affect the steerer stack height and the toe clearance calculation. Finally, the appropriate handlebar description should be loaded if the reach is being measured to the extreme of the handlebar.

With the geometry and component data loaded in, the saddle deviation from neutral, the required steerer and spacer lengths and the toe clearance can be observed on the position and toe clearance plots, and in the calculated outputs section. Stem length can now be varied to achieve the desired reach. The vertical height of the bar clamp center will be maintained, and a new steerer and spacer length will be calculated for any given stem length.
A Frame Design Scenario

A successful bicycle frame design makes sound mechanical connections with the components that establish the rider’s contact points (saddle, handlebars, and pedals) in their desired positions, is free from interference between the wheels and frame tubes or the rider’s feet, has the desired geometrical characteristics which affect handling (trail, head tube angle, pedal ground clearance, and weight distribution), and is designed such that the frame itself can be constructed and the components fitted with mechanical integrity. That said, the strength of the frame as regards safety and durability, and its desired stiffness are not considered here. These characteristics will be determined by the selection of the frame’s materials and dimensions, and by the fabrication methods used. However, it is asserted that maximizing stiffness/weight is a desirable characteristic, and this is facilitated by minimizing wheelbase while observing the geometrical constraints described above. If wheelbase itself is a design constraint (longer than the minimum possible), it should be increased in such a way that weight distribution is not compromised.

The design space

To meet all of the requirements above, the designer has a number of interrelated variables to manipulate. The design problem is subject to the following constraints:

a) The rider has a desired position, which fixes the relationships between the bottom bracket center, saddle, and handlebars.

b) Bottom bracket height is set by the minimum pedal clearance required. Bottom bracket drop is varied to achieve the required bottom bracket height.

c) Seat tube angle is set by the saddle position (re the bottom bracket center) such that the saddle-mounting clamp will be approximately centered on the saddle rails. A slight variation of seat tube angle (offset within saddle rail adjustment range, or as permitted by an offset seatpost) might be considered to accommodate manufactured lug angles, or adjust rear tire clearance.

d) Head tube angle primarily affects low-speed steering response and vertical compliance. Values from about 71 to 75 degrees have been used successfully in the past, so head tube angle may vary freely within this range.

e) Fork offset (given a head tube angle) is determined by the desired trail.

f) The sum of top tube length and stem length is fixed by the position of the handlebars relative to the saddle. If a stem length and angle are chosen, and the handlebar location is fixed, the front wheel location and the desired trail then determine the exact location of the steerer axis, and therefore the head tube angle and top tube length. Trail, head tube angle, and stem length will have the largest effects on the handling characteristics of the bicycle.
g) The rider’s CG, which dominates weight distribution, will usually be somewhere close to the bottom bracket center. The bottom bracket must therefore be located at about 60 percent of the distance from the front axle to the rear axle to achieve a weight distribution of about 40/60 (front/rear). This, along with the wheel size(s), the minimum seat tube, down tube, and toe clearance, fixes the minimum chain stay length and front center distance. One classic text, *Cycling*, C.O.N.I. (Italian National Olympic Committee), Central Sports School, F.I.A.C., 1972, recommends a 45/55-weight distribution. Modern road bicycles seem to be built closer to 40/60. The range of acceptable weight distribution will therefore be taken as being between these two values.

h) The height of the frame (seat tube and head tube lengths) should be just sufficient to insure that the lengths of steerer tube and seatpost outside the frame are not excessive (requiring too much steerer tube spacer length or leaving too little of the seatpost within the seat tube), and/or the spacing between the top tube and down tube where they are joined to the head tube is not too small. Stand-over height (height of the top tube above the ground) becomes an issue with smaller riders using full-size wheels, and as the riding position becomes more upright. Stand-over height, defined here as the height of the top tube-head tube intersection, should not be more than the inseam measurement, and preferably several centimeters less. A sloping top tube (compact frame geometry) decouples the steerer stack and seatpost length constraints, and provides more stand-over clearance for most of the top tube length.
Using the Solver to Execute a Frame Design

Excel’s Solver utility is a multi-variable iteration scheme that is capable of optimizing (minimizing or maximizing) one “target” variable. The solver can easily be configured to iteratively find a solution to a frame design problem. The yellow and pink shaded cells on the Frame Geometry Worksheet are the independent and dependent variables, respectively, in the Solver scenario. The target (optimization) variable is wheelbase. The independent variables are manipulated by the Solver so as to minimize wheelbase for a given rider position while observing a number of constraints. These include the desired steering geometry, wheel clearances, steerer tube spacer height, available stem length, and keeping weight distribution within an acceptable range. Corresponding yellow and pink shaded cells on the Solver Matrix Worksheet are linked to the cells on the Frame Geometry Worksheet.

On the Solver Matrix Worksheet, the values in the pink shaded cells are read FROM the Frame Geometry Worksheet, and those in the yellow shaded cells are read BY the Frame Geometry Worksheet. The Solver will manipulate the values in the yellow cells, and read the response in the pink cells on the Solver Matrix Worksheet. The blue shaded cells are the values for the various constraints. These are constants that are chosen for a given design. Calculated Reach and Stand-over Height are read from the Frame Geometry Worksheet, but the remaining constraint values are direct inputs. Reverse shading (pink text on a black background) of dependent variable cells indicates variables that do not meet their constraints. Conditional Formatting accomplishes this, and the shading will change to black on pink when the constraint has been satisfied. The column between the dependent variable values and the constraint values shows the constraint type (=, >=, etc.). These are a reminder only, as the actual constraint types are set in the Solver’s dialog box. The table to the right is included for reference. It shows the values for a reference case, and a calculation of the change (the “Delta”) in each independent and dependent variable from the reference case. To quickly reset the design to the reference case, copy and paste the reference case independent variable values into the yellow shaded independent variable value cells.

Important: The pink shaded cells on the Solver Matrix Worksheet can read the values from the Frame Geometry Worksheet without affecting its function in “manual” design mode. If it is desired to use the Solver to design a frame, the independent variable inputs on the Frame geometry Worksheet (yellow shaded cells) must be configured so that their values are read from the Solver Matrix Worksheet. To do this manually, go to the Frame Geometry Worksheet, select (click on) the yellow shaded cell corresponding to the first independent variable, type “=”, then go to the Solver Matrix Worksheet and select the corresponding independent variable value cell and press Enter. This process is repeated for all of the remaining independent variable value cells. Note that there should be a starting value for each independent variable on the Solver Matrix Worksheet (use the input value from the reference case) so that the Solver has a reasonable starting point.

To speed up the process of changing from manual to automated design mode and back, macros have been written to connect and disconnect the solver independent variables from the Frame Geometry Worksheet as described above. The Connect_Solver_Independents macro first copies the existing values from the
independent variable cells on the Frame Geometry Worksheet into the solver matrix, and then sets the Frame Geometry Worksheet cells equal to the solver matrix independent variable cells. The Disconnect_Solver_Independents macro reverses this process by copying the values of the independent variables on the Frame Geometry Worksheet and pasting them back into their respective cells. Another macro, Reset_Solver_Matrix_Reference_Values, copies the independent and dependent values in the solver matrix into the table at the right. This sets the current design as the reference to which the solver matrix values for subsequent solutions are compared.

To use these macros, execute the following steps:

- Choose Tools -> Macro -> Macros from the top menu bar to show the listing of available macros.
- Choose the desired operation by selecting the name of the macro to run, and then click "Run."

**Running the Solver**

Connect the solver independent variable cells to the Frame Geometry Worksheet by running the Connect_Solver_Independents macro. From the Solver Matrix Worksheet, choose Tools, then Solver... from the top menu bar to bring up the solver dialog box. If the Solver does not appear in the Tools drop-down, it may have to be loaded from the Add-Ins menu. Choose Tools, then Add-Ins..., and then check the Solver box to load the Solver Add-In.

The Solver Dialog box is loaded with the cell references for the target cell and the independent (input) and dependent (output) variable constraints. A Solver set-up is unique to the worksheet from which it is opened, and all variables used by the Solver must be on that worksheet. The variables used in the frame design problem are all contained on the Frame Geometry Worksheet, however the Solver Matrix Worksheet is used to collect and organize the variables in such a way as to make them more visible than they are as cell references in the Solver dialog box.

Click on the Solve button to launch the Solver. If nothing has been changed from the default inputs, something close to the default frame geometry solution will result, and the message “Solver found a solution” will appear. If the Frame Geometry Worksheet does not read one or more of the independent variable value cells from the Solver Matrix Worksheet, there will be no effect when the Solver changes the value. An immediate “Solver could not find a feasible solution” message will appear when the Solver is launched. Be sure that the Connect_Solver_Independents macro has been run prior to launching the solver.

**Important:** Executing any macro that recalls values from the Design Library Worksheet (see below) into active Frame Geometry Worksheet independent variable cells will disconnect them from the solver. Rerunning the Connect_Solver_Independents macro will restore the connections.

To get a feel for the effect of various design choices, one can experiment by changing one constraint (say head tube angle), re-running the Solver, and observing the changes to the frame geometry by looking at the independent variables (in this case, top
tube length will be traded for stem length, and fork offset will be adjusted to maintain trail). The position plot can also be examined to see the resulting geometry.

To execute a new design, load the desired position inputs into the Frame Geometry Worksheet, set appropriate values for crank length, pedal stack height, and shoe toe radius, and make any desired changes to the saddle, stem, and handlebar descriptions. At this point the position plot can be examined to see how the saddle and handlebars have been repositioned, and that the new shoe toe arc has been defined. Note that the horizontal positioning of the handlebars will not satisfy the desired reach until the stem and top tube dimensions have been found. Since weight distribution is an active variable in the solution, rider weight and CG should be entered, as well as an estimated bicycle weight and weight distribution. For an approximate guess of rider CG relative to the bottom bracket center, a value of zero will be close, and bicycle (without rider) weight distribution will be approximately 50% on the front axle. See the CG Calculator Worksheet to determine more exact values. Make any changes to the fixed inputs (tube diameters e.g.), and to the constraint values on the Solver Matrix worksheet (such as top tube angle, steerer tube spacer height, bottom bracket height, trail, clearances, etc.), and run the solver.

The existing constraint values can be modified to force particular solutions. For example, the head tube angle, steerer tube spacer height, stem length, and weight distribution constraints specify minimum and maximum values. Using the same value for both will force the design to exactly that value, provided that there is a solution. It may help to enter the desired value into the corresponding independent variable value cell to start the solver with this constraint already satisfied. It is suggested that running the solver with relatively “open” constraints on these parameters be tried first, to see if there is a solution. Then, particular values can be dialed in as desired.

Adding a new constraints requires setting an unused dependent variable value cell in the solver matrix equal to the desired variable (which will typically be a calculated result from the Frame Geometry or Tube Description Worksheet), and adding that cell and a desired value cell reference or value to the constraints in the Solver dialog box.

An independent variable can be constrained by making it both an independent and a dependent variable, or it can simply be eliminated from the solver set-up (removing the cell reference from the “By Changing Cells” list in the Solver dialog box). Caution must be exercised, however, since the problem may become over-constrained. If, for example, an exact seat tube angle is desired the “saddle deviation from neutral” constraint would have to be removed from the solver set-up, since for a given saddle height the seat tube angle and saddle deviation from neutral are not independent. Alternatively, the saddle deviation from neutral that produces the desired seat tube angle can simply be entered as the constraint value.

The solution does not necessarily have to minimize wheelbase (the target cell variable). If a specific wheelbase is desired, the constraint setting for the target cell in the Solver dialog box can be changed from “minimize” to “value of” and a specific value for the target cell can be entered. Asking for a wheelbase that is longer than the minimum will result in increasing the chain stay length and/or front center distance in such a way that weight distribution is kept within the specified range. The solution found by the
solver in this case may not be the only one possible, since weight distribution is floating within the allowable range. Since a minimum wheelbase design will likely have the rear wheel positioned as close to the seat tube as possible, and a weight distribution very near the aft limit (40/60), the chain stay could be lengthened first, and weight distribution allowed to move forward. Another way to solve this problem would be to minimize wheelbase, but specify more rear wheel clearance or a more forward weight distribution. This will keep the front triangle as short as possible, and force the rear triangle to get longer. This example illustrates the power of this technique, since many solutions can be tried quickly.

**Troubleshooting**

If the message “Solver could not find a feasible solution” appears in the dialog box after the solver runs, it may mean that one or more constraints cannot be met. Conditional Formatting is used to highlight dependent variable cells (by reversing the text and background colors) whose values do not meet their constraints, making them easy to identify. If, for example, all constraints are met except steerer tube spacer height $\geq 0$ (spacer height is negative), it may not be possible to achieve the desired handlebar drop with the other choices that have been made. Reducing the minimum gap between the top tube and down tube at the head tube, tube diameters, the front wheel size, or the drop distance itself may permit a solution. The position plot can also be examined to help diagnose solution failures and suggest alternatives.

It is possible that the solver will fail to converge to a solution because the set of independent variable values that it started with placed it in a condition from which it could not recover. Sometimes restarting the solver after changing one of the independent variable values in the Solver Matrix will meet with success. Head tube angle is a good variable to try, since it will affect a number of the constraints.
The Tube Description Worksheet

The Tube Description Worksheet takes the dimensions from the Frame Geometry Worksheet, plus a few more specific tube dimension inputs and calculates the mitered length of each frame tube and creates a two-dimensional description of its finished shape.

A description of the rear dropout and its orientation is factored into the calculated lengths of the seat and chain stays. Cells that are shaded gray are inputs carried over from the Frame Geometry Worksheet. These are repeated here to show which Frame Geometry inputs are used in the calculations on the Tube Description Worksheet.

**Main Frame Tubes**

Figures 7 and 8 show how the dimensions are defined for each of the main tubes and the chain stays. Note that the mitered tubes do not have to be circular in section, or have the same dimensions at both ends. For these calculations it is sufficient to specify the height and width of each mitered tube at each joint. The head tube and bottom bracket shell are assumed to be circular in section, as is the upper end of the seat tube.

Several length dimensions are computed for each tube. The first is the mitered length on the tube axis, which can be thought of as the length as measured along the side, 90-degrees from the top centerline. This accounts for the reduction from the center-to-

![Fig. 7 - Frame Tube Length Nomenclature](image-url)
center length in the event that the mitered tubes are smaller (narrower in width) than the intersected tubes. Note that to have sufficient material to make the full theoretical miter profile, tubes will need to have the end cuts made at the joint angles whenever the joint angle is other than 90 degrees and the mitered tube is narrower than the intersected tube. In this case, a 90-degree cut could leave the tube as much as several millimeters short. This effect can be seen by looking at the plot of mitered tube length vs. angular position on the Tube Mitering Worksheet. The additional length required is the difference between the length shown at 90 degrees and the maximum length on the miter profile plot. The miter relief is the distance (measured along the surface of the tube) that the tube must be relieved from the plane of a cut made at the joint angle to complete the miter.

The second length computed is the overall length of the finished tube, which is found directly from the two-dimensional finished shape definition. This is the length of tube required, with square end cuts, to complete the full theoretical mitered profile.

A minimum length on the top centerline of each tube is also calculated. The top centerline is a line along the tube’s length on its upper-most surface. This dimension may be the most convenient to work from if templates are being used to trace the miter profiles, or if a machine process will be used to miter the tubes. Note that for the down tube’s bottom bracket end, the measuring point is rotated 90 degrees to the side of the tube. This is done because most of the miter interfaces with the bottom bracket shell, which is perpendicular to the head tube. Figure 7 shows these details. Chain stay minimum length is treated similarly, being measured on the lateral (outside) surface.

**Rear Dropout and Stays**

The basic frame geometry is defined with the seat and chain stay axes both passing through the rear axle center, and with the upper end of the seat stay axis passing through the seat tube-top tube intersection point. This may not be the case due to dropout geometry, and for designs where the upper end of the seat stay is located lower or higher on the seat tube. The actual positions of the seat and chain stays are determined on this worksheet.
First, a new intersection point for the seat stays and seat tube axes may be defined by entering an offset from the seat tube-top tube intersection, as measured along the seat tube axis.

Seat and chain stay offsets from the rear axle center at the rear dropouts, as well as the length of the stays, are determined by the specific dropout geometry and by the orientation of the dropout. The important features of dropout geometry as regards the stay lengths and positions are the angle at which the tangs (or sockets) are positioned with respect to each other and with respect to the horizontal, and the lengths of the tangs. The dropout can also be rotated about its nominal axle center to adjust the angles at which the stays meet the tangs. This will alter the chain stay-seat tube angle slightly, which may be important in lugged construction where the bottom bracket shell defines this angle within a small tolerance. If dropout geometry and position results in offsets, the seat stay axis is rotated about its defined intersection with the seat tube axis, and the chain stay axis rotates about its intersection with the bottom bracket center.

Dropout geometry is specified by nine inputs on the Tube Description Worksheet. The salient features of any type of dropout can be expressed using these parameters, which are detailed in Figure 9. Samples of the inputs for various types of dropouts are included on the Component Geometry Worksheet. The angular position of the dropout will nominally be set such that the axis of the chain stay tang will pass through the bottom bracket center. If a deviation from this position is desired, it may be specified.
through an input on the Tube Description Worksheet. A positive value here will cause the dropout to be rotated from the nominal position in a counter-clockwise direction.

Two indicators of the alignment of the stays with the dropout are calculated. One is the deviation angle of the stay axis from the dropout tang, with a value of zero corresponding to the stay axis being aligned with the tang axis. The other is the offset of the stay axis from the rear axle center. This is the perpendicular distance from the nominal rear axle center to the stay axis.

Chain stay length calculations are similar to the main triangle tubes, but since the stays are not parallel to the frame’s central plane, the true length from the bottom bracket center to the dropout must be calculated first. To do this, the spacing of the stay centerlines at the bottom bracket shell must be provided, and the rear dropout spacing to the dropout centerlines is calculated from the rear hub over-locknut dimension and the dropout thickness. The length taken up by the dropout, as determined by the dropout geometry and its specified angular position, is taken into account. For socket-type and plug-type dropouts, the length taken up by the dropout is known exactly. For dropouts that are slotted into the stays, some stay length may be used to blend the dropout-stay joints. In this case it is best to define the dropout tang lengths to the point where the stay material ends.

Dropout dimensions and spacing also define the splay angle and joint angle at the bottom bracket. The length of both straight and curved stays and their splay angles are measured along a theoretical axis defined by the end points. The local joint angle for a curved stay, however, may be different from the splay angle.

Seat stay length calculations are the same as for the chain stays with regard to the effects of dropout geometry and position, and the splay angle. The true length is given to the seat stay-seat tube intersection. More or less length may be needed depending on how the upper ends are joined to the seat tube.

The chain stay-seat tube internal angle and the chain stay-seat stay internal angle are recalculated on this worksheet to reflect the dropout geometry, and replace those found on the Frame Geometry Worksheet. There is also a calculation of the true angle of intersection between the seat stay and seat tube axes. This angle can be used to create miter templates for “fastback” seat stay attachment, where the seat stays are mitered into the back of the seat lug or seat tube, below the seat post binder bolt.

Curved chain stays

The Tube Description Worksheet includes provision for defining chain stays that are curved to provide additional tire or chainring clearance. Curved chain stays are defined by the shape of their central axes. These will remain in the same plane as for straight stays, and have the same end points. Left and right stays are drawn as mirror images, but two distinct patterns can be defined and used.

Beginning at the bottom bracket shell and proceeding rearward, the available features are: a straight length; a first bend defined by its radius and swept angle; a second straight length; and a second bend defined by its radius and swept angle. The remaining straight length is calculated to match the required length from the bottom bracket shell to the rear dropout. If the total length resulting from the two input lengths and bends
exceeds the required length, the remaining length calculated will be negative, and the stay will appear to fold back on itself. In this case, the straight lengths or bend radii must be reduced. Setting all inputs to zero will result in a straight stay with uniform taper.

For the bends, a positive swept angle input causes the stay to bend away from the central plane of the bicycle, and a negative value has the opposite effect. A final input defines a length along the central axis, measured from the bottom bracket shell, over which the cross section of the stay will remain constant. Any taper, as specified by a difference in height and width dimensions from the front of the stay to the back, will begin at this length.

The shaped stay and the resulting clearances for the rear tire and chainrings can be seen in the Drive Train Plot. The Tube Layout Plot also shows a view of the finished stay, and includes the locations of the bends.

**Rear Brake Dimensions and Location**

These inputs are used to determine the location of the rear brake bridge or cantilever brake pivots on the seat stays. The resulting rear axle to brake center bolt distance is measured in the central plane of the frame, and parallel to the plane defined by the seat stay axes. It includes the effect of both the rear brake offset input and the calculated rear axle offset from the seat stay axis as determined by the rear dropout geometry. Note that the rear brake offset is measured from and perpendicular to the plane defined by the axes of the seat stays to the center of the brake pad. Positive offset positions the brake pads behind the seat stays.
The Frame Plot

Additional calculations on the Tube Description Worksheet take the dimensions from the tube cut list and complete a definition of each tube as seen in an elevation view. The tubes are then positioned over the frame geometry to create a plot of the assembled frame, as shown in Figure 10. This confirms that the calculated dimensions of each tube are correct, and shows the intended positions of the rear dropout and the seat and chain stays. The intersection of the steerer axis with horizontal lines drawn through the rear wheel axle and the bottom bracket center are calculated and shown on the plot to aid in setting up a fixture. Placing the cursor over these points on the frame plot will cause the exact values of these coordinates to be shown.

Making a Full-Size Plot of the Frame

It is possible to make a full-size print of the frame plot if the computer has access to an "E" size plotter. Select it and choose E-size media, 36 x 48". A print shop should be able to do this for you too. It may take one or two tries to get the print to come out exactly 1:1, which is accomplished by appropriately choosing the scales on the plot. In a recent test plot, a field of 1128mm horizontal x 837mm vertical resulted with all page margins (in the page set-up dialog box) set at 0.5" and 0" header and footer margins. The scales on the plot (in "format axis") would then be -500 (min) to 628 (max) on the x-axis, and -100 (min) to 737 (max) on the y-axis. Background shading should be white.
The Drive Train Plot

The Tube Description Worksheet contains inputs describing the drive train components. A definition of the chain stays as seen from above is used to create a view in the plane of the chain stay axes that shows the positions of the rear tire, chainrings, rear cassette, and crank arm end in relation to the chain stays. This plot, shown in Figure 11, can be used to check the tire clearance between the stays, and the clearances between the right-side chain stay and the chainrings, the cassette, and the crank arm. Curved or dimpled stays can be used to alter the clearances.

**Crankset Description**

For the crankset description, the chain line distance (center of the bottom bracket to the center of a single chainring, or the middle of a two or three chainring group), the spacing and sizes of the chainrings, the diameter of the crank arm end at the pedal attachment and the crankset’s “Q-factor” must be supplied. Q-factor is defined as the distance between the outer faces of the crank arms at the pedal attachment points.

Chainring data is entered beginning from the innermost and going to the outermost. A single-chainring crankset uses chainring one; a double uses chainrings one and two; and a triple one, two, and three. On the Drive Train Plot each chainring is shown as
a line with length equal to the pitch diameter. A typical tooth profile is added at the trailing end near the chain stay to show the actual clearance.

**Rear Cassette Description**

The cassette is represented by its outermost and innermost sprockets, which are spaced according to the total number of sprockets and the spacing between their centerlines. The cassette is positioned on the axle centerline according to the distance from the axle locknut (or dropout inner face) to the centerline of the outermost sprocket. As with the chainrings, the sprockets are shown as a line with length equal to the pitch diameter. A typical tooth profile is added to the outermost sprocket to show the clearance to the chain stay. Any number of sprockets may be entered.
The Tube Layout Plot

To facilitate the cutting and mitering the frame tubes, the Tube Layout Plot, Figure 12, shows the finished shapes of the individual tubes (except for the seat stays), with some key dimensions.

Each tube is indexed at a length reference point identified on the plot by an open circle symbol. A “+” symbol shows the location of other reference points, to which a dimension is given. The value shown corresponds to the length from the index point to the reference point as measured parallel to the tube’s central axis. For curved chain stays, the length shown is measured parallel to the central axis at the bottom bracket end. The overall lengths indicate the total length of tube required, and in the case of a curved chain stay, this will be for the length as measured along the axis.

The view of the main tubes is as they are seen from the right side of the frame, and the view of the right-hand (drive-side) chain stay is as it would be seen from above. The left-hand chain stay is assumed to be a mirror image of the right. Note that the miter profiles shown are for either round or elliptical tube sections as specified by the tube height and width inputs. The dimensions shown are at the extreme of the height specified, and so are independent of the actual tube cross sections.

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Fig. 12 - Tube Layout Plot
The Design Library Worksheet

The Design Library Worksheet serves as a repository for completed designs and as a source of information for building new designs based on previous work. Users who have become familiar with this tool may want to assemble a complete input set on the Design Library Worksheet, and then load it into the model using the macros described below.

**Design Data Records**

On the Design Library Worksheet, a design record consists of a single row with columns numbered from 0 to 126. The actual data is in columns 1 through 126, while column zero is a data set identifier that is or will be the Project Title from the Frame Geometry Worksheet. It is also the reference column for the automated storage and retrieval macros (see below). Each record may contain some or all of the inputs from the Frame Geometry and Tube Description worksheets.

**Data Groups and Design Library Macros**

To automate the recording and retrieval of completed designs and the development of new ones, a series of Visual Basic macros has been created to move input data to and from the Design Library worksheet and the Frame Geometry and Tube Description worksheets.

Separate macros handle the design data in the following groups:

**Rider Measurements**

These are the four anatomical measurements used to calculate estimated frame dimensions and rider position, plus the foot length measurement and the constant used to estimate the shoe toe arc. Note that the estimated shoe toe arc calculation uses the pedal stack height input, which is not included in this group of inputs.

**Estimated Position and Frame Dimension Constants**

These are the constants used to estimate the top tube, stem, and seat tube dimensions, and the position inputs (rider contact point locations). The “override” values are not stored, but the actual inputs used will be stored in subsequent groups.

**Position Inputs**

These are the inputs that actually position the saddle and display the desired position of the handlebar contact point on the Position Plot. The rider and bicycle mass and CG inputs are also included in this group.

**Basic Frame Geometry**

These inputs describe the frame angles, the tube lengths between intersections, the bottom bracket drop, the fork offset, and the wheel diameters.
Interface Components

The interface component input group comprises the stem description, the crank length and the pedal stack height, the saddle description and saddle reference point definition, the handlebar description, and the information used to calculate toe clearance.

Tube, Fork, and Dropout Dimensions

This group contains all of the dimensional information related to the tube diameters and extensions (length beyond the intersection points), the fork crown, front and rear brakes, and headset stack dimensions, as well as the stay dimensions and the rear dropout description.

Drive Train Components

The drive train component input group includes the rear hub width and rear tire size, the crankset description (chainrings, chain line, “Q” factor, and crank arm end), and the rear cassette description.

Using the Design Library macros

Each macro is named for the group of data that it handles, with the prefix ‘Store’ or ‘Recall,’ depending upon its function. Two additional macros, Store_All and Recall_All, have been created to record or retrieve the entire set of inputs for a design by running all of the individual store or recall macros. The Store_All and Recall_All macros are the only ones that read or write the Project Title. These also have button objects on the Library Worksheet to run them with a single mouse-click.

The data group to which each input parameter belongs is identified by a color code at the top of the columns on the Design Library Worksheet.

To use the Design Library macros, use the following steps:

- Go to the Design Library Worksheet
- Select a design by clicking on its Project Title cell in column zero.
- If new design data is to be stored, choose a blank row, type a name in the Design Case Identifier Cell, and press enter. Note: if Store_All is used, the Project Title from the Frame Geometry Worksheet will be written to the
- Choose Tools -> Macro -> Macros from the top menu bar to show the listing of available macros.

Choose the desired operation by selecting the name of the macro to run, and then click "Run."

The macros will store and retrieve data with reference to the Project Title cell that is selected when the macro is run, and finish with that same cell selected.

Cautions

Be sure to select a cell in column zero of the Design Library worksheet before running any of the macros. The ‘Store’ macros will write over some or all of the 126
cells immediately to the right of the cell that is selected when the macro runs, and this cannot be reversed. If a ‘Recall’ function has been run in error, however, selecting the correct starting reference cell and rerunning the operation will load the correct data on the Frame Geometry and Tube Description worksheets. Of course, this will only be possible if the data that was overwritten on the Frame Geometry and/or Tube Description worksheets was previously saved to the Design Library. Also be aware that a ‘Recall’ function may interfere with the automated design process using the Solver by replacing a reference to a Solver Matrix independent variable cell with a constant, thus disconnecting that variable from the Solver Matrix Worksheet. Rerunning the Connect_Solver_Independents macro will correct this situation.

Using the Design Library as a Database

Additional identifying information may be added to each record by inserting new columns to the left of column zero, or to the right of column 126 (the last input data column). If not included in the Project Title, information such as a date or record number might be useful, as would such things as a description of the tube set used, or the type or model name of the frame. Using the database functions available in Excel, any or several of these identifiers can be used to sort or filter the data records.

To sort, select the rows to be sorted, and then choose Data -> Sort from the top menu bar. If a blank row is maintained above the design record data, selecting a cell anywhere within the block of records before choosing Data -> Sort from the menu bar will automatically cause the entire block to be selected for sorting. Filtering can be used to select certain data records, such as those sharing a common identifier or those within a certain range of an identifier. Selecting a cell within the block of records and then choosing Data -> Filter -> Autofilter will activate a filter pull-down for all columns.
Comparing Against a Reference Design and Position

Often it is desirable to graphically compare a new design or riding position against a fixed reference. This can be used to track the evolution of a design, compare a new design to an existing one, or similarly to compare or track alterations to the riding position. This feature is available for the Position and Toe Clearance Plots. The reference data that is to be displayed is stored on and controlled by inputs on the Plot Controls Worksheet as described below. The reference design is shown on the plots in dark gray to differentiate it from the current design’s colored lines.

The Plot Controls Worksheet

The Plot Controls Worksheet replicates most of the data for the Position and Toe Clearance Plots for the current design case. At any point, a static copy of this data can be saved and subsequently displayed as a reference along with the data for another design. Inputs on the Plot Controls worksheet select which elements of the reference design are to be shown on the plots. An example of this is shown in Figure 13. The user may elect to display any or all of the following on the Position Plot: the Project Title, Saddle, Handlebars, Frame and Fork, Wheels, Position Dimension Lines, and Frame Dimension Lines. The user may also choose whether to display the reference case toe clearance.
diagram on the Toe Clearance Plot. Entering ‘yes’ in the cell opposite a data set makes the selection, and any other value will turn that particular element off.

To fix the reference design, the replicated data for the current design is copied from the current design area into the fixed reference area on the Plot Controls worksheet by running the Set_Pos_Plot_References macro. A button that runs the macro is provided on the Plot Controls worksheet for this purpose. This macro copies all of the values in columns A and B, and writes them into the fixed reference area, columns C and D. Since only the numerical values are carried over, this data will remain unchanged as the current design is altered, or a new design is loaded.

Since only “output” information is saved for the reference design, it is suggested that the entire design for the reference case be stored to the Design Library Worksheet, if it is not already an existing record, before proceeding with changes to the design or overwriting it by loading another design from the library.
The Tube Mitering Worksheet and Miter Template Plot

The Tube Mitering Worksheet calculates the coordinates at the end of a circular tube, as defined by its intersection with another circular tube. The influence of an optional third tube, whose axis is perpendicular to the plane of intersection of the first two, and passes through the same intersection point, can also be calculated. These data are used to produce a plot which, when printed on paper at full-scale, can be used to make a template for tracing the miter profile on a frame tube.

The required inputs for an intersection of two tubes are the diameter and wall thickness of the mitered tube, the angle formed by the axes of the tubes, and the diameter of the intersected tube. The reference point for the miter profile is the top centerline of the mitered tube, at the point where it meets the intersected tube. The intersection angle is defined at that reference point also, so that a top tube-head tube intersection will use the external frame angle, and it will typically be less than 90 degrees. A down tube-head tube intersection will use the internal frame angle, and it will typically be greater than 90 degrees.

A left or right offset of the mitered tube can also be specified. This is where the mitered tube is displaced in a direction perpendicular to the plane of intersection (as defined when there is no offset) with no rotation. If the mitered tube is offset enough to put some part of it outside the boundary of the intersected tube, the mitered tube profile

Fig. 14 - Miter Template Plot
will be cut off at the length at which it last touches the intersected tube. For convenience, a duplicate, independent calculation of the true angle of intersection of the seat stays and seat tube is included on the Tube Mitering Worksheet. This is the same as the calculation on the Tube Description Worksheet.

To add a third tube, the only additional input required is its diameter. This option is used to produce a template for the lower end of the down tube, which may intersect with both the seat tube and the bottom bracket shell. The mitered tube is the down tube, the first intersected tube is the seat tube, and the second intersected tube is the bottom bracket shell. The angle of intersection specified is the seat tube-down tube internal angle. A down tube miter template with seat tube notch is shown in Figure 14.

The Tube Mitering Worksheet includes a table that collects the required inputs for the main triangle tube miters for the current design. These assume that the tubes are circular in section, with the diameters being taken from the “height” inputs on the Frame Geometry and Tube Description Worksheets. Each row in the table corresponds to a particular miter, and includes a descriptive label. This information can be copied and pasted (Edit -> Paste Special -> Values) into the miter template input cells. The descriptive label and information describing the miter (angle, diameters, and wall thickness of mitered tube) will be printed on the template plot.

**Getting a full-size template from the printer**

Producing a full-size template requires that the vertical and horizontal scales on the printed miter template plot have matching divisions and that they are of actual size. This is achieved by measuring the height and width of the plot area on a test plot, in the same units used to generate the template (millimeters, e.g.), and then adjusting the plot scales so that their lengths match the measured values.

The axes in an Excel plot are indexed at the lower-left corner, meaning that the minimum values specified for each axis will appear there. The template should appear approximately in the center of the page, and the major divisions on the plot should be “round” numbers (10 mm, e.g.).

The procedure then, for each axis is:

1) Measure the full width (or height) of the plot area (the area containing the grid) on a test plot in the same units as used to define the tube dimensions.

2) Divide this measurement by 2, and round it to the nearest value corresponding to a major unit on the plot.

3) On the Miter Template page of the workbook, select (click on) the plot axis to be adjusted.

4) Choose Format, then Selected Axis… from the menu bar at the top of the page.

5) Set the minimum value to the negative of the value found in 2) above.

6) Set the maximum value to the measured plot area dimension minus the value found in 2) above.
Example: Measured plot width = 224 mm. Minimum scale value = 224/2 = 112; round to 110 for major unit = 10 mm. Maximum scale value = 224 - 110 = 114.
Final note

No warranties expressed or implied - use at your own risk. Constructive criticism graciously accepted.

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