Australian 5" Gauge Track Notes

Track gauge

The track gauge is normally specified as 5" with a tolerance of -0 / +$^{1}/_{32}$" or 127mm -0 / +0.8mm. The rail is generally made from rectangular bar (25 x 10 or 20 x 10) and the top of this bar (the railhead) is flat and horizontal. Most wheels have tapered treads (approx 1.5º). There is no corresponding cant on the railhead and the contact point between the wheel and rail is at or near the inner edge of the rail.

Following sections discuss railhead profile and gauge widening.

Wheelset profiles

Metric dimensions here are overly precise to reduce errors when components are summed.

SLSLS (base for AALS)

Dimension	Inches	Millimetres
Back to Back (BB)	4 $^{9}/_{16}$ = 4.562	115.90
Flange Thickness (FT)	$^{5}/_{32}$ = 0.156	3.96
Root Radius (RR)	$^{1}/_{16}$ = 0.063	1.59
Wheel Check (BB + FT + RR)	4.782	121.45
Wheelset (BB + 2 * (FT + RR))	5.000	127.00
Flangeway (FT + RR)	0.219	5.55
Checkrail max spacing	4 $^{17}/_{32}$ = 4.531	115.09
Wheel minimum width	$^{5}/_{8}$ = 0.625	15.88

Fine Scale

Dimension	Inches	Millimetres
Back to Back (BB)	4 $^{11}/_{16}$ = 4.688	119.06
Flange Thickness (FT)	$^{3}/_{32}$ = 0.093	2.38
Root Radius (RR)	$^{1}/_{16}$ = 0.063	1.59
Wheel Check (BB + FT + RR)	4.844	123.03
Wheelset (BB + 2 * (FT + RR))	5.000	127.00
Flangeway (FT + RR)	0.156	3.97
Checkrail max spacing	4 $^{21}/_{32}$ = 4.656	118.27
Wheel minimum width	0.535	13.59

Warwick Allison has written some excellent articles about track and wheel design (see AME circa 2007). One highlighted point is the importance of the root radius and that it must be significantly larger than the railhead radius. This difference assists the wheelset to centre between the rails and provides a cushioned restraint when the wheelset drifts laterally. AALS specifies a root radius of 1.8mm and some UK profiles specify $^{3}/_{32}$" (2.38mm).

The wheelset profiles above pre-date the AALS profiles and are still applicable because wheelsets made to these profiles are still in use. The AALS wheelset profiles are very similar and compatible except that they rely on a slight railhead radius.

Ideal track

Good trackwork should accommodate the multiple wheelset profiles in use here. Some old profiles (e.g. SLSLS) make things simple by allowing for rail with no railhead radius and having the wheelset gauge (including the flange root radii) be exactly 5". AALS profiles are slightly more sophisticated and rely on a railhead radius (which will always happen in practice). Most UK wheelset profiles are slightly overgauge and do rely on a railhead radius. The EJ Winter profile does not require a railhead radius.

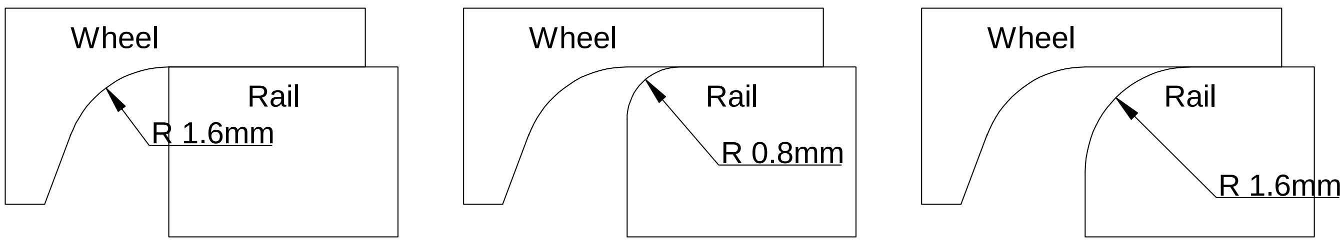
Railhead profile

Full-size rails have a domed railhead and the contact point with wheels is about 40mm from the inside edge. So for 1435mm gauge track the distance between the contact points is about 1515mm. 5" rail is rectangular bar with a flat top and rounded arrises. The radius of the inner arris is nominally $^1/_{32}$" (0.79mm) and as this is less than the flange root radius it follows that the distance between the contact points will be 5 $^1/_{16}$" or 128.59mm. Since the distance between the treads on a wheelset is 127mm it follows that a wheelset can wander laterally before being restrained by the root radius or the flange proper. This lateral clearance explains why track can be slightly undergauge and not cause problems. However, AALS might have included this clearance in their calculations because the sum of their wheelset dimensions exceeds 127mm. Railhead radius is not specified or considered by SLSLS. Some UK wheel profiles have a root radius of $^3/_{32}$" and do rely on a railhead radius.

Because the rectangular bar used for 5" rails is rolled and not machined it is risky to rely on the radius. AALS specifications state it should be from 0.5 to 1.0mm. If the radius is very small the arris will be sharp and might damage cast-iron wheels. If the radius is larger than 1.5mm it will be close to the flange root radius and this will increase rolling resistance when the wheel has lateral force pushing it against the rail and more importantly it means that lateral restraint will occur suddenly as the flange hits the rail instead of the restraint increasing gradually as the flange approaches the rail and the contact point moves across the root radius (see explanation below).

Because the railhead radius provides extra lateral clearance it appears to be the same as gauge widening. But this is not the case and any extra clearance here is due to the wheel flange and root radius design. If the wheels had vertical flanges and no root radius then the railhead radius would not affect the lateral clearance. Since most wheels with flanges do have a root radius the railhead radius might affect lateral restraint.

Railhead radius considerations



These examples use a flange root radius of 1.6mm and the gauge face of the rectangular rail is at the outer edge of the root radius. The first example has no railhead radius. The second has a railhead radius of 0.8mm. The third has a railhead radius of 1.6mm which is the same as the flange root radius.

With the first example the contact point is at the gauge face of the rail and as soon as the wheel moves right this point will move down the root radius. The ratio of the lateral and vertical force is equal to the tangent of the contact angle. This ratio starts at 0 and increases to 2.69 when the angle is 70º which is the end of the root radius and the start of the flange face. The key point with this example is that the angle increases from 0 as soon as the wheel moves right. When the wheel has moved 1.5mm right the angle is 70º.

With the second example there is a 0.8mm portion of the wheel tread between the start of the root radius and the top of the rail. So the wheel can move 0.8mm right before contact meets the root radius and the contact angle increases. At 1.55mm the angle is 70º and the tangent is 2.69. The distance from when the restraint starts till the limit is 1.55 – 0.8 = 0.75mm.

With the third example there is 1.6mm of tread before the root radius meets the top of the rail. So the wheel can move 1.6mm before the restraint starts. At this point the contact angle goes immediately from 0 to 70º. The distance from zero restraint to the limit is 0.

When the tangent is 2.69 (at a contact angle of 70º from vertical) the lateral force to maintain equilibrium is 2.69 times the vertical force. This far exceeds any normal lateral force on a wheel but not necessarily the instantaneous force when a locomotive encounters a bad kink in the track. Also the vertical force on the wheel (due to the weight on this wheel) can be reduced by undulations in the track or the flange trying to climb the rail. These reductions will increase the lateral/vertical ratio resulting from any lateral force.

These examples show that a railhead radius provides some lateral movement with no restraint. This is the same effect as gauge widening while the flange root radius does not meet the rail. But this clearance reduces the distance from the start of the restraint to the point of maximum restraint. The first example has the most cushioning because the restraint increases over a distance of 1.5mm. In the second example the distance is 0.75mm. In the third example the distance is 0 and the restraint is abrupt. This provides no distance to absorb the momentum of the lateral movement and the high spot force at the instant of contact is likely to push the wheel up and the flange will climb the rail.

These examples use the SLSLS policy where the outer edge of the root radius is directly above the rail gauge face. This policy is good because it allows for a railhead with a minuscule radius as might be expected with rectangular bar.

An alternative approach is to rely on a railhead radius and profile the wheelset so the outer edge of the flange root radius is at the point where the railhead radius meets the top face of the rail. In the middle example above the flange root radius could be increased from 1.6mm to 2.4mm and the outer edge of this radius would meet the outer edge of the 0.8mm railhead radius. The soft arris on the railhead will last longer than a sharp arris and be less likely to scar cast-iron wheels. The larger flange root radius increases the lateral distance across which the contact angle changes and results in a softer L/V curve similar to the first example.

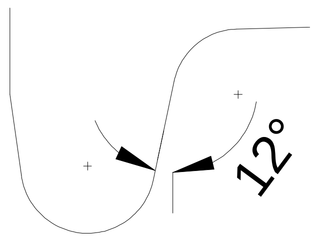
Some UK profiles (e.g. Martin Evans) use a $^{3}/_{32}$" root radius and the wheelset gauge (including the root radii) is 5 $^{1}/_{16}$" and this means it expects a 5" track gauge with a $^{1}/_{32}$" radius on each railhead.

The AALS profiles employ this approach to a lesser extent. Both profiles have a flange root radius of 1.8mm. The preferred profile sums to 127.6mm and the fine-scale profile sums to 128mm.

Because a railhead radius of $^{1}/_{32}$" (0.79mm) is required by some wheelset profiles and AALS recommends that the radius not exceed 1.0mm there really isn't much latitude here. Considering all the points here it is definitely best to ignore the railhead radius in gauge width calculations and just assume it is sufficient for the slightly overgauge wheelset profiles.

The considerations here suggest that the optimum railhead radius is $^{1}/_{32}$" (0.8mm).

Flange face angle



Rather than being vertical, the face of the flange slopes away from the rail at an angle of at least 12º. The AALS profiles specify a range of 12º to 20º. This is a very important feature of flange design and greatly assists when the wheel is being guided by the flange. The angle means there is always clearance between the outer circumference of the flange face and the gauge face of the rail. As a wheel travels forward the outer edge of the flange face comes down to rail level before the inner edge. This outer edge is inwards from the rail gauge face and this clearance stops the flange catching on small obstructions on the rail gauge face.

This clearance will also reduce the chance of the flange hitting a frog nose. For a fine-scale flange (most susceptible to hitting a frog nose) this clearance is about 0.34mm. Not much but maybe enough to help a wheel through a frog when there is zero flange clearance. The ride will still be rough but better than a derailment.

Gauge widening

Gauge widening is required on curves so vehicles with more than two axles in a rigid wheelbase can travel on the track without binding or derailing.

The formula to calculate the widening required is $w = r - \sqrt{(r^2 – (f / 2)^2)}$ where w = widening, r = curve radius, and f = fixed wheelbase length. The widening calculated here can be reduced slightly because there is clearance between the flange face and the gauge face of the rail. Reductions here (in excess of any clearance between the railhead and the flange root radius) will push the point of wheel and rail contact farther into the flange root radius and increase the lateral force particularly on the outer wheel of the leading axle. This increase in lateral force is not a good thing. Against this, gauge widening allows short wheelbase vehicles (e.g. bogies) to slew against the curve which is also not a good thing. So gauge widening should be the minimum required and perhaps even slightly less.

The widening calculated here can be reduced by factors such as the side play in all axles, wheels riding on the flange root radius, and the railhead radius. As the flange root radius and railhead radius will vary in this multi-profile environment they should be ignored here. If all locomotive axles have at least 0.5mm side play then the gauge widening can be reduced by 0.5mm. I'm not sure that relying on this side play is a good idea.

Generous gauge widening will accommodate a fixed wheelbase of 20 inches. For a 40 foot radius curve this calculates to $480 - \sqrt{(480^2 – 10^2)} = 0.104" = 2.65\text{mm}$. For this gauge widening at a frog the stock rail must be moved away 2.65mm, the checkrail stays in its original location, and the frog flangeway width is increased by 2.65mm by moving the wing rail away from the frog nose.

For a fixed wheelbase of 16" and a 40' curve the widening is 0.067" = 1.69mm.

Gauge widening should start before the curve and extend after. For a simple curve (no transition) the widening should start half the wheelbase before the curve and be half the required widening at the start of the curve. For a wheelbase of 16" and a 40' curve the widening should start 8" before the curve and be 0.85mm at the start of the curve.

Gauge widening should be done by moving the inner rail of the curve towards the centre of the curve rather than moving the outer rail away. This will provide a smoother path when entering and particularly when exiting the curve.

Some locomotives have thin flanges on intermediate driving wheels and this thinning is generally restricted to $^{1}/_{32}$" (0.79mm). This reduces but not necessarily eliminates the need for gauge widening. Factors that reduce the need for gauge widening are not considered here because they don't cater for the worst case scenario.

Gauge widening and checkrails

What must also be considered with gauge widening is the effect on flangeway widths. All flangeways must be widened by the calculated amount. If both rails on a curve have a checkrail at the same point then the checkrail spacing will be reduced by the widening amount. For example, if a track has a gauge of 127mm and flangeways of 6mm then the checkrail spacing will be 115mm. With gauge widening of 2mm the track gauge will be 129mm, the flangeways will be 8mm and the checkrail spacing will be 113mm.

Wheels with thin flanges do not affect the flangeway width adjustment for checkrails at the outer rail of the curve because the flange thinning is effected by trimming the front of the flange and not the back. Flangeways on the outer rail of a curve are rare except for the wing rails at the V-crossing of a turnout.

Insufficient flangeway widening on the inner rail of the curve can be more damaging than insufficient gauge widening. Because there is no root radius on the back of a flange the leading and trailing wheelsets can't move out when the back of the flange is trapped by a checkrail. So the intermediate wheelsets have to move farther in and this will increase the lateral force on these inner wheels. Without a checkrail some wheels can move out and some in and share the problem of getting a straight wheelbase through the curve.

Perceived problems with AALS specs

The AALS track/wheel specs referred to here are in the "Cop Stds" document dated April 2012.

a) On page 12 the track gauge is 127mm, the flangeway width is 6mm, and the track check gauge is 122mm. The track check gauge plus one flangeway width should equal the track gauge. The error is that the flangeway width plus check gauge add to 128mm which is not the track gauge.

b) On page 13 the check gauge is listed as 4.937" or 122mm. 4.937" is 4 $^{15}/_{16}$" which is not reasonable here. 122mm = 4.803". Possibly the imperial version is meant to be 4 $^{13}/_{16}$" or 4.8125". In the note below it mentions a check gauge of 4 $^{13}/_{16}$" and says this is 122.4mm. In fact it is 122.2mm. So it looks like a dimension of about 122.2mm is intended here.

c) On page 13 note 1 the formula assumes that check gauge plus flangeway width equals track gauge. This is not the case in these track specs. Also, this formula loses any clearance resulting from the wheelset check gauge being less than the track check gauge.

d) Metric measurements have been rounded and this introduces imprecision. Since the clearances available in the track profile here when accommodating both wheelset profiles are so small any imprecision here can cause problems. It is better to use the imperial dimensions and convert to sub-millimetre values if required.

e) The track flangeway width is 0.235". With a track gauge of 5.000" this means the track check gauge is 4.765". The fine-scale wheelset profile has a back to back dimension of 4.688" and a flange thickness of 0.106" giving a wheelset check gauge of 4.794". This exceeds the track check gauge by 0.029" and this means the flange will hit the frog nose. A solution employed by some is to increase the track gauge by $^{1}/_{32}$". This is done by moving the stock rail, the check rail, and the wing rail away from the frog nose. This will provide (just) a safe passage through the frog. The fine-scale wheelset will probably be running on the flange root radius and there will be a dip as it passes through the frog.

Example of corrected AALS track specs

For simplicity here I'll use the metric version of the track/wheel specs.

The track gauge is 127mm.

The fine-scale wheelset check gauge (back to back plus flange thickness) is 119mm + 2.7mm = 121.7mm. This does not include any clearance and so the track check gauge must be larger. The stated value is 122mm which is suitable and does provide some clearance.

The track check gauge is the track gauge minus one flangeway width. So the maximum flangeway width is 127 – 122 = 5mm.

The maximum checkrail spacing (to accommodate the preferred wheelset profile) is 115mm. Since the flangeway width just calculated is 5mm maximum the flangeway width for the opposite rail must be at least 122mm – 115mm = 7mm. In the case of a turnout the checkrail flangeway width is maximum 5mm and the frog flangeway width is minimum 7mm.

The preferred wheel profile has a flange thickness of 4mm and a root radius of 1.8mm which totals 5.8mm. The 5mm flangeway will accommodate the flange but because it's less than the flange plus root radius the wheel will bind slightly here.

Changing the track specifications to have a checkrail flangeway width of 5mm and a frog flangeway width of 7mm does provide a solution in this example. A railhead radius of 0.8mm should be specified to fully accommodate the preferred wheel profile.

Please note that this example uses the metric dimensions which are not necessarily accurate. A serious solution needs more precise dimensions.

Track Design at V-crossings

Using full-width flangeways

At the turnout crossing, checkrail flangeway = 5.55 (for SLSLS) and wheel check = 123.03 (for fine scale) so track gauge must be 128.58mm. Because checkrail max spacing is 115.09 (for SLSLS) the frog flangeway will be 128.58 – 115.09 – 5.55 = 7.94mm. This is before any adjustment for gauge widening.

The track gauge required here is 128.58mm plus any extra for gauge widening.

Sticking to 5" gauge

It is possible to reduce the required gauge to 5" by reducing the allowance for the root radius on each flange by 0.79mm. If the railhead is horizontal and has a sharp inner arris then the angle between the railhead and the wheel tread will be 30º. Since the inner arris should be rounded the angle will be less and the increase in the effective wheel diameter will be reduced.

If this approach is adopted, the checkrail flangeway width will be 4.76mm and the frog flangeway width will be 7.15mm. This is before any adjustment for gauge widening.

A variant here is to stick to 5" gauge and have a checkrail flangeway width of 5.55mm. This is fine for SLSLS wheels but risky for fine-scale wheels because there will be no clearance between the flange and the frog nose and any errors in the wheels or track will cause a rough ride or a derailment. AALS fine-scale flanges are 0.3mm thicker than UK fine-scale and will be even more prone to problems here.

Compromise

Sticking to 5" gauge (as above) will increase the rolling resistance of trains with SLSLS flanges because the wheels will bind at the checkrails due to the narrow flangeway width of 4.76mm. A compromise is to increase the track gauge by 0.79mm and use the proper checkrail flangeway width of 5.55mm. This will avoid the binding of SLSLS wheels. The distance from the checkrail to the frog nose will be 122.24mm. This is less than the fine-scale standard of 123.03mm and this means a fine-scale wheel might be running on the root radius when traversing a frog. But the error here is 0.79mm which is less than half the root radius and this means the flange will clear the frog nose by at least 0.80mm.

Track gauge	127.79mm
Checkrail flangeway	5.55mm
Frog flangeway	7.15mm

Each of these three measurements must be increased by any gauge widening in effect.

Summary

This compromise approach seems the best to me because it accommodates SLSLS profile wheelsets and fine-scale wheelsets and the AALS profiles (preferred and fine-scale). The frog flangeway width is the minimum possible to support these wheelset profiles and will provide smooth passage of a wheelset over the transfer point. Gauge widening might cause problems and if so the track curvature and widening should be reduced for a distance of 10" before and after the frog. The lateral clearance due to the railhead profile is variable and sometimes assumed and should be ignored here.

Track Design at K-crossings

K-crossings present more of a challenge because they occur in close proximity on both rails and both rails in the crossing area will have a check rail.

Using full-width flangeways

The checkrail max spacing is 115.09 (for SLSLS) and the wheel check is 123.03 (for fine scale) so each flangeway must be 123.03 – 115.09 = 7.94mm. The track gauge will be 115.09 + 7.94 + 7.94 = 130.97mm.

The track gauge required here is 130.97mm plus any extra for gauge widening.

Attempting to stick to 5" gauge

Removing the root radius allowance from the wheel check gauge gives us a wheel check of 121.44mm. This means the flangeway width is 121.44 – 115.09 = 6.35mm. The track gauge will be 115.09 + 6.35 + 6.35 = 127.79mm. This is the minimum possible and definitely not recommended. AALS fine-scale flanges are 0.3mm thicker than UK fine-scale and will be even more prone to problems here.

Compromise

Considering the case above and increasing each flangeway width by 0.79mm ($^{1}/_{32}$") results in flangeway widths of 7.14mm and a track gauge of 129.37mm. The wheels might partially run on the flange root radius but the flanges will clear the frog noses. Passage through the K-crossings area will be safe and reliable.

Track gauge	129.37mm
Flangeway width	7.15mm

Gauge widening should not be necessary because both tracks are generally straight.

Summary

This compromise approach seems the best to me because it accommodates SLSLS profile wheelsets and fine-scale wheelsets and the AALS profiles (preferred and fine-scale). The flangeway width is the minimum possible to support these wheelset profiles and allow a smooth passage of a wheelset.