The FlexiCurve bogie is UGL’s premium locomotive bogie that provides unprecedented benefits in locomotive performance, reliability and maintainability. FlexiCurve is a family of bogies for applications ranging from 90t 1m Narrow Gauge through to 160t 1.7m Broad Gauge.

Evolved from over 20 years of fabricated bogie design and manufacturing experience.

Bogie Design and Manufacturing History
UGL is an Australian rail engineering company specialising in designing, building, maintaining and refurbishing diesel locomotives, diesel and electric multiple units, freight wagons and passenger cars. Through enduring technology and industry partnerships, UGL provides access to world leading technology and best practice engineering solutions.

- UGL has designed and supplied over 2,000 locomotive bogies to national and international markets since 1993
- since 2006, over 1,600 locomotive bogies have now been manufactured by UGL under license outside Australia by technology transfer
- UGL is a leading supplier of the latest locomotive bogie technology from GE Transportation

Experience
Over 115 years of rollingstock experience

Freight

- C44ACi Locomotive
- Evolution Series Locomotive
- Powerhaul Series Locomotive

Passenger

- Diesel Multiple Unit DMU
- Double Deck Electric Multiple Unit
- Light Rail Vehicle
- Luxury High Speed Diesel Multiple Unit

A sample of UGL’s design, manufacture and maintain capability
AUSTRALIAN BOGIE DESIGN AND MANUFACTURE

<table>
<thead>
<tr>
<th>Vehicle model</th>
<th>Quantity produced</th>
<th>Vehicle mass (t)</th>
<th>Bogie type</th>
<th>Manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cv40-9i</td>
<td>240</td>
<td>132</td>
<td>Pedestal</td>
<td>1996</td>
</tr>
<tr>
<td>CM30-Mmi</td>
<td>100</td>
<td>116</td>
<td>Pedestal</td>
<td>1996</td>
</tr>
<tr>
<td>OSCar EMU</td>
<td>442</td>
<td>50</td>
<td>Air spring</td>
<td>2005</td>
</tr>
<tr>
<td>HRC DMU</td>
<td>14</td>
<td>50</td>
<td>Air spring</td>
<td>2004</td>
</tr>
<tr>
<td>C44-ACi</td>
<td>268</td>
<td>132 - 139</td>
<td>Pedestal</td>
<td>2007</td>
</tr>
<tr>
<td>PH37 ACmai</td>
<td>6</td>
<td>132</td>
<td>FlexiCurve</td>
<td>2013</td>
</tr>
</tbody>
</table>

UGL’s bogies are under many UGL designed rollingstock:
- Standard Gauge 134t C44ACi locomotive
- OSCar passenger EMU
- Hunter Rail Car passenger DMU fleet
- 5G 120t coal wagons use the one piece fabricated primary suspension EBA bogie

INFORMATION BOGIE DESIGN AND MANUFACTURE

<table>
<thead>
<tr>
<th>Client</th>
<th>Country</th>
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<td>Thailand</td>
<td>CM22-Ti</td>
<td>80</td>
<td>104</td>
<td>Pedestal</td>
<td>1996</td>
</tr>
<tr>
<td>GE (Dinghai Tibet Railway)</td>
<td>Tibet</td>
<td>C38-AChe</td>
<td>156</td>
<td>138</td>
<td>Pedestal</td>
<td>2005</td>
</tr>
<tr>
<td>GE (China Mainline Railway)</td>
<td>China</td>
<td>E59-PACi</td>
<td>5 + 300¹</td>
<td>150</td>
<td>Pedestal</td>
<td>2006</td>
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<tr>
<td>GE (Egyptian National Railways)</td>
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<td>164</td>
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<td>440 + 88²</td>
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<td>GE (TRF - Transnet Freight Rail)</td>
<td>South Africa</td>
<td>C30-ACi</td>
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<td>Pedestal</td>
<td>2010</td>
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<tr>
<td>GE (GCT) (UCLA &amp; CDN under construction)</td>
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<td>C30-ACi</td>
<td>20 + 44</td>
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NOTES

1. China Mainline
   UGL produced 5 bogies, over 1,300 bogies produced in China by CSR Qishuyan under Technology Transfer (TT)
2. Kazakhstan
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3. Transnet Freight Railways
   UGL produced 73 bogies, 226 bogies built to date in South Africa by Transnet Engineering under Technology Transfer
4. Transnet Freight Railways
   465 Diesel Locomotive program - UGL to produce 12 bogies, 454 bogies to be built in South Africa by Transnet Engineering under TT

ROLLINGSTOCK SERVICING, MAINTENANCE AND OVERHAUL

Unrivalled experience in servicing Australian rail clients

UGL’s key attribute is its integrity in working with clients to deliver flexible and transparent maintenance solutions tailored to meet each client’s business needs. This strength is demonstrated by UGL’s national footprint in servicing clients through multi-discipline arrangements, each developed to meet individual client requirements. These maintenance solutions range from service and support through to complete design, build and maintenance of both rollingstock and facilities.

Our client base in Australia includes producers, operators and government agencies that transport a diverse range of products such as coal, ore, bulk goods, container freight as well as paying passengers - all with appreciably varying maintenance requirements.

UGL has one of the broadest rail maintenance services footprints in Australia, with international offices in India and Hong Kong supporting manufacturing and maintenance.

AUSTRALIAN BOGIE DESIGN AND MANUFACTURE

![Bogie Design](image)

INTERNATIONAL BOGIE DESIGN AND MANUFACTURE

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Design
Locomotive bogie design – high tractive effort
UGL have been designing and manufacturing rollingstock for over 115 years.

In the early 1990’s, UGL started designing fabricated bogies in response to demand for a lightweight locomotive bogie to bring heavy haul DC and AC traction performance to tracks with axle load constraints. The resulting Co-Co pedestal leg bogie has been in widespread use throughout Australia and internationally for over 20 years.

A SELF-STEERING BOGIE DESIGN

Wheel turning and replacement are a significant part of the through-life cost for a bogie. As the demand for AC traction spread from dedicated heavy haul networks and into intermodal and bulk haulage service with more widespread access to existing track with tighter track radii the wheel wear characteristics of the pedestal leg bogie, with its minimal steerage of the axles around curves, were recognised as sub-optimal.

In light of the obvious limitations of the pedestal leg bogie, and the more recently discovered limitations of the linked-axle locomotive bogie, UGL decided that a different approach would be used for the development of the FlexiCurve bogie.

In the 1990s the concept of the ‘radial steering’ bogie with linked outer axles on a Co-Co bogie arrangement was developed with the aim of extending wheel life. Although the radial steering bogie reduces the lateral curving forces while the locomotive is coasting, it was found in practice that under high tractive effort the steering effect is lost. Radial steering bogies were implemented by many heavy haul locomotive operators in North America. However, due to the extra cost, complexity and mass, along with the disappointing curving performance in actual operation, these bogies have fallen out of favour.

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What are the options?

**RADIAL STEERING LINKED-AXLE**
- Only suitable for low speed
- Additional linkages required for higher speeds
- High maintenance required to retain performance

**RADIAL STEERING FlexiCurve**
- Shorter axle spacing reduces angle required for radial steering
- Suitable for higher speeds
- Maintenance free

The applicability of the pedestal leg bogie, and the complexity of existing radial steering arrangements required a step change in design thinking; the development by UGL of the FlexiCurve bogie.

SOLUTION - SIMPLE AND EFFECTIVE
FlexiCurve is a properly implemented yaw relaxed self-steering design with the following key benefits and features:

- Even wheel wear across axles
- Low curving forces, flange lubrication not required
- Better adhesion in curves
- Good stability and ride in all service conditions
- Simple frame design and use of castings reduces capital cost and manufacture
- Low parts count, common suspension components
- No wearing surfaces – only elastomeric bushes
- Greater than 25% increase in wheel life for diesel locomotives in heavy haul service
- Simple maintenance, low lifecycle costs
- Faster change out of wheel and traction motor combos
- Lower bogie mass
- Lowest feasible axle spacing provides a more compact bogie design
- Maximises underframe space
KEY DESIGN FEATURES FOR SUPERIOR RIDE, CURVING AND TRACTION PERFORMANCE

Dynamics
Key attributes for good dynamic performance and in-service consistency

LOW X-FACTOR
- Low yaw rotational stiffness of secondary suspension
- The side bearer pads must be very soft in shear
- Almost all the secondary lateral stiffness should be provided by the traction centre

GOOD CONTROL OF WHEELSETS
- Linear elastic location of wheelsets is required in all directions, vertical, longitudinal and lateral
- Hard stops must only engage in extreme circumstances
- The lateral/longitudinal wheelset location stiffnesses must be chosen in order to provide good stability while allowing for passive steering

GOOD CONTROL OF WHEELSETS
- Linear elastic location of wheelsets is required in all directions, vertical, longitudinal and lateral
- Hard stops must only engage in extreme circumstances

RIDE QUALITY AND DRIVER COMFORT
- Linear elastic location of wheelsets is required in all directions, vertical, longitudinal and lateral
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DYNAMIC PERFORMANCE
The improvements predicted using VAMPIRE simulations were able to be physically verified recently when new AC locomotives fitted with Cape Gauge FlexiCurve bogies were tested in South Africa for curving and ride performance. The same testing authority had a few years earlier performed the same tests on a similar locomotive fitted with UGL pedestal bogies, enabling a direct comparison to be made. Instrumented curved track was used to measure curving forces. Ride performance was tested on a high speed section of track for which inertial track data was made available. The predicted improvements in both curving performance and ride performance were proven by the testing.

CURVING PERFORMANCE
Curving performance is indicated by the measured Lateral over Vertical wheel/rail force (L/V) ratio. The allowable client specification limit is 1.0. The average L/V measured was 0.46.

RIDE PERFORMANCE
Ride performance is measured using the Sperling Ride Index. The allowable client specification limit is 3.5 up to 100km/h. The maximum vertical and lateral Ride Index at 100km/h was below 2.5.

Ride and traction
Attributes for high traction performance on a 3-axle bogie

TANDEM MOTORS
- All motors push up (or pull down) on the bogie frame

STIFF SECONDARY PITCH SUSPENSION
- Prevents significant pitching of the bogie frame
- Provided by vertically stiff side bearer pads

SOFT PRIMARY VERTICAL SUSPENSION
- Reduces the load variation in the primary springs due to bogie pitch
- Reduces the wheel load variation due to track conditions

YAW RELAXATION OF WHEEL SETS
- Improved adhesion in curves

YAW RELAXATION OF WHEEL SETS
- Improved adhesion in curves

TAKEOFF PERFORMANCE
- Less than 7% axle load variation at maximum tractive effort (39% adhesion)

LOW MASS AND COMPACT
- The latest computer aided engineering simulation and analysis tools are used in the design process and this methodology is correlated with accelerated life testing and in-service dynamic strain gauge testing on every new bogie project. This capability combined with UGL’s extensive experience in the design, manufacture and type test validation of fabricated steel bogies results in optimised frame mass.

- The simple primary suspension of FlexiCurve is a lower mass solution than other bogie designs such as the pedestal leg configuration and also a compact bogie space envelope.
- The lower mass and compact dimensions provide the locomotive designer with a means to significantly increase fuel capacity and range, and/or install additional equipment for increased operational efficiency and performance.
Simple manufacture

FlexiCurve BOGIE FRAME BENEFITS
• Less fabrication hours for FlexiCurve frame versus a typical pedestal leg bogie
• Optimised frame casting to lower cost and fabrication time
• Does not require the manufacture of large steering arms, pivot points and linkage pins

TRACTION CENTRE
The traction centre transmits traction, braking and inertial loads generated in the bogie to the platform via the pivot pin. The traction centre also provides the bulk of the secondary lateral suspension stiffness, and limits lateral motion through rubber bump stops, backed by metal stops

SUSPENSION COMPONENTS
Reduced costs - use of common parts

Simple maintenance

NO WEAR SURFACES
• Elastic guidance of moving parts is used throughout the FlexiCurve bogie suspension
• “Set and forget”. Long-lasting elastomeric components require no regular maintenance or lubrication between major overhauls

SIMPLE INSPECTION REQUIREMENTS
• Visual inspection is sufficient
• No measurement or adjustment required

• Traction motor cables, earth connections and speed sensor are disconnected
• Primary damper is removed
• Lower tie bar is removed (3 bolts per axle box)
• Motor suspension link is disconnected
• Sanding brackets removed (end axles)
• Wheelset dropped from frame
• Primary suspension, axle box and guide links are not disturbed

WHEEL LIFE
• 25-50% greater wheel life over non self-steering bogies
• The low lateral track forces of FlexiCurve provides exceptional wheelset tracking and straight track stability, resulting in very low flange wear and even wear across all wheels. These improved performance characteristics significantly reduce the depth of material removed at wheel turning which translate into significantly improved wheel life.

The optional use of Mirco Alloy B wheel with FlexiCurve reduces tread hollowing even further and when combined with a tailored Wheel Management Plan provides an ability to further increase wheel life.

INCREASED MAJOR OVERHAUL INTERVALS
• Major overhaul is normally combined with wheelset change out
• Use of long lasting elastomeric suspension parts to match the longer wheel life

QUICK WHEELSET CHANGE OUT
• An open axle box enables the wheelsets to be changed without dismantling the primary suspension

SERVICING, MAINTENANCE AND OVERHAUL COMPARISON

<table>
<thead>
<tr>
<th>Servicing &amp; Maintenance Activity</th>
<th>Pedestal Leg Bogie</th>
<th>Linked-Axle Radial Self-Steering Bogie</th>
<th>Radial FlexiCurve Self-Steering Bogie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear surfaces</td>
<td>Pedestal leg wear liners</td>
<td>HIGH</td>
<td>Pins and bushes for steering arm linkages and bell cranks</td>
</tr>
<tr>
<td>Inspection time</td>
<td>Frequent inspection and measurement of pedestal wear liners</td>
<td>HIGH</td>
<td>Long inspection and tolerance measurement of steering arm linkages and bell cranks</td>
</tr>
<tr>
<td>Bogie Overhaul (excl. traction motor combo, unit brakes overhaul, inspection and test of frame and suspension)</td>
<td>Inspect and/or replace pedestal leg wear liners</td>
<td>MED</td>
<td>Inspect and/or replace steering arm linkages and bell cranks</td>
</tr>
</tbody>
</table>
Design process and specification standards

To optimise the performance and reliability of bogies UGL undertakes a robust engineering design, simulation, testing and verification/validation process:

- Systems engineering lifecycle methodology, allowing UGL to focus on client requirements through to verification and validation of the product
- Designs bogie frames, suspension components, axles and wheels to the International EN, AAR and relevant Australian Standards
- Detailed track measurement data for the operating track are used in ‘Vampire’ track analysis simulation

Locomotive integration tests including bogie swing (slew) test are performed
- Ride and haulage testing is performed by instrumenting the bogie (strain gauges, displacement transducers, velocity transducers and accelerometers) to confirm the analysis loads are above the actual loads and to correlate the test performance with the FEA strength and fatigue modelling
- Accelerated life-testing of the bogie frame and components is conducted depending on the complexity of design
- The FlexiCurve bogie frame and suspension components in UGL PH37 Cape Gauge G 132t form have been successfully accelerated life tested to EN13749 during 2013 to over 11 million cycles.

International technology transfer

As well as designing and manufacturing fabricated bogies for its own locomotives in Australia, UGL has been a prime partner with GE for the design, test, validation and manufacture of bogies since 1995.

- UGL has undertaken technology transfers to six different countries outside of Australia
- UGL is the prime sub-contractor to GE for the design, test, validation and manufacture of bogies
- State Railways of Thailand first contract for GE as complete turnkey bogie solution commenced in 1995 - metre gauge pedestal bogie
- Subsequent turnkey contracts for:
  - Qinghai-Tibet Railway
  - China Mainland
  - Egyptian National Railways
  - Libya Rail, Kazakhstan Railways
  - Transnet Freight Rail - South Africa
  - Mozambique (CFM and Vale)

200KM/H HIGH SPEED PASSENGER LOCOMOTIVES
- The FlexiCurve is also suitable for 200km/h passenger operation with the addition of:
  - Yaw dampers
  - Vertical resilience and damping of the suspension
  - Frame-mounted traction motors
  - Disc brakes in place of tread brakes
- UGL has experience with higher speed bogie design using frame-mounted traction motors and disc brakes through its development of EMU and DMU passenger car contracts

Conclusion

UGL’s bogie design capability is mature with 20 years of successful experience in fabricated bogie design, test validation, manufacture and technology transfer for heavy haul Co-Co bogies.

UGL’s FlexiCurve bogie provides the performance benefits of a self-steering bogie but a lower mass and significantly reduced manufacturing complexity. Testing of the FlexiCurve has proven lower curving forces and class leading ride quality.

Lower wheel wear and significantly reduced maintenance costs will result from this impressive performance.
UGL is a diversified services company delivering critical assets and essential services that sustain and enhance the environment in which we live.

UGL provides end-to-end outsourced engineering, construction, asset management and maintenance services with a diversified end-market exposure across the core sectors of rail, transport & technology systems, power, resources, water and defence.

Our complete rail offering covers the entire spectrum of rail transportation products and services in design, engineering, manufacture, construction, maintenance, refurbishment and asset management of locomotives, passenger cars, trams, freight wagons, bogies, sub-assemblies and rail infrastructure systems and is the largest provider of complete rail solutions in the Asia Pacific region, and Australia’s largest supplier of outsourced asset management and rolling stock maintenance services.

UGL’s services are underpinned by a track record that spans over 115 years.

Headquartered in Sydney, Australia, UGL employs over 7,700 people across Australia, New Zealand and South Asia.

For further information

Rod Morrison
Head of Sales, Freight
Level 8, 80 Dorcas Street
South Melbourne VIC 3205
P: +61 3 8341 3915
M: +61 418 284 162
E: rod.morrison@ugllimited.com

CORPORATE OFFICE
UGL
Level 5, 40 Miller Street
North Sydney NSW 2060
P: +61 2 8925 8925
F: +61 2 8925 8926
E: uginfo@ugllimited.com

www.ugllimited.com/flexicurve