Modify or Repair Chassis/Frame and Associated Components

Workbook (AUM8101A)
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Introduction

Repairing and modifying chassis

The chassis frame forms the backbone of a heavy vehicle so the chassis must be able to safely carry the maximum load for which the vehicle is designed. The chassis must also absorb engine and drive-line torque, endure shock loading and accommodate twisting caused by uneven road surfaces. Satisfactory performance of a heavy vehicle chassis is the result of careful design and rigorous testing. Consequently, no modification to a chassis frame should be made before consultation with the vehicle manufacturer or an engineer experienced in commercial vehicle chassis modifications. This will ensure that any proposed chassis modification will not reduce the vehicle’s safety or performance.

Different chassis manufacturers have their own design concepts and varying ways of achieving satisfactory overall chassis performance, so not all chassis are the same and chassis components are not normally interchangeable between different makes and models of vehicles.

Chassis frames are designed to offer good support for the body and payload and at the same time provide torsional flexibility, mainly in the region between the gearbox cross member and the cross member ahead of the rear suspension. Allowing for chassis flexing is necessary because a rigid frame is more likely to fail than a flexible one that can twist and bend in arduous conditions. A torsionally flexible frame also has the advantage of decreasing the suspension loading when the vehicle is on uneven surfaces, as all wheels can make contact with the road thus sharing the payload over all of the wheels.

Chassis types

Monocoque

Monocoque bodies do not have a separate chassis but instead rely on their one-piece body and chassis construction to gain rigidity. Monocoque vehicles are usually found on smaller vehicles such as a small van, where weight is saved by not having a separate chassis; the chassis and body are combined to make up one unit, with the body sharing the load stresses. Monocoque is a French word meaning single shell or unibody and is a construction technique that uses the external skin of the body to support some or most of the load on the vehicle.
Space frame

Another type of chassis is the space chassis. These chassis are light-weight and usually made of braced tube or RHS. Suburban omnibuses commonly use a space chassis because they are light and flexible and the body adds to the vehicle’s rigidity.

Ladder type

The most common type of chassis consists of two chassis rails which run the full length of the vehicle. The chassis rails are made of high tensile pressed steel channels. In a ladder type of chassis, the chassis rails carry all the main components of the vehicle, such as the engine, gearbox, front and rear axle suspensions. Also adding to the burden of the chassis are components such as fuel tanks and air tanks.

This style of chassis is called a ‘ladder’ chassis because, when laid out with cross members, they roughly represent a ladder configuration.

Chassis rails

Chassis rails are made of high tensile steel usually in the order of about 440 Mpa and upwards with a yield strength of 760 Mpa, compared with mild steel, which has a tensile strength of around 410 Mpa.

A chassis rail is made up of two flanges and a web. The flanges make up the top and bottom of the chassis rail and carry most of the stresses imposed on the chassis.
When the chassis is unladen the flanges are not stressed.

When the chassis flexes downward the top flange is compressed and the bottom flange is stretched. The centre area of the web is considered stress neutral and flexes very little as illustrated by the three holes in the web.

Due to the stresses imposed on the flanges drilling of the flanges is not recommended with most manufacturers forbidding this practice. Welding on the flanges is only allowed when joining the chassis rails, and of course the welding quality is particularly important.
**Single skin**

A single skin chassis consists of one channel pressing for each chassis rail. This is the standard chassis found on most small to medium-size vehicles.

![Diagram of single skin chassis](image)

**Double skin**

Some chassis are double skinned, which means there is a second chassis rail either inside or outside the major chassis rail.

![Diagram of double skin chassis](image)

This design allows for added strength where needed without losing flexibility. Larger prime movers use this chassis style. Often the double skin is only used for a section of the chassis.
Questions

1. State the advantage a monocoque van has over a van with a ladder chassis.

_________________________________________________________________

2. In a space frame chassis the vehicle’s body adds additional ____________________

3. On the above single skin chassis rail, name the parts indicated by arrows.

4. On the above sketch indicate the theoretical effect of downward flex on the holes drilled in the chassis rail.

5. What advantage is there of using a double skin chassis rail in preference to single chassis rail?

__________________________________________________________________
Reasons for chassis modifications

The most common reasons for chassis modifications are:

- to increase or decrease the wheelbase
- to increase front or rear overhang
- to increase the gross vehicle mass rating by adding additional axles
- to meet special body requirements such as low load height
- to repair the chassis after an accident or overstressing
- to accommodate localised loading imposed by special equipment such as hoists, cranes or large fuel tanks.

Inspection of the chassis frames

Measuring chassis frame

There are several methods of measuring a chassis to establish whether the chassis is bowed or out of square. All methods use a straight line as a datum and compare the chassis to the datum to establish the straightness of the chassis. Methods of establishing a datum line include using a laser beam, string line or the drop line test using a plumb-bob.

Laser measuring

Using a laser beam is an accurate method. The laser head is set up at one end of the chassis, say 50 mm away from the web, and aimed along the chassis to the other end at the same distance away from the web, in this case 50 mm. A piece of flat material such as cardboard is held at intervals along the chassis and the distance is measured away from the web and down from the flange. This is done at several points along the chassis. These measurements are noted and ideally should be the same at all points along a straight chassis. A variation from the distance to the web will indicate a bent chassis. At the same time the height of the flange can be noted; if this varies upward or downward a bow in the chassis will be indicated.
String line

This is a similar method to using a laser beam except that the laser is replaced by a string line. When using this method it is necessary to measure to the string line from the chassis flange and web.

These measurements are noted and ideally should be the same at all points along a straight chassis. A variation from this will indicate a bent or bowed chassis.
Drop line test

The drop line method does not require specialist equipment and is ideal if there is too much obstruction along the chassis to remove. This method uses a plumb-bob to mark points on a workshop floor and a string line to connect the points.

Points are selected from the underside of the chassis rail, these are usually the centre of rivet heads or brackets providing there is a matching point on the opposite rail.

A plumb-bob is used to transfer these points from the underside of the chassis to the workshop floor.
Points taken from the underside of the chassis rail

These dots are connected diagonally using a chalk line.

A centre line is marked out. If the chassis is straight the centre line will pass through where the diagonal lines cross.

In a bowed chassis the diagonal lines will not cross the centre line and may appear like this.

Additional diagonal lines will establish the exact area where the chassis bow occurs.
Paperwork

**Inspection report**

After testing, an inspection report can be made out indicating the condition of the chassis, the area of damage and the severity.

<table>
<thead>
<tr>
<th>Bloggs Chassis Repairers</th>
</tr>
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<tbody>
<tr>
<td>Date</td>
</tr>
<tr>
<td>Make of vehicle</td>
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<tr>
<td>Inspection Report</td>
</tr>
<tr>
<td>Horizontal alignment of the chassis</td>
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<tr>
<td>Chassis Point 1</td>
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<tr>
<td>Chassis Point 2</td>
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<tr>
<td>Chassis Point 3</td>
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<tr>
<td>Chassis Point 4</td>
</tr>
<tr>
<td>Vertical alignment of chassis</td>
</tr>
<tr>
<td>Draw drop test results</td>
</tr>
<tr>
<td>Centre line</td>
</tr>
</tbody>
</table>
**Job specification**

If the work is to be carried out a Job Specification is issued. The Specification sheet points out what work will be required to rectify the damage.

<table>
<thead>
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<th>Bloggs Chassis Repairers</th>
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<tr>
<td>Date</td>
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<tr>
<td>Make of vehicle</td>
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<td></td>
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<tr>
<td>Removal of chassis attachment</td>
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<tr>
<td></td>
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<tr>
<td>Horizontal points to be realigned</td>
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<td></td>
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<tr>
<td>Vertical points to be realigned</td>
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<td></td>
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<tr>
<td>Chassis components to be replaced</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>
Questions

1. The above marks from a drop line of a damaged chassis are marked out on the workshop floor.

   (a) What type of damage has been sustained?

       ______________________________________________________________

   (b) Suggest how this damage could be rectified.

       ______________________________________________________________

2. List four reasons why a customer may want to have a chassis modified.

   (a) ______________________________________________________________

   (b) ______________________________________________________________

   (c) ______________________________________________________________

   (d) ______________________________________________________________

3. List three methods of establishing whether a chassis is bowed or out of square.

   (a) ______________________________________________________________

   (b) ______________________________________________________________

   (c) ______________________________________________________________
4. When taking a reading off a laser beam along the chassis, what is indicated by the following reading when only half the chassis has been checked?
Replacement or rectification of chassis components

It is sometimes necessary to replace damaged chassis components such as cross members or install additional supports such as centre bearing brackets. After a wheelbase extension, additional cross members will be required if the length of the unbraced chassis rail exceeds 1300 mm. If a compatible cross member is not available then it will be necessary to fabricate one. All cross members of the vehicle should be of similar design to the original cross members, as this will prevent stress focusing in an area where it may have greater torsional strength. When moving an axle assembly, ideally each spring hanger should be supported by a cross member.

Rectification and replacement of chassis frame components must be carried out in accordance with the vehicle manufacturer’s specifications and tolerances relative to the vehicle.

When fabricating a cross member the material used should not be thicker than the web thickness of the chassis rail the cross member will be fastened to. A channel or top hat section should be used as the cross member and fitted with triangular gussets. This allows for torsional flexibility. Welding must not be carried out within 40 mm of the triangular gusset’s edge.

- 3 x M12 bolts, Gr. 10.9 hardened washers and locknuts per gusset
- Channel section to be well clear of gusset bend radius
- Minimum internal bend radii to be 2t (where t = thickness of material)
- Centres of bolt holes to be no closer than 40 mm
- Channel only NOT RHS
- Plug weld
- No welds or bolt holes within 40 mm of edge of gusset
- Minimum bolt size is M12
In general it is not recommended to use round tube or RHS to manufacture cross members as these materials are not flexible enough. Check with the chassis manufacturer, as some do recommend the use of round tube for cross members.

Drilling and bolting of attachments

When attaching components to the chassis rails the following general conditions apply, although there are slight variations between chassis manufacturers. If in doubt, check with the chassis manufacturer.

- All attachments should be fastened to the web of the chassis.
- Holes are not be drilled in the flanges of the chassis rail or in an area of the web 40 mm from the top or bottom flange.

- All holes must be drilled. Flame-cut holes are not allowed.
- De-burr holes after drilling.
- Hole centres are to be no closer than 50 mm or three times the diameter of the largest hole, whichever is the lesser.
- Hole diameters must not exceed the bolt diameter by more than 1.0 mm.
- Holes must not be elongated.
• Do not drill more than two holes in a vertical line within the frame web, as this may cause fracturing in the chassis when stress is applied.

![Diagram showing maximum of two holes in a line](image)

• All structural bolts should be fitted with suitable washers or doubling plates with self-locking nuts. Spring-type washers are not allowed on structural members.
• Bolts and locknuts that are removed from used vehicles should be replaced with new bolts and locknuts of the correct size and grade.
• All bolts for structural purpose must be ‘high tensile’, ISO Metric Grade 8.8 or 10.9 (or SAE Grade 5 or 8), using the original manufacturer’s practice as a guide for bolt diameter selection.

• All bolts must be tightened to the correct torque.
• For additional or relocated cross members, the original manufacturer’s design maximum spacing, strength and attachment strength should be maintained.
• Cross members should only be fitted to the web of the chassis rail with the exception of an end of frame cross member, which can be fitted to the flange.
Questions

1. A chassis rail is 8 mm thick. To make a cross member, which of the following thickness material should be chosen? Circle your answer.
   - 8 mm thick
   - 10 mm thick
   - 12 mm thick

2. Give a reason for your choice, in the above question.

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________

3. What type of washers should not be used when bolting components to a chassis?

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________

4. For the manufacture of cross members, why is RHS and pipe not generally recommended?

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________

5.

On the above chassis, indicate and dimension the area where no drilling is to be carried out.
6. What grade metric bolt must be used for attaching a bracket to carry an additional fuel tank?

_________________________________________________________________
_________________________________________________________________

7. When using 16 mm diameter bolts to fasten a bracket to the web of a chassis, what will be the minimum distance apart of the hole centres?

_________________________________________________________________
Alignment and modification of chassis frame

General requirements
The following minimum requirements apply to all frame modifications:

- All additional material used for modifying the frame rails should be of the same dimensions and material specifications.
- All fabricated sections of the chassis frame rail and components must have suitable radiused bends and be free from cracks, notches and imperfections.
- All bolts for structural purpose must be ‘high tensile’, ISO Metric Grade 8.8 or 10.9 (or SAE Grade 5 or 8), using the original manufacturer’s practice as a guide for bolt diameter selection. Bolts used to secure suspension hangers and brackets to frame rails must be ISO Metric 10.9 (or SAE Grade 8). Fitted bolts are preferable but not essential. ‘Huck’ bolts may be used for fastening chassis components. **Note:** The use of countersunk is not recommended and should be avoided.
- All modified frame rails should be straight and square prior to assembly. Bowed frame rails should not be straightened by assembly of the frame.

Wheelbase alteration
It is recommended that wherever possible, wheelbase alterations are achieved by moving the rear axle along the frame. Cutting of the frame should only be carried out if sliding the axle cannot be accommodated.

Rear overhang
Altering the wheelbase alters the rear overhang of the chassis. If the axles are moved forward it will be necessary to calculate the new rear overhang to establish whether the vehicle will remain legal with the intended body attached to the chassis. Legal overhang on a rigid vehicle is calculated as 60% of the wheelbase or 3.7 m, whichever is the lesser.

**Formula:**

\[
\text{Rear overhang (ROH)} = \text{wheelbase} \times 60\%
\]

\[= 3.7 \text{ if lesser}\]

Example:
The new wheelbase is to be 5500 mm, what will be the maximum legal rear overhang?

\[
\text{Rear overhang (ROH)} = 5500 \times 0.6
\]

\[
= 3300 \text{ mm}
\]

The rear overhang in our calculation is 3300 mm or 3.3 m, which is less than 3.7 m, therefore the legal rear overhang must not exceed 3.3 m.
Suspension relocation

In this case the axle suspension is unbolted from its current position and relocated to the desired position. The chassis is then redrilled to accommodate the new suspension position and the suspension bolted into place.

Recommended steps to follow when relocating a suspension.

- Before beginning any work on the chassis disconnect the battery.
- A recommended method of carrying out the relocation work is to mark the centre line of the suspension on the chassis before the suspension is removed.
- Centre punch reference points on the chassis frame so that measurements can be taken between them and the spring brackets, for example, before and after the rear axle is moved.
- Measure the drive-line shaft angle and make a note of this as it will be required to calculate the new angle of the next drive shaft. An electronics spirit level or similar can be used to take this measurement.
- Remove the tail shaft (propeller shaft, drive shaft), compressed air lines to the rear bogie and any other components which may get in the way.
- Support the chassis on a stand at the rear.
- Remove the spring brackets and their cross members.
Once the suspension is unbolted, a template of the existing holes can be made from a steel sheet folded at right angles at the top edge. The template is placed on the top flange of the chassis and the centre line marked on the chassis is lined up with the centre line marked on the template. The suspension holes are scribed from the inside of the chassis rail onto the steel sheet. These marks are transferred to the new position on the chassis by lining up the centre line on the sheet steel with the centre line of the new suspension position. A centre punch is used to mark the chassis before drilling pilot holes and completing the drilling with the finished hole size drill bit.

Slide the suspension in place and bolt into position.

The tail shaft will need to be altered to suit the new axle position, as will any other lines which may not be long enough.

The holes which remain from the original suspension position should be plug welded and ground flush or bolts placed back into the holes.

Components that may be affected are:
- drive line
- electrical leads
- air lines.
Questions

1. The wheelbase of a vehicle is 5800 mm. This is to be extended by 400 mm. Calculate the legal rear overhang.

_________________________________________________________________
_________________________________________________________________

2. The wheelbase of a vehicle is 4800 mm. This is to be shortened by 300 mm. Calculate the legal rear overhang.

_________________________________________________________________
_________________________________________________________________

3. To lengthen a wheelbase there are two possible choices. What are they?
   (a) ______________________________________________________________________
       ______________________________________________________________________
   (b) ______________________________________________________________________
       ______________________________________________________________________

4. Which of the above choices is preferred by chassis manufacturers?

_________________________________________________________________
_________________________________________________________________

5. What is the purpose of centre punching the chassis prior to relocation the suspension?

_________________________________________________________________
_________________________________________________________________

6. Name three components that may be affected by a suspension relocation.
   (a) ______________________________________________________________________
   (b) ______________________________________________________________________
   (c) ______________________________________________________________________
7. Sketch the correct method of plug welding an unwanted hole in the chassis frame.
Cutting the chassis

If relocation of the suspension assembly is not an option, then it will be necessary to cut and extend or cut and contract the chassis. This is a major chassis modification and is achieved by cutting the chassis between the axles.

The joining of the chassis is done by different methods, depending on the chassis manufacturer’s recommendation. It is necessary to comply with these recommendations to prevent voiding any truck warranty, so gather this information before commencing the job.

The most common methods of cutting a chassis

- **Straight 90° cut on the flanges and web.**
- **Straight 90° cut on the flanges and a 45° cut on the web.**
- **A 45° cut on the top flange, a 45° cut on the web and a 45° cut on the bottom flange in the opposite direction to the top flange.**
A straight 90° cut on the flanges with a semicircle cut on the web.

**Double skinned chassis**

Care must be taken not to damage the second skin when cutting the chassis. When joining the chassis rails, both the inner and outer skins must be welded at different places with a minimum distance apart of 300 mm.

Sometimes it is difficult not to damage the second skin when cutting the chassis. If possible, it is often easier to remove the inner skin prior to cutting.

Some chassis manufacturers allow a 90° cut in both skins.
Where it is too difficult to cut each skin as a separate unit, both skins may be cut at the same place, but longer insert rails are required.
Contracting (shortening) the chassis
Strip the chassis of all lines such as air and electrical, disconnect the drive shaft.
Mark out datum points with centre punch marks each side of the proposed cut.

These reference points must extend over the section to be removed. They need to be in the centre of the chassis and diagonally equal in length.

Check for square, recording the measurements on the chassis. These measurements will be required later.
Mark out the section to be removed and prick punch the line.

Stabilise the chassis each side of the proposed cut with stands.
Brace the chassis each side of the cut to prevent distortion.

Plasma cut or disc cut the chassis on the marked lines.
Prepare the joint for welding, veeing out to $30^\circ$–$35^\circ$.
Reposition the rear portion of the chassis and clamp into position.

Use a trammel or tape to measure the distance of the centre punch marks. They should be the original distance less the removed section. Check that it is diagonally square.
Make adjustments as required and tack into place.
Check all is well.
Weld up the joint.
Dress the welds so they are flush.

Fit a stiffening plate as specified by the manufacturer.
Welding of the chassis

Trucks have a number of electronic control units and computers to control such things as ABS braking, automatic gearboxes, fuel injection, torque converters, over-revving protectors etc. These are sensitive to electrical interference which would be provided by a welding machine.

- Before welding remove the battery negative terminal.
- Disconnect all computers.
- Fuel tanks and pipes in the vicinity of welding should be removed.
- Pipes and conduits made of synthetic material such as airlines and electrical cables should be protected against spatter and temperatures exceeding 80°C Celsius.
- Air bags and parabolic leaf springs need to be protected from weld spatter. Spring leaf fracture can be caused by even a momentary exposure to welding spatter.
- Attach the welding ‘earth’ terminal as close to the weld area as possible. Never earth components such as axles, wheels, springs, gearbox etc. Electrical arcing through these points will cause serious damage to the internal components such as the bearings and gears.
- Remove paint completely from the weld area before welding.
- Do not cool the weld with water.
- Weld should comply with Australian Standard AS1554 Structural steel welding Category SP.

To ensure full penetration, the chassis should be prepared as a double v and welded on both sides. Undercutting is not permitted.

![Diagram of double v weld](image-url)
On a double skin chassis the welding preparation should be as a single ‘v’ for each skin.

On completion of the welding all excess weld metal must be ground flush to the chassis. A 10% increase in frame thickness is permitted but not recommended.

All grinding should be in the direction of the chassis rail length.
**Frame rail reinforcement**

After modification, the chassis will require reinforcement. There are two types of reinforcement, a pressed channel reinforcement or a flitch plate. The method chosen will depend on the position of the modification. All reinforcement materials should be the same material and thickness as the chassis frame; that is high tensile reinforcement on a high tensile steel chassis frame.

In the case of a wheelbase extension or reduction, the reinforcement must extend to a minimum of 300 mm past the jointed area, but should not be terminated within a distance equal to 2H from the centre of a spring hanger (H = the frame rail depth) unless contrary practice is adopted by the vehicle manufacturer.

Each end of the reinforcement should be tapered at 45°, to help spread the stress along the web of the chassis frame, or, alternatively, a ‘frog-mouth’ tapering may be used.

![Diagram of interior tapered reinforcement](image1)

**Interior tapered reinforcement**

![Diagram of frog-mouth reinforcement](image2)

**Frog-mouth reinforcement**
The corner radius of the reinforcement piece must be clear of the corner radius of the chassis frame, whether the reinforcement is on the inside or the outside of the frame.

There are several methods of reinforcing the chassis rails; what they have in common is tapered ends to more evenly dissipate the stresses in the chassis.

Each method offers a different degree of strength. The method chosen is usually what fits the chassis best and the strength required.
This table gives a comparison guide to relative strengths of the reinforcing methods.

<table>
<thead>
<tr>
<th>Chassis depth</th>
<th>Material thickness</th>
<th>Section modulus (x 10 – 6m³)</th>
</tr>
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<tbody>
<tr>
<td>(H) mm</td>
<td>(t) mm</td>
<td>Method A</td>
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<td></td>
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<td>Method B</td>
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<td>391.98</td>
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</table>

Weld joints

Chassis

Reinforcement

An illustration of reinforcement Method E would look like the above. If the chassis is 6.4 mm thick with a depth of 200 mm the modulus strength would be 253.02 (x 10 – 6m³).

**Australian Design Rules**

No checklist of ADRs can be provided as nearly all chassis modifications are carried out as a result of other vehicle modifications, which themselves affect the vehicle’s continuing compliance with ADRs. It is then necessary to review every ADR that is applicable to the vehicle and determine whether the modified vehicle is capable of complying. This should be done before any chassis modification is commenced.
Questions

1. On the above drawing sketch three different methods of chassis cuts.

2. Sketch a top view of two chassis rails. Indicate and dimension where to place centre punch marks prior to cutting the chassis.

3. Sketch and dimension the weld preparation for welding a double skinned chassis using a GMAW process.
4. Sketch and dimension the weld preparation for welding an 8 mm single skinned chassis using a MMAW process.

5. List the relative strengths of reinforcing a 300 mm deep chassis with 7.9 mm thickness material using the following methods.
   - Method D ______________________________
   - Method B ______________________________
   - Method C ______________________________
   Refer to the relative strengths table for chassis reinforcing.

6. With the aid of the relative strength table, which illustrated method of reinforcing is the strongest?

_________________________________________________________________
_________________________________________________________________

7. Of all the illustrated methods of reinforcing, which is the least strong?

_________________________________________________________________
_________________________________________________________________

8. How far away from a spring hanger should a tapered reinforcement stop?

_________________________________________________________________
Turning circle

The turning circle of a vehicle is measured at the front outside tyre of the vehicle. This will vary in proportion to the change in the wheelbase. If the turning circle of a vehicle increases to above 25 metres, the work should not be carried out. It is important to calculate the new turning circle prior to altering the chassis. For example, a vehicle with a wheelbase of 4200 mm has been extended to 4800 mm. The turning circle will increase from 16 800 mm to 19 200 mm. This is calculated using the following formula.

**Formula:**

\[
\frac{\text{original turning circle} \times \text{new wheelbase}}{\text{old wheelbase}} = \text{new turning circle}
\]

\[
\frac{16\,800 \times 4800}{4200} = 19\,200 \text{ (new turning circle)}
\]
Questions

1. Calculate the turning circle of a chassis which will have the wheelbase increased by 400 mm. The current wheelbase is 5500 mm. The current turning circle is 18 450 mm.

_________________________________________________________________
_________________________________________________________________

2. Will this new turning circle be legal?

_________________________________________________________________

3. A rigid vehicle is to have its chassis reduced by 600 mm, what will the new turning circle be? The chassis is 6200 mm long with a turning circle of 20 200 mm.

_________________________________________________________________
Drive shaft alterations

After a wheelbase alteration the drive shaft will also need to be modified to match the new wheelbase. The basic function of a drive shaft is to transmit power from the engine via the transmission to the drive axles via the differential. This must be carried out in a smooth and continuous action.

The axle of a vehicle is not attached directly to the chassis but rides suspended by the springs in an irregular floating motion. This means the drive shaft must be able to lengthen and contract as well as operate through constantly changing relative angles between the transmission and the axle. All of these functions are accomplished by the use of slip joints and universal joints.

The safety implications of tail shaft modifications must be understood. The rotating tail shafts of a heavy vehicle contain a high level of energy, and their accidental failure may cause considerable damage and possible injury. Failure may result from incorrect selection, design or construction; therefore any modification must be carried out with great care.

For the tail shaft to be capable of transmitting the maximum driveline torque, the size of the tail shaft components including universal joints, flanges, centre bearings, tubing diameter and wall thickness, and tail shaft length must be within the truck manufacturer’s specifications.

It is recommended that a tail shaft safety loop be fitted to restrain the front end of each tail shaft on light omnibuses, in case of shaft failure.

If the vehicle was originally fitted with safety loops, these must remain and any additional shafts must be fitted with them.
Critical speed and length of tail shaft

All rotating shafts deflect during rotation. The magnitude of this deflection is dependent on the shaft speed and the stiffness of the shaft.

The stiffness of the shaft is dependent on the length of the shaft, the tube diameter and the tube wall thickness. Shafts are designed to resist bending at a particular speed; this is called the 'critical' speed. If rotating speed of the shaft is increased beyond its critical speed this will result in ‘whirling’, vibrations, bending and sometimes destruction of the shaft. Shafts must be designed to operate comfortably above their maximum operating speed.

The safe operating speed for shafts in straight normal drives is not greater than 85 per cent of the critical speed. As a guide to safe working speeds and lengths for various tube sizes there are monograms available, but most vehicle body builders send this work out to specialised engineering firms. For universal joint angles up to 4°, the safe operating speed is not greater than 65 per cent of the first critical speed. For larger universal joint angles, the safe operating speed should be taken as 50 per cent of the first critical speed.

The maximum operating speed of the tail shaft is the highest shaft speed that the vehicle is likely to generate in service. This must be assumed to be higher than road speed at maximum engine speed in top gear (with transmission over-drive if applicable) to take into account downhill coasting. The following maximum speeds are recommended for shaft design calculations:

- Light duty trucks – 160 km/h (100 mph);
- Heavy vehicles – 135 km/h (85 mph); or
- 20 per cent above governed road speed, whichever is the lesser.

A high standard of workmanship must be maintained when installing a drive shaft to prevent any undue vibration or reduction on the working life of any components.

General rules

- When shortening the wheelbase only the front drive shaft should be altered.
- For wheelbase extensions the increase in drive-line length should be accompanied by the addition of an intermediate drive shaft, a cross member and a centre bearing. In some cases a heavier drive shaft may suffice.
- The transmission angle must be maintained.
Universal joint angle

Whilst these recommended angles of operation should not be exceeded, joints should not be allowed to operate at very low angles for extended periods, or brinelling of the journals and cups by the needle rollers may occur. To prevent the load between the needles and journals and cups being applied in the one region all the time, a minimum operating angle of 0.5° should be used to ensure that the needles roll slightly.

Hence, the operating angles for universal joints should fall between 0.5° and 4° for heavy applications and 0.5° and 6° for light applications, although the maximum angles vary with some manufacturers.

To calculate whether this configuration complies with the basic rules of operating angles, some basic measurements will be necessary. To determine the angle of the tail shaft off horizontal, it will be necessary to use a magnetic base protractor or an electronic protractor.

Operating angle calculations for tail shafts

The operational angles should be a maximum of 6° for heavy vehicles and 8° for light vehicles. However, vibration problems may arise even at these angles, so to minimise this possibility and maximise the working life of the universal joints, operational angles greater than 4° for heavy applications and greater than 6° for light applications should be avoided. Most chassis manufacturers prefer an angle of 3°.

Operating angles to consider

There are several angles to consider when altering tail shafts, combined they make up the overall operating angle of the entire drive line.

• First to consider is the operating angle of the universal joints. (Most manufacturers recommend around 3° but definitely greater than 0.5°).
• The angle of the component parts each side of a tail shaft joint (universal). For example, the angle between the transmission and the first slip joint.
• From the angle of the component parts can be calculated the operating angle of each individual joint of the tail shaft (by either adding or subtracting the angles of the component parts).
• The individual joint angles of the tail shaft are used to calculate the operating angle of the tail shafts, such as the operating angle of the front tail shaft and operating angle of the rear tail shaft. Most manufacturers recommend an angle of 3°.
• The overall operating angle of the entire drive line can now be calculated by comparing the individual tail shaft angles. (this should be less than 1°).

The basic rules to keep in mind are:

• Shaft operating angles at the universal joints must be greater than one half of a degree or 0.5 of a degree.
• For light vehicles the shaft operating angles at the universal joints must be less than 6°.
• For heavy vehicles the shaft operating angles at the universal joints must be less than 4°.
• When comparing all the angles in a drive-line there must be no greater difference than 1°.
**Two joint tail shaft**

Two joint tail shafts are the most simplistic. There are two different types of tail shaft configurations:

- Parallel joint shaft.
- Nonparallel joint shaft.

**Parallel joint tail shaft**

Ideally angle A should be equal to angle B (angle A = angle B)

It is desirable that angle A should be the same as angle B, however a tolerance of one degree is normally acceptable.

To calculate the overall tail shaft operating angle, apply the following rules:

- Always start from the front of the vehicle.
- If the rearward section is inclining down, it is downward.
- If the rearward section is inclining up, it is upward.
- When the inclination is in the same direction of two connected components, subtract the smaller number from the larger number to find the operating angle of the universal joint. If the two angles are down (↓↓) or the two angles are up (↑↑), subtract the smaller from the larger.
- When the inclination is in the opposite direction of two connected components, add the measurements find the operating angle of the universal joint. For one up and one down (↑↓) or for one down and one up (↓↑) add.

If there were a greater angle than one degree this could be remedied by one of the following options:

- Introduce a centre bearing.
- Change the height of the centre bearing.
- Change the inclination angle of the rear differential by the use of shims.
- Change the inclination angle of the gearbox.
Nonparallel joint tail shaft

It is desirable that angle A should be the same as angle B; however a tolerance, of one degree is normally acceptable.

If there were a greater angle than one degree this could be remedied by one of the following options:

- Introduce a centre bearing.
- Tilt the rear differential by the use of shims.

Three joint shaft

In this case the transmission is downward at 3° and the tail shaft runs downwards at 5°, which means the operating angle at that universal joint is 2° downwards. (5°– 3° = 2°). This is greater than 0.5 of a degree and less than 6°, so the universal angle joint is within recommended limits.

The next universal joint behind the centre bearing is 5° downward and the tail shaft is 8° downward making the joint angle of 3°. (8° – 5° = 3°). Once again within limits.

The last universal joint is 1.8° downward. (8° – 6.2° = 1.8°), and again within limits.
The operating angle of the front shaft is $1^\circ$ ($3^\circ - 2^\circ = 1^\circ$).
The operating angle of the rear shaft is $1.2^\circ$ ($3^\circ - 1.8^\circ = 1.2^\circ$).
To find the overall operating angle of the entire shaft we will need to take the smaller number from the greater number.
The front shaft has an operating angle of $1^\circ$ ($1.2^\circ - 1^\circ = 0.2^\circ$).
The rear shaft has an operating angle of $1.2^\circ$.
Therefore, the overall operating angle is 0.2 of a degree, which is below $1^\circ$ so within the accepted operating limits.

**Height of new centre bearing**

The formula for calculating the height of the additional or repositioned centre bearing is:

**Formula:**

\[
F = E + DA
\]

- $F$ = the height of an additional centre bearing when extending a wheelbase or the height of the repositioned centre bearing for a wheelbase reduction
- $E$ = height of existing centre bearing below the top of the chassis
- $D$ = the tangent of the transmission angle
- $A$ = the amount of the wheelbase change (either + or –).

**Note:** $A$ is positive (+) for a wheelbase extension and negative (–) for a wheelbase reduction.
The vehicle's wheelbase is extended by 550 mm. What will be the height of the new centre bearing?

**Formula:**

\[ F = E + DA \]

- \( E = 88 \text{ mm} \)
- \( D = \text{Tan angle of } 3^\circ \)
- \( A = 550 \text{ mm positive} \)

\[ F = 88 + \text{Tan } 3^\circ \times 550 \]
\[ F = 88 + (0.052407779 \times 550) \]
\[ F = 88 + 28.82427861 \]
\[ F = 116.8242786 \]

The height of the additional centre bearing will be 166.82 mm below the height of the chassis.

Where the vehicle's wheelbase is reduced by 450 mm

**Formula:**

\[ F = E + DA \]

- \( E = 88 \text{ mm} \)
- \( D = \text{Tan angle of } 3^\circ \)
- \( A = 450 \text{ mm negative} \)
\[ F = 88 + \tan 3^\circ \times -450 \]
\[ F = 88 + (0.052407779 \times -450) \]
\[ F = 88 + (-23.58350068) \]
\[ F = 64.42 \text{ mm} \]

The height of the repositioned cross member will be 64.42 mm below the top of the chassis and 450 mm forward of its current position.

This will maintain the tail shaft operating angle.
Questions

1. What is meant by the critical speed of a tail shaft?

_________________________________________________________________

_________________________________________________________________

2. State the purpose of the following:
   • a tail shaft  _______________________________________________
   • a universal joint _____________________________________________
   • a slip joint  _______________________________________________

3. Why is there a limit to the length of the tail shaft tube?

_________________________________________________________________

_________________________________________________________________

4. The operating angle of a tail shaft at the universal joint should be no less than _____ degrees and ideally no greater than the manufacturers’ preferred angle of _____ degrees.

5. The overall operating angle of the tail shaft should be no greater than _____.

6. Sketch the difference between a parallel two joint shaft and a non parallel two joint shaft.
7. The wheelbase on the above vehicle is to be extended by 450 mm. The transmission angle is $4^\circ$.

Calculate the height of the repositioned centre bearing.

_________________________________________________________________

_________________________________________________________________

8. The wheelbase of the previous vehicle has been shortened by 520 mm. The transmission angle is $2^\circ$.

Calculate the new height of the repositioned centre bearing.

9. Calculate the operating angle of the tail shaft drive line below.
10. State the function of a centre bearing in a tail shaft assembly.

_________________________________________________________________
_________________________________________________________________

11. Why is it important to have the operating angles on each end of a tail shaft line equal to or within 1° of each other?

_________________________________________________________________
_________________________________________________________________
Universal joints

A universal joint is constructed of two yokes, a cross between the yokes and four bearings assembled on the trunions of the cross. One yoke is connected to the transmission and revolves at a constant velocity at the same rate as the transmission and in a circular path. The other yoke revolves in a non-uniform rotation in an elliptical path.

Transmission yoke

Cross and bearing kit

Tube yoke

Drive shaft tubing

Phasing

The universal joints should be installed in phase throughout the drive line to prevent vibration, although in some complex drive line systems 'out of phasing' may be required to eliminate vibration.

As the whole joint makes one complete revolution, the yoke that is attached to the transmission is held at a constant speed but the second yoke attached to the tail shaft speeds up and slows down twice per revolution. This non-uniform output speed causes the drive shaft to pulsate when the shaft is operating at an angle.
The distances travelled on the circular path between w, x, and y are the same. This is the path travelled by the yoke from the transmission.

The elliptical path travelled by the tube yoke is not uniform, with the distances travelled between w and x being far greater than between x and y. This means the yoke will travel much faster between w and x than between x and y. This occurs twice every revolution of the tail shaft.

<table>
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<th>0°</th>
<th>90°</th>
<th>180°</th>
<th>270°</th>
<th>360°</th>
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<td>Increasing</td>
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<tr>
<td>Constant</td>
<td>-</td>
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<td>+</td>
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<td>Decreasing</td>
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Transmission yoke speed is constant

If the ellipse travelled by the transmission yoke were put on a graph it would look like this.

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<tr>
<th>Speed</th>
<th>0°</th>
<th>90°</th>
<th>180°</th>
<th>270°</th>
<th>360°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
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<tr>
<td>Tube yoke speed varies</td>
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<td></td>
<td></td>
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<tr>
<td>Constant</td>
<td>-</td>
<td></td>
<td>-</td>
<td>+</td>
<td></td>
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<tr>
<td>Decreasing</td>
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<td></td>
<td>+</td>
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Single phase

To compensate for the increase and decrease in rotational speed a second universal joint is located at the opposite end of the tail shaft and is placed in phase. The second universal joint has exactly the same effect as the first one but in the opposite way. When the front universal joint is speeding up, the second one is slowing down and vice versa. This is called phasing.
There is usually an arrow stamped on the tube yoke and the slip yoke so they will be lined up correctly.
**Length of slip joints**

It must be ensured that the sliding joint of the slip shaft never bottoms out or fully extends (known as binding) under any operational conditions. All possible suspension deflections and axle rotation under torque must be considered, and the length of the shaft and amount of slip selected accordingly. The minimum spline engagement with joint extended is 1.5 x spline diameter. The minimum spline end clearance with joint contracted is 1.0 x spline diameter.

**General design and installation guidelines**

- Support bearings are required when the distance from the transmission to rear axles exceeds the maximum length at which a particular shaft can safely operate.
- As the wheelbase increases, it may be necessary to use more than one bearing.
- The support bearing locations should be chosen to minimise the variations in angular velocity over the complete drive line and in the individual shafts.
- When shaft diameters are increased, clearances from other chassis and body components must be checked through the whole range of suspension travel.
- Support bearing adaptor brackets, if used, must be designed to provide adequate strength of attachment to the cross members and bearing housing without prejudicing the strength of these parts. The flexible bushings of the support system must not be distorted by axial misalignment.
Questions

1. If a tail shaft is out of phase, how may this affect the performance of a vehicle?
_________________________________________________________________
_________________________________________________________________

2. Manufacturers usually identify the slip yoke with the tail shaft yoke to avoid out of phase assembly. What should you look for?
_________________________________________________________________
_________________________________________________________________

3. Explain why a single universal joint operating at a 3° angle would be out-of-phase.
_________________________________________________________________
_________________________________________________________________

4. How is out-of-phasing overcome?
_________________________________________________________________
_________________________________________________________________

5. Why must universal joints be operated at an angle?
_________________________________________________________________
_________________________________________________________________

6. Describe the purpose of a spline.
_________________________________________________________________
_________________________________________________________________
7. What is the minimum spline engagement for a 50 mm spline?

_________________________________________________________________

_________________________________________________________________

8. State the minimum end clearance for a 40 mm spline.

_________________________________________________________________

_________________________________________________________________

9. Why should a drive shaft and slip yoke be marked before disassembly?

_________________________________________________________________

_________________________________________________________________
Suggested practical exercises

- Conduct a drop line test from a truck chassis onto a workshop floor.
- From the results of the drop line test complete an inspection report.
- From the inspection report complete a Job Specification sheet.
- Cut and extend a chassis.
- Outside welds must be finished off flush with the chassis rail without any undercut.
- Manufacture a cross member to suit an existing chassis.
- Fit a cross member to an existing chassis.

TIP

It may be necessary to cut the cross member through the centre prior to fitting and weld together once it is in place.
Modify or Repair Chassis/Frame and Associated Components

Workbook (AUM8101A)

DESCRIPTION
The chassis is a major component of vehicles. This workbook deals with how alterations such as cutting, joining and modifying of a chassis will affect the vehicle and how these need to be carried out to comply with the relevant laws, ADRs, and manufacturers’ requirements.

Included are calculations to determine how chassis alterations will affect the operation of the vehicle, such as the turning circle and drive line angle.

EDITION
First edition

CATEGORY
Automotive Manufacture

COURSES AND QUALIFICATIONS
• Certificate III Automotive Manufacture (Bus, truck and trailer)

RELATED PRODUCTS
AUT031 Fabricate Parts for Sub-Assemblies Workbook
AUT032 Perform Gas Metal Arc Welding Workbook
AUT033 Prepare and Operate Equipment, Tools and Machinery – Hand Tools Workbook
AUT034 Prepare and Operate Equipment, Tools and Machinery – Power Tools Workbook

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