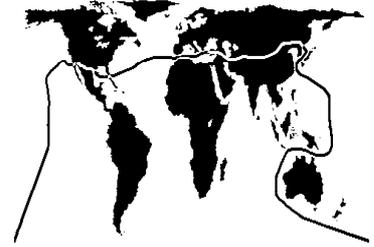


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African Oxcart Design and Manufacture.

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# Contents

<b>PART A: ANIMAL CARTS IN AFRICA &amp; THE BORNO CART.</b>	<b>1</b>
<b>SECTION 1: GENERAL COMMENTS.</b>	<b>1</b>
1.0 Introduction.	1
1.1 Animal-Drawn Carts in Africa.	1
1.2 Main Types of Animal Cart in Africa.	3
<b>SECTION 2: THE DTU BORNO OX-CART.</b>	<b>4</b>
2.0 Background to Development.	4
2.1 Specification of Borno Ox-Cart.	4
2.2 Interaction Philosophy during Project.	5
2.3 Output from Present Project.	5
<b>SECTION 3: CART DESIGN OPTIONS.</b>	<b>6</b>
3.1 Wheels.	6
3.1.1 Solid wood wheels.	6
3.1.2 Fabricated wooden wheels.	7
3.1.3 Fabricated steel wheels.	7
3.1.4 Fabricated all-steel split rim.	8
3.1.5 Pressed steel wheels for local manufacture.	9
3.1.6 Wheel Chosen for Borno Cart.	10
3.1.7 Other Wheel Developments.	10
3.2 Hubs.	10
3.2.1 Traditional wooden hub.	10
3.2.2 Simple pipe hub.	11
3.2.3 Fabricated machined steel hub.	11
3.2.4 Cast or forged hub.	11
3.2.5 Hub Chosen for the Borno Cart.	11
3.2.6 Other Hub Developments in the Programme.	12
3.3 Bearings.	12
3.3.1 Steel pipe or solid axle running in oil soaked wood bearings.	12
3.3.2 Solid steel axle running in a heavy-duty cast iron hub or bearing.	13
3.3.3 Steel axle in cast iron/ steel hub with bronze bush bearings.	14
3.3.4 Steel axle with ball or roller bearings.	14
3.3.5 Bearing Option Chosen for Borno Oxcart.	15
3.3.6 Other developments in programme.	15
3.4 Bodies.	15
3.4.1 Scrap motor vehicles.	16
3.4.2 Wooden flat bed.	15
3.4.3 Wooden box body.	16
3.4.4 Bodies of composite construction.	16
3.4.5 Choice of Body for the Borno Oxcart.	17
3.4.6 Overall Cart Performance.	18

SECTION 4: DESIGN DEVELOPMENT AND TESTING.	19
4.1 Pressed Wheels: Previous Experience.	19
4.2 Safety Tests on Wheels.	19
4.2.1 Test of complete wheel with fully inflated tyre at 2 bar.	20
4.2.2 Complete wheel with fully inflated tyre at 2 bar.	20
4.2.3 Complete wheel with fully inflated tyre at 3 bar.	20
4.2.4 Recommendations.	21
4.3 Mk 4 Cast Aluminium Hubs: Testing.	21
4.3.1 Shear test on lugs.	21
4.3.2 Casting strength around wheel studs.	21
4.3.3 Tensile test on samples taken from a Mk 4 hub.	22
4.3.4 External analysis of five samples taken from a Mk 4 hub.	22
4.3.5 Conclusions.	22
4.4 Bearings.	22
4.4.1 Recent Developments.	22
4.4.2 DTU Cup & Cone Bearings.	23
4.4.3 Tests on Locally Available (Nigeria) Bicycle Balls.	24
4.4.4 Conclusions.	25
4.5 Concluding Remarks on Design Development and Testing.	25
<b>PART B: MANUFACTURING THE BORNO ANIMAL CART.</b>	<b>27</b>
SECTION 5: MANUFACTURE OF PRESSED WHEELS.	27
5.1 Introduction.	27
5.2 Overview of Wheel Manufacture.	28
5.3 14" Pressed Wheels: Detailed Manufacturing Procedures.	29
5.4 Wheel Assembly.	31
SECTION 6: CAST ALUMINIUM HUB MANUFACTURE.	32
6.1 Introduction.	32
6.2 Casting the Mk 4 Aluminium Hub.	32
6.3 Further developments.	34
SECTION 7: BEARING MANUFACTURE.	35
7.1 Introduction.	35
7.2 Production.	36
7.3 Heat Treatment of Steel - General.	36
7.4 Case Hardening - The Process.	37
SECTION 8: CART BODY MANUFACTURE.	39
SECTION 9: TOOLS FOR DTU BORNO CART PARTS.	40
9.1 Introduction.	40
9.2 Forming or Bending Tools - General.	40
9.3 Punching or Blanking Tools - General.	42
9.3.1 Pressing Force for Blanking.	42
9.4 Punching or Blanking Tools for Ox-Cart Manufacture.	43

9.5	Drilling Jigs - General.	44
9.6	Steel Casting Mould.	45

## FIGURES

Figure 1:	solid wood wheel.	6
Figure 2:	wooden spoked wheel.	7
Figure 3:	spoked steel wheel.	8
Figure 4:	ITDG steel split rim for use with pneumatic tyre.	8
Figure 5:	DTU pressed steel wheels for pneumatic tyres.	9
Figure 6:	cast aluminium split rim for use with pneumatic tyre.	10
Figure 7:	fabricated pipe and roller axle.	12
Figure 8:	wooden bearings.	13
Figure 9:	steel axle in cast iron hub.	13
Figure 10:	steel axle in cast iron hub.	14
Figure 11:	cup and cone bearings.	15
Figure 12:	steel box tube framed cart with wooden planking.	17
Figure 13:	all wooden cart using clenched wire fixings.	18
Figure 14:	rolling road test of wheels and bearings.	19
Figure 15:	strength of aluminium castings produced in Nigeria.	21
Figure 16:	cup-and-cone bearing components.	23
Figure 17:	essential cup-and-cone bearing dimensions.	24
Figure 18:	DTU wheel, hub and bearing test rig.	24
Figure 19:	hydraulic press used in pressed wheel manufacture.	27
Figure 20:	pressed steel wheels.	28
Figure 21:	layout of jig used for punching holes in pressed steel wheels.	30
Figure 22:	Mk 4 aluminium hub - gravity die cast in steel mould.	33
Figure 23:	sand-cast aluminium hub - for 6208 tapered roller bearings.	34
Figure 24:	cup and cone ball bearings.	35
Figure 25:	temperatures during carburisation of bearing components.	37
Figure 26:	simple press tooling example - here for a V bracket.	41
Figure 27:	design of a blanking tool to produce a square hole.	43
Figure 28:	simple drilling jig.	45

## TABLES

Table 1:	Hardness Tests: Nigeria purchased Chinese 1/4" balls - July 1993.	26
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## APPENDICES

Appendix 1:	Test results for aluminium cast in Nigeria.	46
Appendix 2:	Test Results for Chinese Ball Bearings.	48
Appendix 3:	Pressed Steel Wheels: Dimensions and Tooling.	50
Appendix 4:	Wheel Hole Punching Tools	56
Appendix 5:	Cup-and-Cone Press Tools.	63
Appendix 6:	Aluminium Hub Casting Tools.	71
Appendix 7:	Drilling Jig for Aluminium Cast Hubs.	88
Appendix 8:	Axle Drawing for Wheel Hubs.	93
Appendix 9:	Wooden Ox-Cart Construction.	95
Appendix 10:	Steel and Wood Donkey Cart Construction.	107
Appendix 11:	Pipe and Roller donkey Cart Axles.	116



# **PART A: ANIMAL CARTS IN AFRICA & THE BORNO CART.**

## **SECTION 1: GENERAL COMMENTS.**

### **1.0 Introduction.**

This paper covers work carried out by HS Pearson and colleagues in northern Nigeria in 1993 and 1994. The paper is divided into two parts: part A (sections 1 to 4) discusses animal carts in general, the design options available for their various components, the particular circumstances affecting the development of the DTU Borno oxcart, and its main design features; part B is a set of full manufacturing instructions for the basic cart and some minor variations of it. We have written the paper because there is a dearth of detailed information about cart design and manufacture - especially information that identifies the context of use and manufacture and the assumptions underlying the approach used.

The DTU Borno cart incorporates a mix of novel and traditional features, and it draws heavily of course, upon designs used elsewhere. We believe it to be substantially cheaper than most alternatives of comparable performance. It has been moderately tested in the laboratory and in the field where production in significant volume started only in late 1993. However certain components were already well proven and others have been fairly easy to test for performance. Every reader of this paper intending to use the design elsewhere should compare their own context and objectives with those described below and feel free to adapt the design to their own circumstances. We believe nevertheless, that the specifications and constraints worked to in NE Nigeria are representative of those in many other parts of Africa.

### **1.1 Animal-Drawn Carts in Africa.**

The use of animal-drawn vehicles for agricultural purposes in rural areas of Africa is relatively new when compared with the millennia-long history of using animals to pull carts, coaches and wagons etc in Europe and Asia. In Europe by the late 19th century, at the height of its development, the animal-drawn wagon required very skilled artisans for its construction. Though examples of these 'high tech' wagons can be found in some African countries (in particular the Republic of South Africa) the technology for construction never took hold amongst African artisans. Perhaps, because the technology took hundreds of years to develop in Europe, insufficient time was available to pass on the relevant skills into Africa before the motor vehicle swept away animal traction in Europe itself.

Some areas of sub-Saharan Africa will not support the use of animal-drawn vehicles because the topography is unsuitable, e.g. very hilly terrain, or because the area is not suitable for draft animals, because of disease. The most common impediment has been sleeping sickness transmitted by the tsetse fly, which is found in rain-fed forest areas.

Animal-drawn vehicles were first used in Africa at ports for the transportation of goods to and from ships. Even today, on balance probably more animal-drawn carts are used in urban areas than rural ones. There is little doubt that if they were more readily available and were cheaper

and of better quality, animal-drawn carts would be used in much greater numbers by rural people.

In the absence of carts, rural people carry goods on their backs or heads - work often left to women. For moving goods and agricultural produce from the farm or homestead to the nearest town or motorable road, pack animals such as donkeys are sometimes used. Even where carts are available, women do not traditionally operate them, and still find themselves carrying loads.

After African independence, development organisations, in cooperation with African governments, have had many programmes aimed at improving designs of animal-drawn carts and increasing their availability to the poorer members of farming communities.

It has always been difficult to justify the expense of a purely agricultural cart, an investment perhaps larger than that of any other equipment the farmer uses (for example a cart can cost about three times as much as a medium sized plough). The ox-cart on the farm does not directly contribute to increased crop production as does the plough, where the relationship to an increased crop is more readily obvious. Moreover the farmer would require extra animals if he wished to use them for transport at the same time as preparing land.

But any farmer operating above subsistence level will need transport to get his/ her produce to the nearest town or line of road or rail. Outside the harvest season farmers living in villages or near towns often hire out their carts and animals, to be operated by a relative, for use in hauling goods other than traditional farm produce. Optimum use of the cart and trained animals is important in terms of income generation, but it does not eliminate the need to reduce substantially the costs of carts in Africa from their present high levels.

Since the moving of heavy loads, crops, water, building materials etc, forms a major part of the working life of African people, the importance of transport is self evident. Programmes aimed at cart development have generally been more successful than efforts in many other technologists. The construction of animal-drawn carts is one of the few industries that can be found readily in most African countries and is undertaken by a broad spectrum of agents - from the blacksmith operating under a shady tree, to large urban companies.

Some African countries have a long history of cart making. For over sixty years in Madagascar, professional cartwrights have been making wooden spoked wheels with metal rims, of a type very similar to those which were formally made in Europe. In other countries, such as the Central African Republic, less skilled artisans with more limited tools, make solid wooden wheels by building up layers of timber and cutting them to shape. In recent years in most African countries however, parts from old motor vehicles have formed the basic materials for cart construction.

Many areas of Africa are heavily dependant on animals for transport and for agricultural purposes. Rural people in Ethiopia rely heavily on the use of animals for crop production - donkeys are extensively used as pack animals, as they are in semi-arid areas in West Africa. Because of the mountainous terrain and the lack of reasonable rural roads in Ethiopia, animal-drawn vehicles are usually used in urban areas. Donkey carts, horse-drawn two-wheeled taxis and flat-bed four-wheeled commercial carts, drawn by three horses are widely used here. The Sahel and Botswana are also rich in mule and donkey carts - in fact over much of Africa there is a realisation that animal traction is a sustainable technology that can deliver useful results without the costs associated with motorised transport. It is often forgotten that animal traction

is new technology in many areas in Africa, ie it is *novel* and the detail of the technology must be developed from a low base. This present work is part of that technology development.

## **1.2 Main Types of Animal Cart in Africa.**

Most carts now available in Africa originate from one of three sources:

- importation from overseas;
- importation of axle assemblies, complete with wheels and tyres, and sometimes including metallic body parts - wooden floor and sides added locally;
- local construction of entire carts using scrap parts from motor vehicles or simple locally-made bearing systems combined with wooden bodies.

The ideal would be full local manufacture using designs at various technological levels to suit different manufacturing facilities and financial situations.

Animal carts are only one of many types of non-motorised vehicle for carrying freight. Such vehicles may be grouped into three classes:

- Human-propelled devices such as wheel-barrows, water-carts, bicycle-carts and hand push or pull carts.
- Horse-drawn wagons and carts. Horses are not widely used in African countries because of disease and high feeding costs, also horses are not as robust working animals as donkeys and oxen.
- Other animal-powered vehicles such as donkey carts, ox carts and wagons for one or two animals.

This report focuses on the third class: donkey and ox-carts and wagons for use with one or two animals.

## **SECTION 2: THE DTU BORNO OX-CART.**

### **2.0 Background to Development.**

Borno State (the site of the activity for the present project) was until recently a very large part of Nigeria but has recently been divided into two smaller states, Borno and Yobe. The Northern part of Borno is dry Sahel Savanna containing three towns, many agricultural villages and Fulani (nomad) camps. The landscape is flat, the soil is sandy and the population density is quite low. There are a few sealed roads, but most villages are at least 10 km from the nearest one. Motor vehicles and motor fuel are quite plentiful in Nigeria (although there are serious fuel shortages from time to time), but there is a substantial demand for animal carts for local movement of crops, fuel, water and building materials.

In 1990 the Nigerian Government and the European Community established a large interlinked rural development programme in North Borno entitled the North East Arid Zone Development Project (NEAZDP). Improving rural conditions, services and incomes were major aims written into the programme. The DTU Borno Cart was developed out of cooperation between the DTU (Warwick University), a new Centre of Appropriate Technology (RAMCAT) at Ramat Polytechnic in Maiduguri (the Borno State capital), and NEAZDP field staff. NEAZDP has also been involved in increasing the number of draught oxen in the arid zone, training urban and rural artisans, and establishing a market distribution system for 'rural equipment'.

Carts are already made in several villages in the arid zone. They use wheels and axles from old pick-ups which are combined with a timber body. The supply is inadequate to meet demand and prices are quite high, yet the assemblers (carpenters) get a poor living from making them. Poor availability of components is a major constraint on output.

Nigeria has a substantial formal industrial sector and, even in relatively isolated Borno State, there are several machine shops in Maiduguri and a couple in smaller towns, such as Gashua. There is also some informal industry, including aluminium casting. Trends in the Nigerian economy discourage ongoing dependence on imported components and articles.

### **2.1 Specification of Borno Ox-Cart.**

The DTU Borno Cart was therefore developed against the following specification:

- to be assembled by village carpenters who will also continue to produce cart bodies (an urban fabricated alternative body was also required);
- to carry loads of up to 1 tonne (1 metric ton = 1 000kg - very nearly the same as an Imperial ton) when pulled by two well fed oxen over flat sandy tracks;
- to use pneumatic tyres, as these are readily available, repairable and non-damaging to sealed roads;
- to make full use of Borno State's existing industrial capacity and not be heavily dependent on imported items:

- to cost less than \$<sub>US</sub>150 to produce (in 1993):
- to reach volume production within 3 years (of 1991) and therefore to use techniques and components that are rapidly provable or already proven elsewhere in Africa.

This working paper has been written in the belief that these conditions in NE Nigeria are not markedly different from those in many other parts of Africa and therefore that both the design and our experiences from other countries will be of interest to organisers of animal drawn transport programmes elsewhere in Africa.

## **2.2 Interaction Philosophy during Project.**

The technology-transfer philosophy adapted in this programme was:

- to aim at durable products of moderate price rather than short-lived ones of extremely low price;
- to employ the highest levels of technology sustainable in the area- for example to use jigs and fixtures to aid production, which themselves require a certain amount of skill to reproduce or modify;
- to upgrade the general skills of the casters, fabricators and assemblers involved in cart production so that they might also improve their range and output of other products;
- to encourage interchangeability of parts by adopting local standards wherever possible - to multi-source components and avoid reliance on any single producer;
- to minimise dependence on imported materials particularly those whose market availability is erratic.

## **2.3 Output from Present Project.**

The Nigerian economy and the institutions involved were subjected to many changes in the period 1991/94 and the objectives adopted in 1991 were not fully achieved. However the cart, whose manufacture as described in detail in Part B of this paper, had been produced in some numbers (over 20) by July 1994 and some hundreds of operating hours had not revealed any major problems in use. One manufacturer of axle sets, one caster of aluminium hubs and two cart body builders were trained and supplied with the necessary jigs and moulds to attain good quality production. However extension of the production of running gear (axles, hubs, bearings, wheels) to several competing urban manufacturers has still to be arranged, as has the training of significant numbers of village carpenters to incorporate the new cart components into their production.

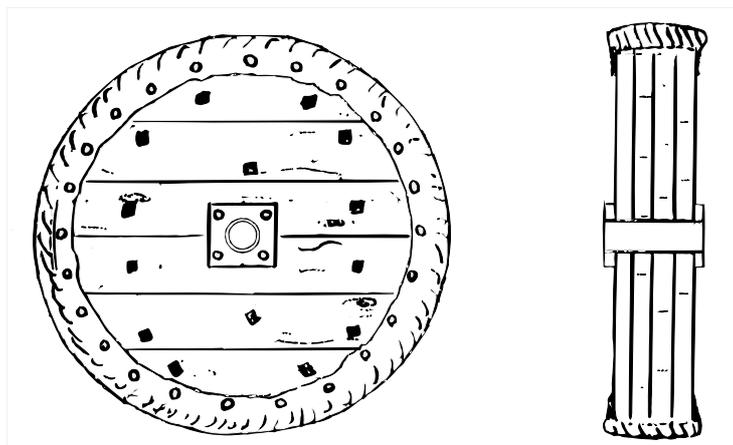
## SECTION 3: CART DESIGN OPTIONS.

### 3.1 Wheels.

In general, fabricators of animal drawn vehicles in sub-Saharan Africa, use second-hand wheels from motor vehicles. Such wheels often come attached to an old rear or front axle, which is also used in the cart's construction. Wheels entirely manufactured in African countries specifically for use on animal drawn vehicles are not so widespread. Several designs however, have been adopted and used with various degrees of success and popularity. These are identified as follows.

#### 3.1.1 Solid wood wheels.

Solid wooden wheels with solid rubber tyre made from old motor vehicle tyre outer cover. This wheel is constructed using layers of flat planks that are cut and bolted together to give the required thickness of about 100mm - with the grain of successive layers set at right angles for strength. The diameter of these wheels is about 1 meter, or a little more. Bearings are likely to be of a simple bush type incorporated in the hub of the wheel.



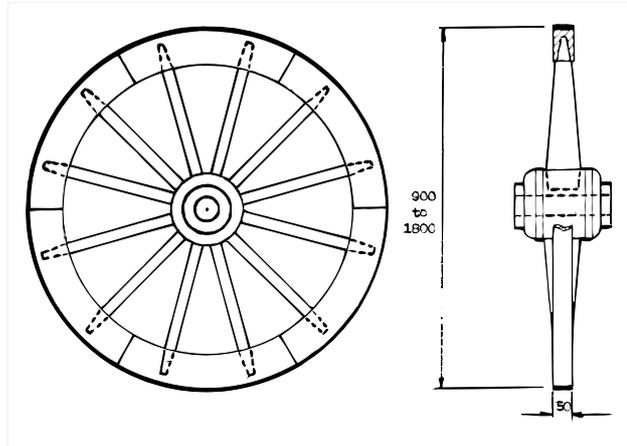
**Figure 1: solid wood wheel.**

**Advantages:** easy to make with readily available materials, simple to repair. Good for use over rough terrain or in remote areas where punctures to pneumatic tyres may be a problem to repair.

**Disadvantages:** there are limitations to the types of bearings that could be used successfully as a more complex hub structure would be required. On hard road surfaces the cart would ride very roughly, transmitting large shock loads to the bearings. The wheels are very heavy (100kg).

### 3.1.2 Fabricated wooden wheels.

Fabricated wooden wheels of traditional European design (Fig 2) with a heavy wood hub supporting wooden spokes fitted into a wooden sectioned rim with a narrow steel band as a tyre. The European spoke wheel is normally dished, whereas the Asian and African versions are not.



**Figure 2: wooden spoked wheel.**

This design of wheel has not been produced in large numbers in Africa. They were most prolific in South Africa where they were used by settlers from Europe, in particular the Boers, on their large ox wagons. Cruder versions of the spoked wooden wheel are however still made in some African countries. These wheels are usually fitted with thin solid rubber tyres cut from old commercial vehicle tyres.

*Advantages:* good for use in remote areas or over rough ground. Much lighter than solid wheels and more flexible under shock loads.

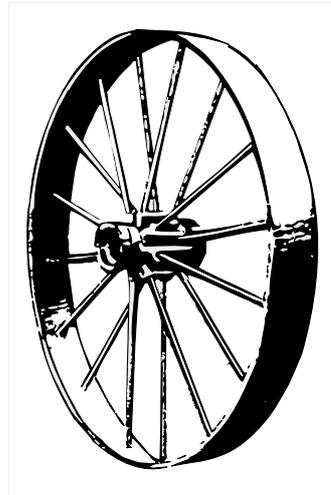
*Disadvantages:* requires considerable woodworking skill in manufacture and repair. 19th century European cart makers underwent a five year apprenticeship. Uses well-seasoned high-quality wood, that is becoming scarce in many countries.

### 3.1.3 Fabricated steel wheels.

Fabricated steel wheels with flat steel rims, 800mm to 1000mm diameter with a 100mm wide rim. Welded or blacksmith riveted construction, Figure 3. The fabricated steel wheel is still occasionally manufactured by large companies in developed countries for use on tractor-drawn agricultural equipment. Designs suitable for use on animal drawn carts have been produced in many African countries. Given reasonable construction they will last for many years without giving trouble, but the joints between spoke and rim can give trouble.

*Advantages:* fairly easy to construct and obvious.

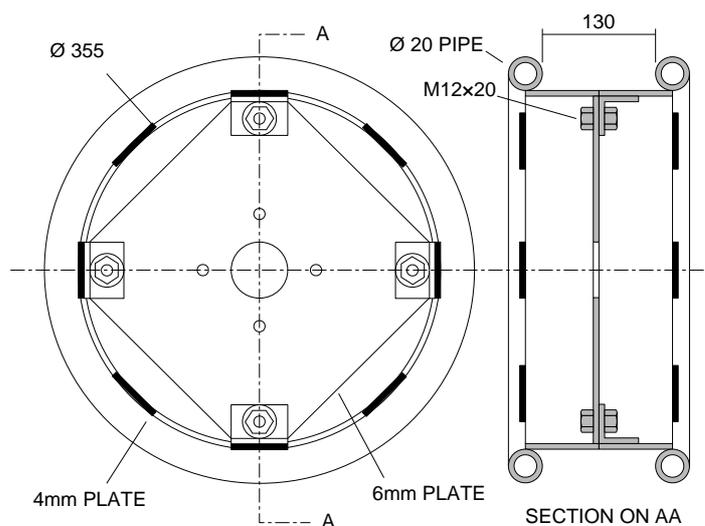
**Disadvantages:** shock loads from bumps fed to bearings, fatigue of welds between spokes and rim, damage to road surfaces, noisy, bumpy ride.



**Figure 3: spoked steel wheel.**

### 3.1.4 Fabricated all-steel split rim.

This rim is designed to be fitted with a commercial inflatable tyre, and is shown in Figure 4. Joseph Wirth, a development engineer working in Tanzania, designed a split rim fabricated wheel in 1965. Many hundreds have been manufactured in Tanzania and other countries since then and used on animal drawn vehicles. Very similar is the design by Intermediate (Technology) Transport. Both models use flat strips and round bars in their construction. Most popular sizes are for 16" (Land Rover) and 14" (Peugeot) tyres.



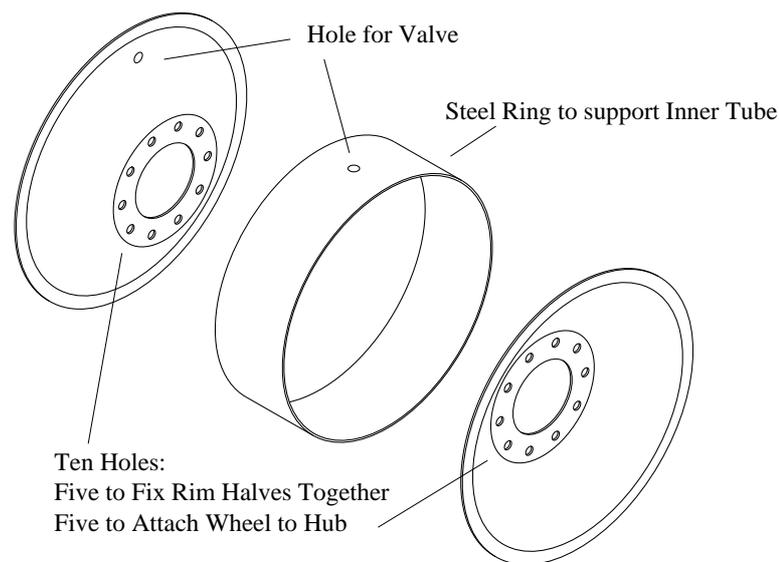
**Figure 4: ITDG steel split rim for use with pneumatic tyre.**

**Advantages:** split-rim design simplifies tyre repair. May be used with a selection of bearing and hub configurations. Use of pneumatic tyres gives an improved ride and a better rolling action.

**Disadvantages:** requires a workshop equipped with electricity for welding and drilling. The metal sections of the wheel have to be bent in a special, and quite expensive bending tool (e.g. that designed by IT Transport for the purpose) or a conventional rolling machine. The wheel is material intensive, using up to 5 different metal sections, and is heavy weighing about 25kg.

### 3.1.5 Pressed steel wheels for local manufacture.

This design (Figure 5) was developed at CAMARTEC in Northern Tanzania in 1988 and several hundred are in use. The construction of the wheel is very simple and is of a split rim design. Rims for two popular tyre sizes are available, 16" (Land Rover) and 14" (Peugeot).



**Figure 5: DTU pressed steel wheels for pneumatic tyres.**

**Advantages:** split rim design simplifies tyre repair. May be used with a selection of bearing and hub configurations. Use of pneumatic tyres gives an improved ride, a better rolling action and lower shock loads on bearings. One size or material, 3mm steel plate, is used throughout the wheel's construction. Simplicity of design will allow many different sizes to be made using the same material and methodology. Adapts easily to small or large batch production. Light weight 12 kg.

**Disadvantages:** Requires a workshop with electrical power and access to an

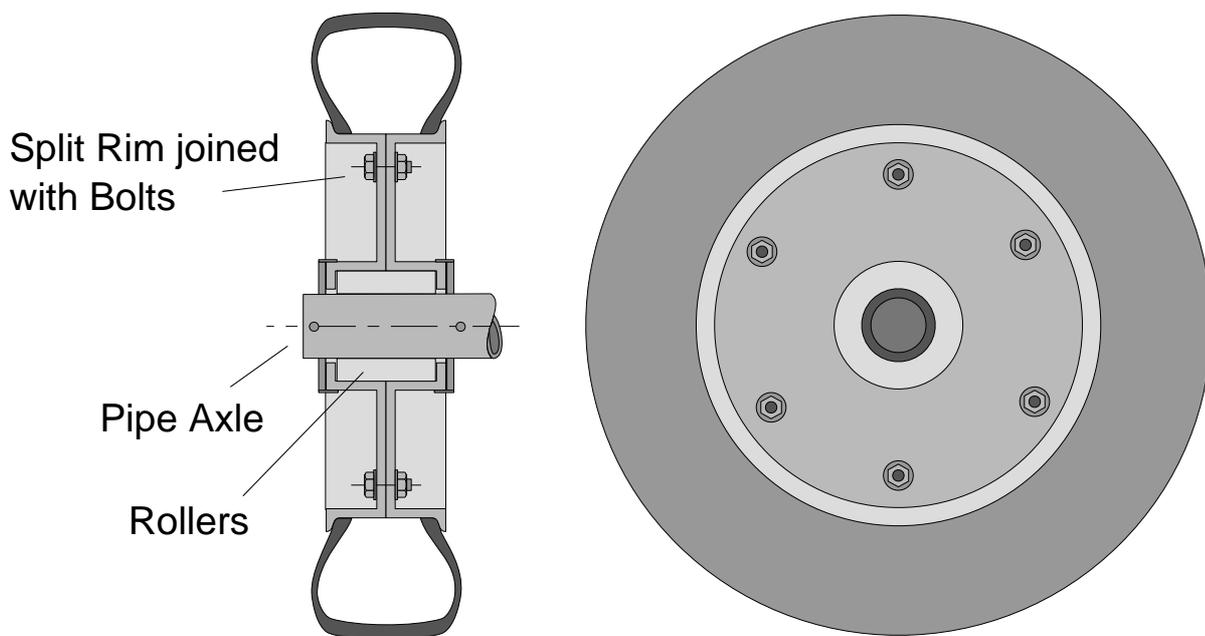
hydraulic garage-type press of not less than 40 tonf capacity (1 tonf is a unit of force = weight of 2240 lb). Not suitable for manufacture in most rural environments.

### 3.1.6 Wheel Chosen for Borno Cart.

The pressed steel wheel design was selected as the most suitable design for use on the DTU Borno oxcart. This decision was based upon previous experience in Tanzania and the availability of facilities and materials availability in the project area, and was taken to reduce wheel costs whilst retaining the advantages of pneumatic tyres already experienced in NE Nigeria.

### 3.1.7 Other Wheel Developments.

An extension of aluminium casting technology is presently being researched is the all-in-one cast aluminium wheel and hub shown in Figure 6. In this design the bore of the hub is unmachined and rollers bear directly on it and on the pipe axle. Test wheels have survived over 4 000 km of continuous running to date.



**Figure 6: cast aluminium split rim for use with pneumatic tyre.**

## 3.2 Hubs.

The design of a hub for local manufacture will depend upon the manufacturing climate, materials availability, bearing system, and wheel fitment. Some of the more well known designs are discussed below.

### **3.2.1 Traditional wooden hub.**

Traditional wooden hub used in conjunction with wooden spokes and rim. Used on carts, wagons and coaches. Popular at the turn of the century in the northern industrialised nations and fitted to carts used by European settlers in Africa.

*Advantages:* strong and easy to maintain, will support heavy loads at slow speeds.

*Disadvantages:* requires skilled craftsmen and good quality wood for its construction. Limitations to bearing designs that can be used.

### **3.2.2 Simple pipe hub.**

Simple pipe hub with a flange welded to it for mounting the wheel. This design is often used in conjunction with a wood bearing pressed into the hub pipe and used in conjunction with rigid wheels of wood or steel.

*Advantages:* can be manufactured locally. Very simple in design and construction and cheap to build. Easy to service.

*Disadvantages:* depends on availability of reasonable workshop facilities and materials supplies. Limitations to the types of bearing that can be fitted.

### **3.2.3 Fabricated machined steel hub.**

Fabricated machined steel hub but with more sophisticated mounting facilities to incorporate bronze bush, roller or ball bearings.

*Advantages:* can be manufactured locally. This design is adaptable for various bearing designs. Used with roller or ball bearings can run at higher speeds.

*Disadvantages:* advanced workshop facilities required with more complex fabrication and increased manufacturing costs. Regular supplies of raw materials may be a problem.

### **3.2.4 Cast or forged hub.**

Cast or forged hub fitted with bush, roller or ball bearings. Cast hubs are used on all commercial high speed vehicles, with the bush-bearing hub used on slow speed agricultural equipment.

*Advantages:* provided that foundry facilities are available, this is very cheap to produce in a wide variation of designs for different bearing configurations and wheel fittings.

*Disadvantages:* requires foundry and machining facilities. Unsuitable for rural manufacture.

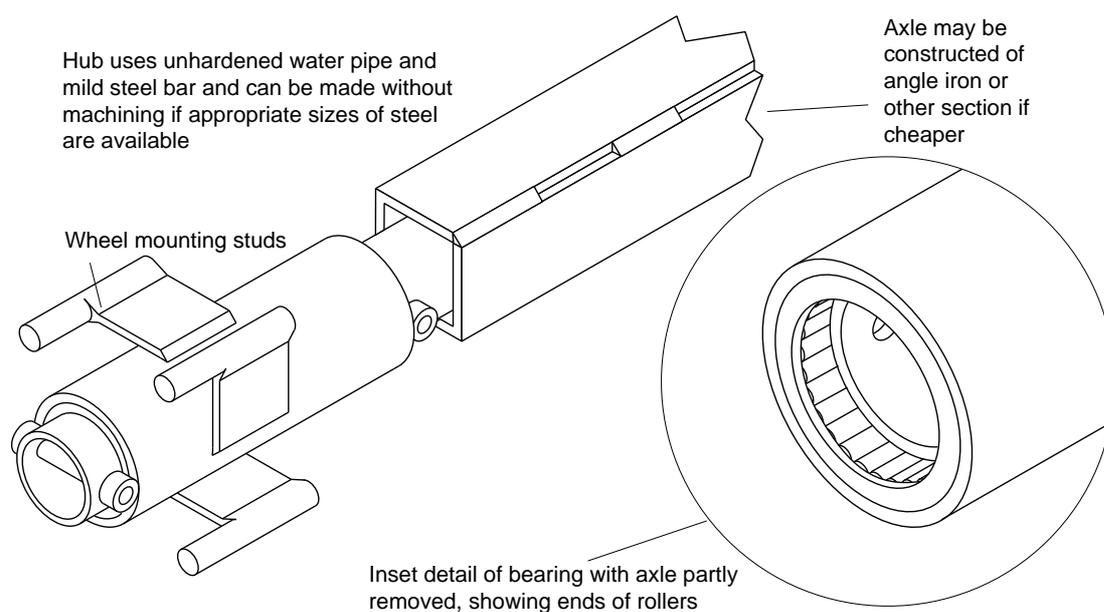
### **3.2.5 Hub Chosen for the Borno Cart.**

A cast hub design using aluminium was selected for the Borno oxcart because of the

availability of facilities, the raw materials cost, and the product quality required.

### 3.2.6 Other Hub Developments in the Programme.

A development of the fabricated hubs discussed above is being pursued by the DTU and is shown in Figure 7. Here low steel requirements have been achieved by mounting the wheel fixing studs on struts welded tangentially to the hub tube. This method has been shown to be cheap and reliable. A further important development has been the use of non commercial roller bearings, discussed briefly in a later section. The hub and bearing are in advanced stages of development and testing, but are not yet ready for widespread use.



**Figure 7: fabricated pipe and roller axle.**

## 3.3 Bearings.

There are many bearing systems available that have been tested for use on animal-drawn carts, the following is a list of the more successful.

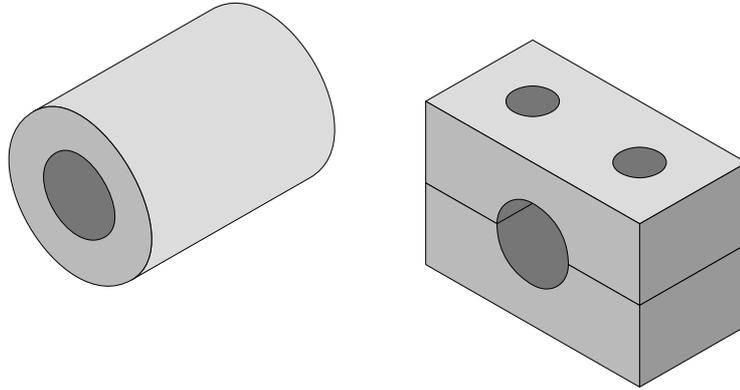
### 3.3.1 Steel pipe or solid axle running in oil soaked wood bearings.

These hubs can be arranged with the bearing (Figure 8) fixed in the hub of the wheel and rotating on a fixed axle, or with four sets of split block bearings arranged on two short axles, these rotating with their respective wheels.

**Advantages:** simple to make and will last reasonably well, providing hardwood is used and lubrication is adequate. Easy to service in rural areas where skills and tools may be limited.

**Disadvantages:** suitable hard wood may not always be readily available (eg many tropical hardwoods have silicate inclusions which cause rapid wear to mating shafts). The hub-fitted bearing requires some skill in manufacture, particularly if the spokes

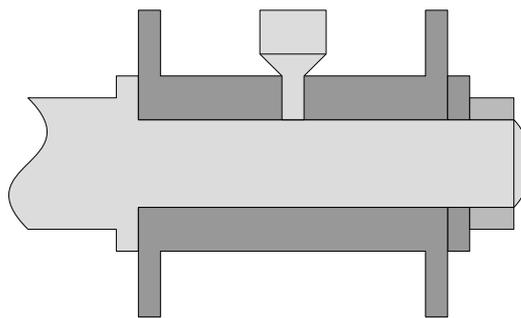
of the wheel are incorporated into the hub. The bearings show quite high friction, especially under load, which makes the cart hard to pull and reduces popularity with users. With four block bearing and overhung wheel designs, the outer bearings carry loads greater than the wheel load, which gives rise to high wear. This wear problem is often aggravated because most wood bearings are open to the ingress of dust and dirt.



**Figure 8: wooden bearings.**

### **3.3.2 Solid steel axle running in a heavy-duty cast iron hub or bearing.**

Figure 9 shows the next generation of bearing design after the wooden bearing. Because of its free graphite, cast iron is to some extent self lubricating, and runs well against other bearing materials such as steel, bronze or even itself. This type of bearing has been extensively used on agricultural equipment such as planters, harvesters and harrows.



**Figure 9: steel axle in cast iron hub.**

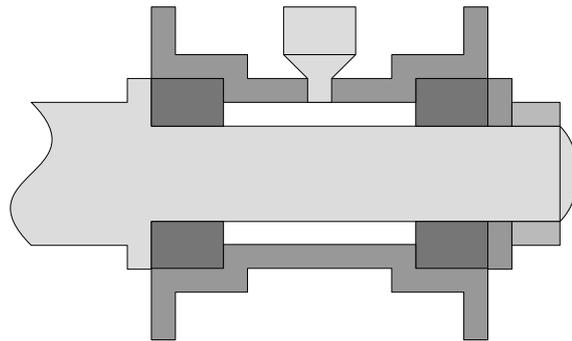
**Advantages:** using cast iron allows for intricate hub shapes with the bearing integral. It wears well provided that lubrication is adequate.

**Disadvantages:** requires iron foundry facilities and skills such as pattern making and moulding and a source of raw materials. The bearing system should be well

lubricated and sealed against dust and dirt. There are some frictional losses and excessive wear in the integral bearing could necessitate replacement of the entire hub.

### 3.3.3 Steel axle in cast iron/ steel hub with bronze bush bearings.

This system (Figure 10) is a natural development from option 3.3.2 above. For interchangeability separate bearings are made and fitted into a cast iron or steel hub. Until the advent of rolling element bearings this system was used extensively in carts, wagons, agricultural equipment, and stationary steam engines worldwide.



**Figure 10: steel axle in cast iron hub.**

*Advantages:* bearings are cheap to manufacture, fairly easy to replace and will tolerate heavy loads at low speeds. Different combinations of bearing materials can be used.

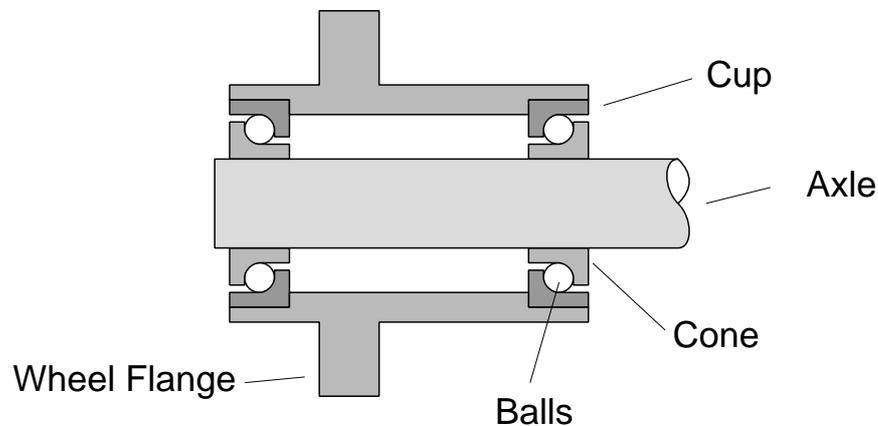
*Disadvantages:* regular lubrication and the exclusion of grit and dirt are very important. A breakdown in lubrication can lead to damage to the hub, and rapid wear. These bearings show significant frictional losses and require extensive workshop facilities and skills in manufacture.

### 3.3.4 Steel axle with ball or roller bearings.

Such an arrangement is shown in Figure 11. Rolling element bearings operate by interposing rollers or balls between the fixed component (usually the axle and the rotating component, (usually the hub). This reduces the frictional losses and results in a very free running bearing with a long life.

*Advantages:* Tapered-roller and cup-and-cone (or angular-contact) designs are adjustable and will accommodate axial as well as radial loads. With minimum maintenance or lubrication they can last a very long time if correctly sized and are particularly good when used in slow vehicles such as oxcarts.

**Disadvantages:** such bearings require complex machinery and accuracy and good quality control in their manufacture. Bearing components must be heat treated and fitted correctly. Heavy shock loading during installation or use can cause rapid destruction of these bearings.



**Figure 11: cup and cone bearings.**

### **3.3.5 Bearing Option Chosen for Borno Oxcart.**

Locally manufactured cup-and-cone ball bearings were selected as most suitable for use on the DTU Borno oxcart. This decision was based on availability of manufacturing skills and materials, performance and potential lifespan of the finished product.

### **3.3.6 Other developments in programme.**

As mentioned above and shown in Figure 7, the DTU is currently developing a system of low-cost rolling-element bearing which can be made without machine tools. Limited trials of these axles have been made in Africa with encouraging results, but further work is needed before designs can be fully released.

## **3.4 Bodies.**

Once a suitable axle has been obtained or built a body will be required. Some of the more popular options are listed below. The dimensions of cart bodies vary from country to country but are approximately as follows: width 1.3 to 1.5 m, length 1.8 to 2 m. Underbody clearance should be as much as possible but should not put the loading platform of the cart unrealistically high, ie above 700 mm. Variation in vertical load on the animal, as bumps are traversed, also increases with load tray height. The main types of cart body used in Africa are discussed below.

### **3.4.1 Scrap motor vehicles.**

Scrap motor vehicles are a common source of oxcart bodies utilised in African countries. A scrap body, salvaged from an old small truck or pick-up, is often used in conjunction with the rear axle assembly from the same or similar vehicle.

*Advantages:* generally found in towns or near main roads where there is a good supply of scrap vehicles. Strong and able to outlast most axle systems, the owner will transfer the body as the axles wear out. Suitable for urban construction.

*Disadvantages:* use of scrap bodies can only be considered in the construction of limited numbers of non-standard carts, because of lack of local availability in large quantities. Often very heavy and best used in conjunction with a ball or roller bearing axle.

### **3.4.2 Wooden flat bed.**

Wooden flat bed without sides made up of 50 mm × 100 mm wooden beams and 25 mm thick planks bolted and nailed together. Often mounted on a scrap rear or front axle from a motor vehicle.

*Advantages:* easily made and repaired under rural conditions. Can be built to suit different axle sizes, can handle bulky but light loads and may be inexpensive.

*Disadvantages:* without sides the underbody requires rigid bracing. Not suitable for carrying loose loads such as sand or grain.

### **3.4.3 Wooden box body.**

Wooden box body similar to that above, but with sides, head and tail-board.

*Advantages:* all the advantages of that above but capable of carrying a wider range of loads.

*Disadvantages:* can become material intensive and heavy if the construction and design is not carefully thought out.

### **3.4.4 Bodies of composite construction.**

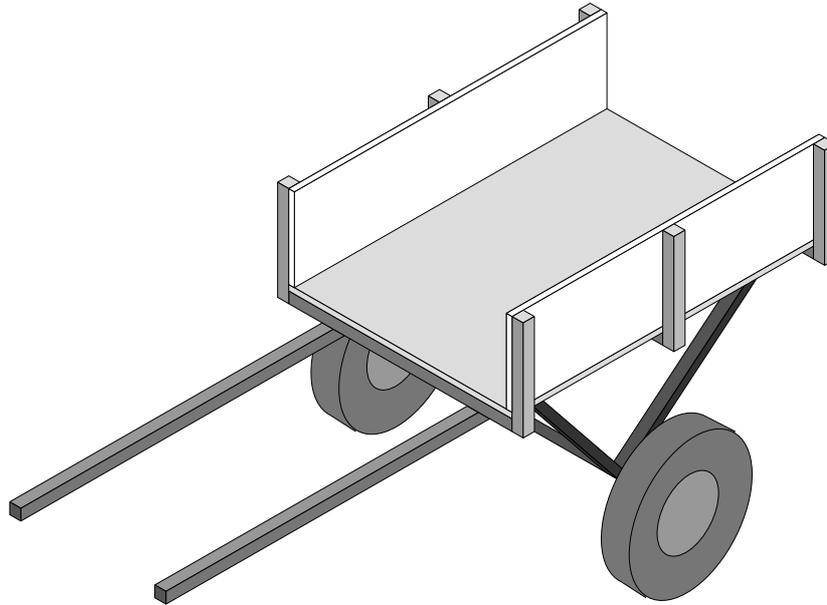
Bodies of composite construction using steel sections of angle iron, flats or box tubing welded and/or bolted with wooden planks for floor and wooden sides bolted on.

*Advantages:* providing the design is well thought out the body will be strong and light.

*Disadvantages:* requires the constructor to be skilled in metal fabrication as well as having some woodworking skills. Less suitable for rural construction, where steel sections and welding facilities may not be readily available.

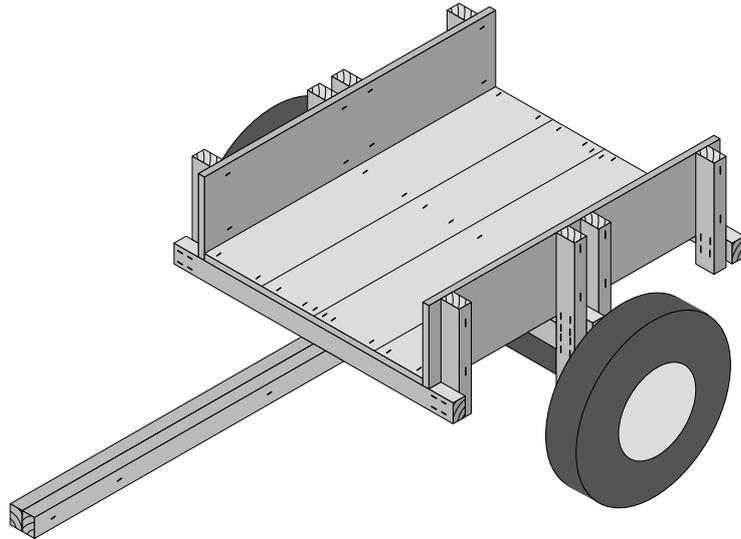
### 3.4.5 Choice of Body for the Borno Oxcart.

The Borno ox-cart can be fitted with either of two DTU designed bodies shown below, one of welded steel box tubing and wood planking (Figure 12); the other of all-wood construction (Figure 13). Both designs have short construction times by virtue of their small component counts and simple manufacturing processes. For example only square cuts are required at the ends of all components and none are required to be cut more accurately than about 5mm.



**Figure 12: steel box tube framed cart with wooden planking.**

In both carts, clenched fixings are used to hold the wooden components together or to the steel frame. This method is quick and straightforward. Lengths of 6mm diameter steel wire or rod (such as that widely used in concrete reinforcement) are inserted into holes drilled in the wood (the drill can be made from the same rod) and the ends of these bent over using a hammer. The wire can then be tightened using a second hammer as if tightening a rivet.



**Figure 13: all wooden cart using clenched wire fixings.**

### **3.4.6 Overall Cart Performance.**

Testing both in the UK and in Nigeria of all-wood and of combination designs of cart have shown few problems so far. The all wooden design has been loaded with 400 kg of sandbags and towed over a repeated-kurb track at speeds of up to 15 km/h without damage, and the combination design has been supplied to about twenty farmers who have used the carts for up to one year at the time of writing.

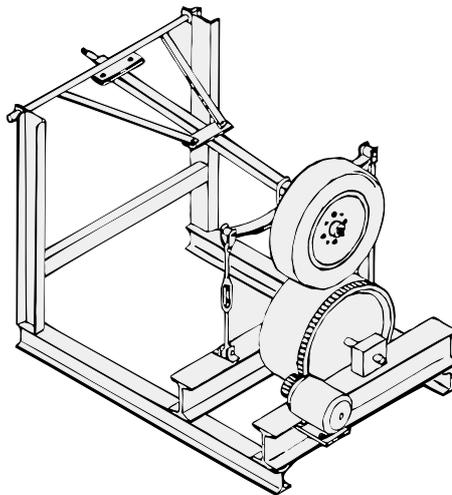
## **SECTION 4: DESIGN DEVELOPMENT AND TESTING.**

### **4.1 Pressed Wheels: Previous Experience.**

Development of locally manufactured pressed steel wheels began when the first author was working at CAMARTEC, Arusha, Tanzania in 1988/90 with the United Nations. Development demands in Tanzania called for an improved wheel design to supersede the dated steel fabricated one similar to that shown in Figure 4 that had been manufactured locally since the mid 1960's. Between 1988 and 1990 tests were carried out on pressed steel wheels by running them, complete with an inflated tyre, on a static test rig. The wheel under test was run, day and night, at a speed 9 km/h (double that of an animal drawn cart) with a load of 300 kg. A bump was introduced to simulate partially rough road conditions. Tested wheels covered over 3 000 km trouble free. Figure 14 shows the Tanzanian test rig.

Pressed wheels were also tested in Tanzania by use with two wheeled trailers towed behind Station's tractors. These trailers were often loaded in excess of one ton and taken over very rough ground. Since 1990 several hundred wheels have been produced and used on animal-drawn carts.

The DTU programme in Nigeria has further developed and tested pressed steel wheels over the period 1992/4. Two sizes of wheel (16" and 14") are now available, both manufactured from 3 mm steel plate.



**Figure 14: rolling road test of wheels and bearings.**

### **4.2 Safety Tests on Wheels.**

The DTU pressed steel wheel is a split rim design with the two halves of the wheel bolted together. With a tyre fitted and inflated to 2 bar (30 psi) a force of several tons is exerted on the rims, trying to push them apart. Concerns have been expressed that a potential danger exists to anyone attempting to split the rim halves with the tyre inflated. Clearly this is

unlikely because the wheel is not usually taken off the cart unless the tyre is punctured. Nevertheless initial tests were conducted in Nigeria to determine the results of an attempt to split the rim with an inflated tyre in place.

These tests and findings are discussed below.

#### **4.2.1 Test of complete wheel with fully inflated tyre at 2 bar.**

**Purpose of test:** to determine the restraining capabilities of the four 10 mm Ø (diameter) bolts.

With the wheel securely held in a safe manner, an attempt was made to undo the four 10 mm Ø bolts. The force on the bolts was high and progressive and could be felt in the force required to undo them. It was obvious to those observing that all was not well. Three of the bolts were removed completely and the fourth undone half-way. At this point the two halves of the wheel sprang open on the unsupported side, allowing the inner-tube to escape into the inside of the rim and there rupture. The single 10 mm Ø bolt maintained the wheel's integrity.

**Conclusions:** the four retaining bolts are strong enough to hold the wheel together whilst inflated. A single bolt is strong enough to keep the wheel assembly together, albeit with some distortion to wheel and bolt.

#### **4.2.2 Complete wheel with fully inflated tyre at 2 bar.**

**Purpose of test:** to determine at what point the inflated inner tube would rupture upon separation of the wheel halves.

The wheel was placed in a hydraulic press with the two halves of the wheel held together by the force of the press. The tyre was then inflated to 2 bar (30 psi) and the restraining force on the wheel gradually released, allowing the two halves of the wheel to come apart. At a point when the wheel half discs had separated by 25 mm the inflated inner-tube began to migrate into the inside of the rim, rupturing on an unprotected sharp edge.

**Conclusion:** It was found that once the wheel discs had separated by 25 mm or so the inner-tube would expand into the inside of the wheel and possibly rupture against a sharp edge.

#### **4.2.3 Complete wheel with fully inflated tyre at 3 bar.**

**Purpose of test:** to measure wheel rim movement as tyre is inflated.

A complete wheel, supported at its centre, was slowly inflated to 3 bar (45 lbf.in<sup>-2</sup>) and deflection measurements taken at the extreme edge of the of the wheel rim. A dial indicator showed that, under inflation, the rim halves moved apart 1.5 mm in total. The movement was progressive during inflation, but stopped as soon as the compressed air flow ceased.

**Conclusion:** the very small amount of movement was expected. Any movement during service occurs under the tyre bead and is therefore unable to induce puncture

in the inner tube. If movement must be eliminated the width of the inner-tube support ring shown in Figure 5 can be increased slightly and the wheel discs given a small pre-load during assembly of the wheel.

#### 4.2.4 Recommendations.

- 1) The four bolts holding the two halves of the wheel together should be long enough that if undone with the tyre inflated, the rim halves will come apart more than 25 mm before the nuts can be removed from the bolts.
- 2) A sharp component (a small spike) should be welded inside the inner rim to rupture the inflated inner tube before the bolts being fully undone.
- 3) A notice should be printed clearly on the wheel in the appropriate language, warning of the dangers involved in splitting a wheel with the tyre inflated.
- 4) Develop the design to make it impossible to split the wheel with an inflated tyre fitted (these design changes have been made but not practically implemented as yet).

### 4.3 Mk 4 Cast Aluminium Hubs: Testing.

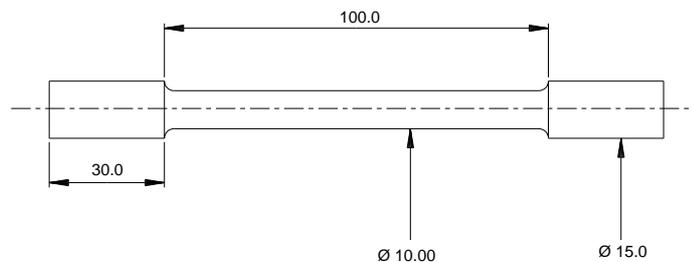
The use of cast aluminium as a material for a low speed vehicle hub as been questioned on the point of strength. In order to address the issue some basic tests have been carried out in Nigeria and at Warwick and these are described below.

#### 4.3.1 Shear test on lugs.

A Mk 4 hub was mounted (axis vertical) in a 60 tonf hydraulic press so that the ram applied load to one wheel mounting lug. In two tests the average force required to fracture the lug from the body of the casting was 17.5 tonf.

#### 4.3.2 Casting strength around wheel studs.

A Mk 4 hub was mounted (axis horizontal) with one 12 mm  $\varnothing$  (diameter) wheel stud under the ram of a 60 tonf hydraulic press. In tests with two different presses the average force required to push the 12 mm  $\varnothing$  steel stud sideways out of the casting was 2.5 tonf. The stud suffered some bending before the casting gave way.



**Figure 15: test piece: strength of aluminium castings produced in Nigeria.**

### **4.3.3 Tensile test on samples taken from a Mk 4 hub.**

In these tests carried out at Warwick, two samples taken from the hub were machined as shown in Figure 15 and tested in tension. Failure occurred at about 165 MPa at approximately 3% strain - well within the range expected for good quality alloy castings.

### **4.3.4 External analysis of five samples taken from a Mk 4 hub.**

Results of these tests on five samples are presented in Appendix 1, and show the alloy to have about 8.5% silicon, 2% copper, 0.8% iron and 0.6% zinc, plus traces of many other elements. This is typical of the sand-casting alloys used in automotive components from which the scrap metal is obtained.

### **4.3.5 Conclusions.**

The strength of cast aluminium hubs is well up to the loads, even at extremes, likely to be encountered in animal drawn carts, or even tractor drawn trailers. A regular good casting quality can be expected from the small aluminum foundries in the Nigeria project area. Monitoring of casting quality would be required if this technology were used in other countries for the production of hubs.

## **4.4 Bearings.**

### **4.4.1 Recent Developments.**

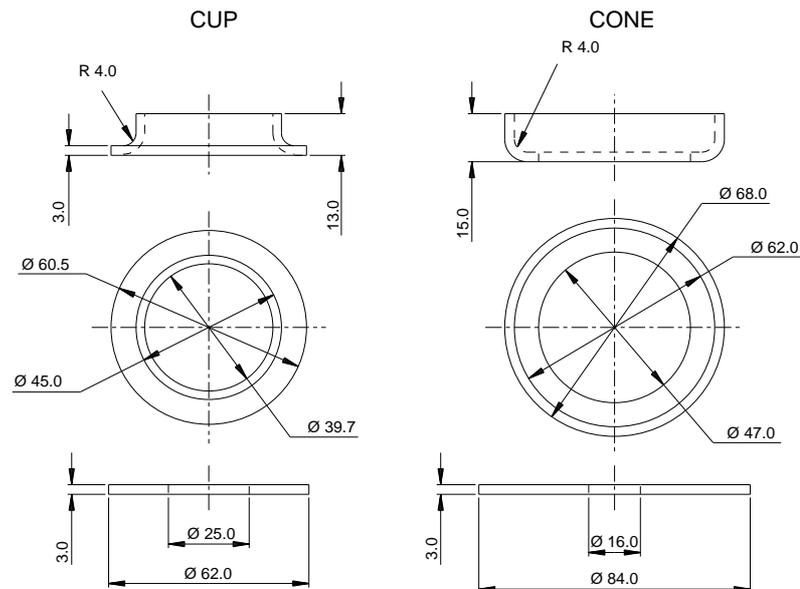
Prototype cup and cone bearings made at CAMARTEC, Tanzania in 1989 were put on a test rig (Figure 14) and run at 9 km/h with a load of 300 kgf. The drive roller of the test rig had a bump on it to simulate something of rural road conditions. An inspection was made after 3,000 km continuous running. The bearings were in very good condition with very little sign of wear. These bearings had cups and cones machined from solid mild steel bar, case hardened in charcoal as described below, and fitted with 17 × 8 mm diameter balls.

An identical set of bearings were fitted to a tractor drawn trailer for use by CAMARTEC in September 1989. In just under one year the cart covered 500 km, often with loads in excess of 750 kg. Whilst the distance covered was not great, the speed, load and road conditions were very severe. The bearings fitted to this cart were inspected a year later in September 1990 and found to be in good order. Communications with CAMARTEC in 1993 confirmed that the cart is still in daily use, fitted with the original bearings. By 1990 an initial order for 25 ball bearing axle systems was in production and to date about 200 axles have been produced.

#### 4.4.2 DTU Cup & Cone Bearings.

Development and testing of cup and cone bearings continued under the RAMAT/Warwick linkage programme.

Early in 1993 two complete sets (for one axle) of cup and cone bearings were made in the Warwick Department of Engineering workshops to the dimensions shown in Figure 16 and heat treated with 'KASNET' (a proprietary carbon bearing formulation specifically developed for case-hardening).



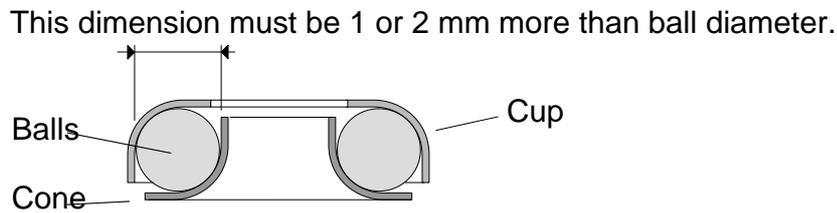
NB Blanks (shown below components pressed from them) must be annealed before pressing. Case harden after pressing in charcoal plus 1% sodium carbonate for three hours at 850/900°C. Allow to cool in the carburizing box, then remove, re-heat to 800°C and quench in oil.

**Figure 16: cup-and-cone bearing components.**

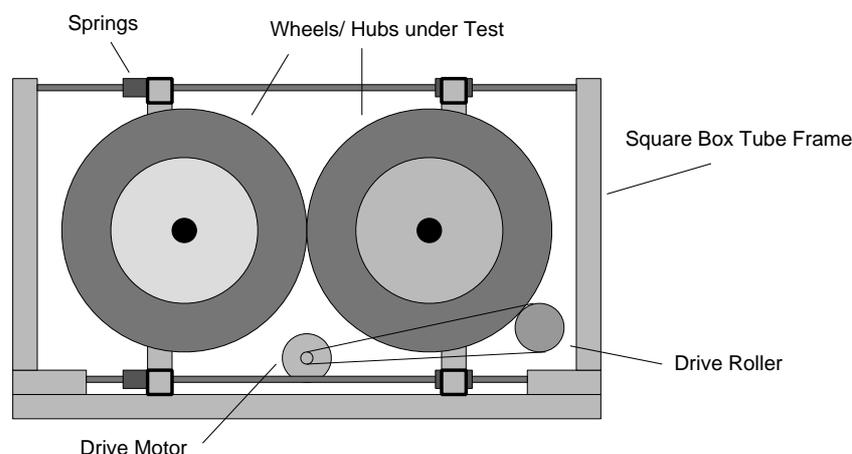
Loaded with 17 × 8 mm diameter balls the bearings were mounted in DTU design cast aluminium hubs imported from Nigeria. The hubs were fitted with Land Rover wheels and run on the DTU bearing test rig (Figure 18) with a load of 200 kgf per hub at 120 rpm for 32 000 km. Inspection showed that wear was advanced, in particular on the cones, which had worn severely (approximately 1.5 mm) on the loaded side. The 8 mm diameter balls did not show any signs of wear. Grease had been packed into the bearings before the start of the test - the rig being stopped only to check for bearing free play and for adjustment of the bearings about mid way.

Pressed cups and cones, made from 3mm thick steel sheet and carburized with charcoal as described below, were tested next. Being very thin, these pressed components allowed an increase in the number of 8 mm balls used from 17 to 20, whilst also allowing thick walled pipe to be used for the stub axle. (More expensive 30 mm diameter solid bar was required with the cones machined from solid material.)

The bearings were fitted into Nigerian cast aluminium hubs and run at 80 rpm at Warwick over a period of seven months loaded to 200 kgf. A complete inspection showed very little wear with lubricant still in place, when the rig was stopped at 30 000 km.



**Figure 17: essential cup-and-cone bearing dimensions.**



**Figure 18: DTU wheel, hub and bearing test rig.**

#### 4.4.3 Tests on Locally Available (Nigeria) Bicycle Balls.

Commercially available bearing balls normally have a hardness of about 55 Rockwell C. The most readily available balls in Nigeria were those sold widely and cheaply for use in bicycles. These balls are 1/4" diameter and come in small tins of about 150 units from China and sometimes from India. Experience in Tanzania in 1988/90 with a product of the same origin, had been disappointing, with balls failing after a few hours of running under test conditions.

However low cost and ready availability in Nigeria tempted the author and his Nigerian colleagues, to conduct further tests on Chinese and Indian 1/4" balls. Samples brought back to Warwick were sent to GKN Materials Ltd testing laboratory for analysis and the results are shown in the test certificate (Appendix 2). The important constituents to note are C (carbon), Cr (chrome) and Mn (manganese). Carbon content in the samples is much too low at 0.29% and should be in the range 0.9% to 1.0%, Chrome content is similarly extremely low at 0.02% - commercial bearing steels would normally be from 1.0% to 1.5%.

Cup-and-cone races case-hardened in charcoal, were run at 80 rpm and 200 kgf load at Warwick with  $26 \times 1/4$ " Chinese balls. Only the equivalent of 14 km was covered before the test rig began to omit nasty grinding noises. On inspection it was found that several of the balls had disintegrated totally, although the cups and cones were intact.

Back to the drawing board!

Thus the Chinese/Indian balls were not hard or strong enough for the purpose. An attempt was made therefore to treat some balls to bring them up to satisfactory hardness. Balls were heated to 900°C and quenched, some in cold water and others in oil. Some Chinese balls that had been carburised by Nigerian staff, but not hardened, were sent to Warwick and were treated in the same way as the 'off the shelf' samples above. Hardness test results for these balls are shown in Table 1. As can be seen there is much variation, even within the groups of five balls, suggesting that quality control during production is poor.

This variation and poor hardness rendered unviable the use of Chinese and Indian balls in the present cup-and-cone bearing systems for animal-drawn carts. The suggestion that better quality 1/4" balls be used was rejected because of the strong temptation for unknowledgable or unscrupulous constructors to revert to the use of inferior balls. Guarding against such a possibility would not be possible and the decision was therefore taken to standardise on 8 mm diameter balls, this size being available new or second hand in Nigeria only from quality manufacturers.

#### **4.4.4 Conclusions.**

The development of locally pressed cup-and-cone bearings can be seen as a breakthrough for indigenous manufacture of animal drawn vehicles and other equipment in Sub-Saharan Africa. Technicians in Nigeria were most pleased to realise that local manufacture of quality rolling-element bearings was within their capability. Important or "key" technologies have also been introduced including simple press tooling and heat treatment processes. The fundamental understanding of such key processes is a very important step forward for small manufacturing industries in Africa.

### **4.5 Concluding Remarks on Design Development and Testing.**

Key components of the Borno cart are the results of previous developments and testing. Wheels, bearings and to some extent hubs, have a development history dating back to 1988 in Tanzania. The basic technology applied in the making of pressed steel wheels is not new and was used in the early days of wheel development in Europe to carry pneumatic tyres. Cup-and-cone ball bearings represent some of the earliest developments of rolling-element bearings - though fairly simple in construction they are capable of withstanding heavy loads and giving good bearing life because of their tolerance of dirt and poor manufacturing standards. Such qualities have been proven by their universal use in bicycles for example. Improved bearing technologies needed better and more versatile hubs to accommodate them. Cast-iron hubs are cheap to produce if the technology is available, but aluminium castings make a very acceptable alternative.

**Table 1: Hardness Tests: Nigeria purchased Chinese 1/4" balls - July 1993.**

Ball #	Treatment	Rockwell C #	Vickers #
1	As purchased	46	460
2		35	350
3		40	400
4		48	490
5		47	480
6	Heated to 800/900°C Quenched in oil.	43	430
7		33	330
8		26	275
9		33	330
10		45	450
11	Heated to 800/900°C Quenched in water.	55	600
12		45	450
13		60	700
14		55	600
15		52	550
16	Carburized in Nigeria for 8 hours in charcoal. Re-heated (at Warwick) to 800/900°C and Quenched in oil.	41	410
17		57	650
18		55	600
19		52	550
20		54	580
21	Carburized in Nigeria for 8 hours in charcoal. Re-heated (at Warwick) to 800/900°C and Quenched in water.	58	660
22		54	580
23		52	550
24		63	780
25		60	700

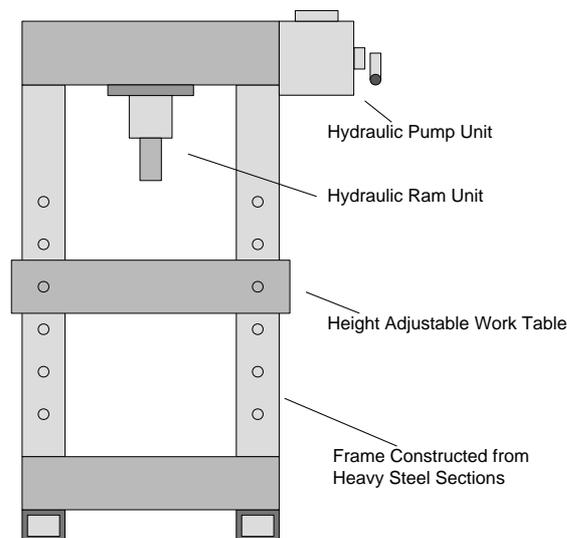
1 to 5	Average = 436,	Standard Deviation = 60
6 to 10	Average = 363,	Standard Deviation = 74
11 to 15	Average = 580,	Standard Deviation = 90
16 to 20	Average = 558,	Standard Deviation = 90
21 to 25	Average = 654,	Standard Deviation = 93

## PART B: MANUFACTURING THE BORNO ANIMAL CART.

### SECTION 5: MANUFACTURE OF PRESSED WHEELS.

#### 5.1 Introduction.

Second-hand wheels from motor vehicles are the usual choice of the animal cart builder in Africa. Considering the number of motor vehicles imported or assembled in Africa since the second world war - particularly since independence in the 60's - it is not surprising that many discarded wheels are available. Although the use of such wheels is a reasonable solution for the needs of cart builders constructing small numbers of carts, they should not be thought of as the only alternatives to wooden or heavy steel rimmed wheels. In fact they have several disadvantages for cart builders including a lack of controlled quality from one wheel to the next, a lack of consistency and standardisation in size of mounting and centre holes, and a shortage of supply leading to rapid rises in price as soon as any number are purchased in one area.

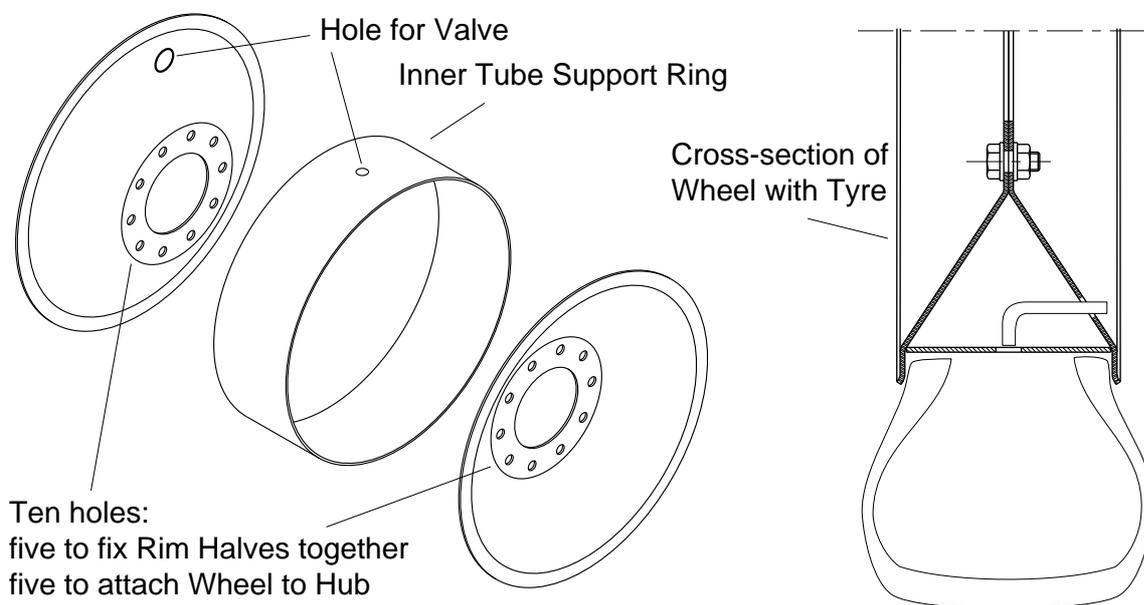


**Figure 19: hydraulic press used in pressed wheel manufacture.**

Manufacture of the pressed steel wheels described in this document utilizes a hydraulic press of minimum 40 tonf capacity. In fact such presses are not so rare in developing countries, as may be thought. Rail systems have never really developed in Africa and bulk goods and people are transported along roads. It is inevitable, therefore that a network of auto-repair workshops and garages has sprung up along roads carrying motorised traffic of any density. Buses and lorries in Africa break down regularly, ensuring plenty of work for the workshops. Breakdowns often involve damage to heavy suspension and transmission parts, and the repair

of these cannot be carried out solely by hand as the forces required are considerable and must be carefully controlled. Thus it has become essential for many garage workshops to have an hydraulic press. These presses are not to be confused with the power presses used in manufacturing industry - the garage press (Figure 19) is a simple affair which uses a hydraulic unit similar to a hydraulic jack, set in a very robust frame, to exert large forces slowly in a controlled manner.

Before proceeding with pressed wheel development in Nigeria, a brief survey was made of Maiduguri town to determine the availability of a suitable press. It took only a couple of hours to locate six hydraulic presses of 60 tonf capacity. Three of these presses were located in Government controlled workshops, the other three were in the private sector. All were available for use by one means or another - the government presses free, the private sector presses by paying a small fee. All but one of the presses was manually pumped - probably an advantage because manual operation is likely to be safer than electric operation in unskilled hands.



**Figure 20: pressed steel wheels.**

## 5.2 Overview of Wheel Manufacture.

The development of pressed steel wheels was centred around the use of 3mm (or 1/8") thick black mild steel sheet. The aim was to produce a wheel (Figure 20) that would be simple to make using a minimum of differing material sizes and manufacturing processes.

The manufacturing process involves pressing two round steel blanks into dish shapes, which are then bolted back to back. A circular inner rim, also made from 3mm steel sheet, is added to support the inner tube. The entire fabrication process consists of about thirty steps and when complete results in a wheel weighing about 12 kg. This may be compared with the earlier Worth and IT Transport designs which weigh about 25 kg, require five different

material sections and take up to fifty construction steps to complete.

The hydraulic press is the central piece of equipment, extensively used in the manufacture of this particular design of wheel. The press is used for all the following processes :

- First and secondary wheel-rim pressings.
- Punching a 16mm diameter pilot centre hole in each wheel blank.
- Punching a 113mm diameter wheel centre hole.
- Punching the 16mm diameter valve hole in the wheel rim
- Punching a 30mm diameter valve access hole in one wheel blank.
- Punching the 14mm diameter wheel hub bolt holes and the 11mm diameter wheel rim holes, a total of sixteen per wheel.
- Pressing the bearings into the hubs.

Note, the 113 mm diameter blanks produced when punching the centre of the wheel discs can be reduced using a press tool and then utilized as bearing cover plates at each end of the hubs.

### **5.3 14" Pressed Wheels: Detailed Manufacturing Procedures.**

Two sizes of pressed steel wheel have been developed for use with 14" and 16" tyres, two very popular sizes in Africa. The description below concentrates on the 14" variant and refers to the drawings in Appendix 3. The methodology for making 16" wheels is identical.

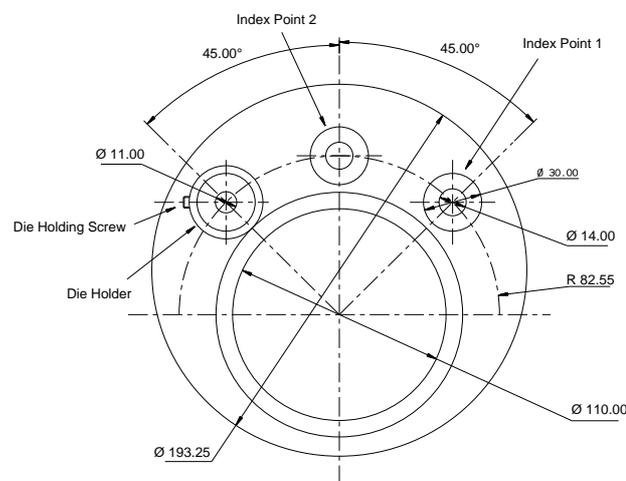
Wheel disc blanks are cut from standard 3 mm or 1/8" thick steel sheet and a 4 ft × 8 ft sheet provides enough circular blanks and flat strips for five complete wheels with their inner rims. The remainder of the plate may be used for making cup and cone bearing housings and hub end bearing cover plates, resulting in very economical use of the material.

The manufacturing procedures for the 14" wheels are as follows:

1. Blanks for 14" wheels are marked out on the sheet and cut to the diameter shown in the drawings. Cutting can use oxy-acetylene equipment or a band saw. After cutting, a 16 mm pilot hole is punched in the centre of each blank disc and one disc also requires a 30 mm diameter inner tube valve access hole in the position shown. The blanks must then be annealed, or softened to make them suitable for pressing. This is most readily done by standing the blanks evenly spaced and building a fire around them of scrap wood. The plates need to be heated for about 30 minutes, but they need not reach red heat. The plates should be moved about within the fire for even treatment and left to cool when the fire goes out.
2. Annealing may distort some of the blanks, but this is not a problem provided that each blank will fit into the press tool and the top clamp ring can be bolted in place. Any badly distorted blanks may be straightened by placing them on a flat floor and jumping on them, as in its annealed state the plate is soft and is easily bent back into shape. Eight 16 mm diameter bolts hold the top clamp ring down - it in turn holds the blank in place and forms the outer flat section of the wheel, preventing distortion around the rim during pressing. The blank is centralised in the press tools using the

16mm diameter centring post in the bottom tool.

3. The top tool is now put in place, again using the 16 mm centre post for positioning and the press operated which will force the top tool down into the bottom tool and form the blank into the desired shape. Depth of pressing will be controlled by the plywood spacer in the bottom of the bottom tool: when this is reached ram pressure will rise rapidly. From experience 35 tonf is enough with 40 tonf as a maximum. On inspection the pressed blank should be evenly formed with the central hub mounting area, 200 mm diameter, well defined and flat. After pressing, the rims of two wheel discs placed back to back should be separated by 94 mm internally. In order to maintain this dimension it is important that the pressing force used should not vary from one pressing operation to another.



**Figure 21: layout of jig used for punching holes in pressed steel wheels.**

4. Once all the blanks have been pressed, secondary pressing of the outer rim (which takes the sharp disc edge away from the wall of the tyre) can take place. For this the clamping ring is left in place, but the top tool is turned over. Each disc is then placed, dish side down, on top of the clamping ring, the inverted top tool placed in position, and the press operated to around 30 tonf. The outer rim should be turned up about 30 degrees as a result.
5. A small clearance over the aluminium hub is provided by the 113 mm diameter central hole and this allows for slight deviations in casting size. It is important that the size of the hole is exactly the same in all the wheel discs, as the placement of the four rim bolting holes and four wheel-to-hub fixing holes is determined from the centre hole. This central hole can be produced most quickly and accurately by punching with a simple press tool in the hydraulic press: the force required will be about 38 tonf. In Nigeria a suitable set of tools were made from scrap gears from a lorry gearbox. Blanking forces can be calculated by multiplying metal thickness by length of perimeter of blank, to get the area to be cut, and then multiplying this area by the shear strength of the material.

6. Eight bolt holes are punched in the wheel disc, all on a 165 mm PCD (pitch circle diameter; ie the centres of the holes all lie on a circle of 165 mm diameter). Four of these holes are 14 mm diameter (for fixing the wheel to the hub) and four are 11mm diameter (for bolting the two wheel halves together). A complete wheel has 16 bolt holes (eight in each half) which must not only align when the wheel halves are put together, but the holes must also align with the four studs of the hub. One method of achieving sufficient accuracy is by using a drilling jig, a circular plate which has the holes to be drilled accurately set in it. To avoid rapid wear through repeated use, it is best to fit hardened steel bushes in the jig which can be replaced when worn. A second method is to punch the holes using a press tool that, ideally, produces all eight holes in the correct location, at one time. An alternative punching method, and the one used by the project in Nigeria, produces one hole at a time in conjunction with an indexing system (Figure 21).
- 7) The inner rim of a complete wheel is a flat strip of 3 mm steel sheet 1094 mm long and 94 mm wide. Before bending the strip into a cylinder the 16 mm diameter valve hole has to be punched in the position shown, and the ends of the strip pre-bent in a vice. It is not necessary to anneal the material as the bend is a gentle one. If a sheet roller is not available the strip can be bent around a wooden former which should be 350 mm diameter. After bending, the ends of the strip can be welded together on the inside of the ring only.

## **5.4 Wheel Assembly.**

On assembly, with the bolts slack, rotate the cylindrical inner rim to be sure that the valve hole in the wheel disc half and the valve hole in the inner rim are aligned. The inner rim should sit comfortably in the pressed area. With the second disc in place and bolts finger tight, the two halves should come nearly together with a gap of about 2 mm. If the gap is greater than this the inner rim will have to be reduced in width and all other inner rims made to the new dimension. With the two halves bolted tightly together the inner rim can be tack welded in two places to the rim disc that DOES NOT have the valve hole in it. After tack welding disassemble the wheel and make four heavy tack welds between the inner rim and disc on the inside of the inner rim. The inner rim is welded to the disc only to prevent movement when the wheel is being taken to pieces or assembled, the strength of the wheel when in use is not dependent upon the welding.

## **SECTION 6: CAST ALUMINIUM HUB MANUFACTURE.**

### **6.1 Introduction.**

In several towns in the north of Nigeria, including Maiduguri, Jos, Kano and Zaria, there is a small but thriving cottage industry of aluminium foundries making cauldron type cooking pots and other small aluminium goods. The Linkage Programme worked with one of these small foundries in Maiduguri. Scrap aluminium is readily available in quantity (by the ton if required) from specialist merchants operating from Kano, Jos, Onitsha, and Lagos, among others. The caster also operates an exchange scheme with his customers, ie new pots for old, as part of his source of scrap. Aluminium, as of May 1994, cost Naira 40/kg (= 0.60 p/kg).

The company (Aluminium Pot Makers and Casting Workshop, Gwange Sabon Line, Post Box 4181, Maiduguri) employs from four to six workers and produces up to 60 cooking pots of 350 mm diameter maximum per day. The owner, Malam Umar Usman is about 35 years old and had been in business for nine years at the time of our involvement. His workshop comprises a floor of about 10 m × 15 m, partially covered with a corrugated iron roof mounted on wooden poles. The floor of the covered area is a thick layer of local sand which is used for the moulds. Aluminium is melted in steel pots (cut from old LPG cylinders) in a ground level furnace, using an blown-air charcoal fire. Air is supplied from two or three metres away, by an underground pipe fed from a centrifugal blower, cast locally in aluminium. It is driven by a rubber belt (made from old inner-tube) from a bicycle wheel turned by a small boy.

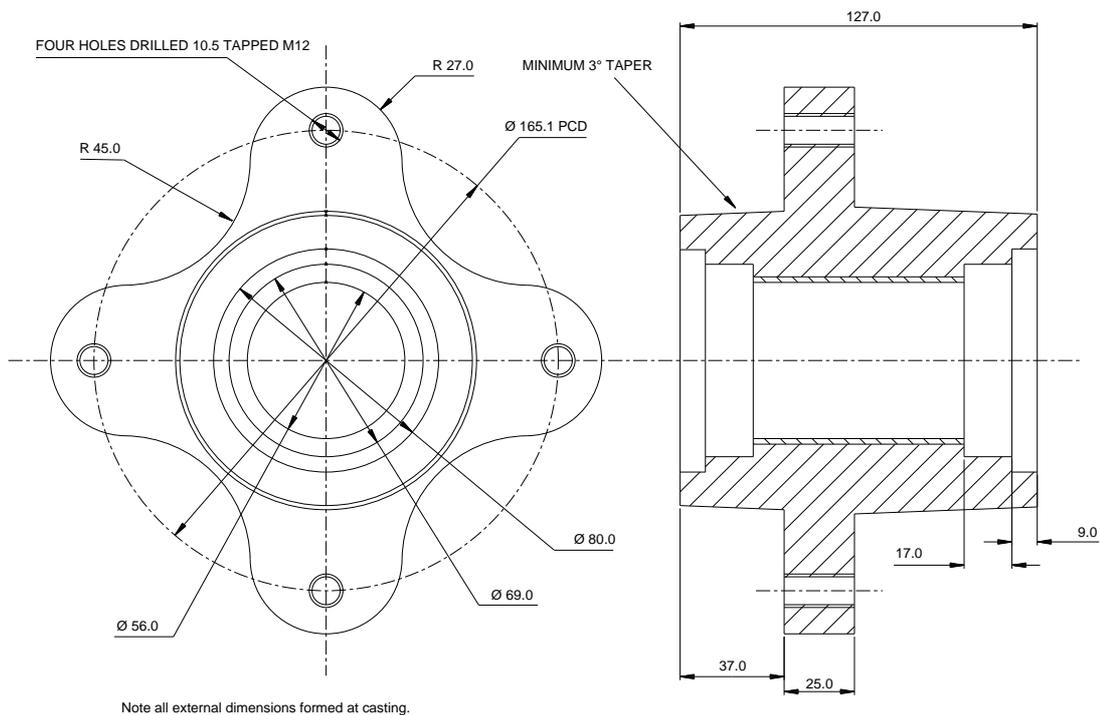
Observation of Mal Umar in operation shows that he and his workers are highly skilled from long experience, and have an in-depth knowledge of the process and of solutions to the technical problems involved in aluminium casting (for example old dry cell batteries are added to the melt to assist in de-gassing), and this skill allows the consistent manufacture of high quality products.

### **6.2 Casting the Mk 4 Aluminium Hub.**

The MK 4 cast aluminium hub (Figure 22) represents the final hub development in the present programme. The hub has four studs on a 165 mm PCD and weighs 2.8 kg. Only limited machining of the preformed bearing housings and the drilling and tapping of the four stud holes is required to complete the hub after casting, because a steel mould giving accurate outside dimensions, is used. About four castings per hour can be produced by this method and machining time for the two bearing housings and the four wheel stud holes is twenty to thirty minutes.

Inserts in the steel mould preform bearing housings in both ends of the casting, and a finished-to-length steel core pipe is located in the mould before pouring to provide the central axle space. The mould, totally enclosed, is filled through a simple filler and riser system consisting of two short lengths of 40 mm diameter pipe which stand over holes in the top of the mould (nb they are not fixed to it). The mould and these filler and riser pipes are

completely filled during pouring, and as freezing progresses the aluminium in the pipes feeds down into the casting and prevents shrinkage cavities forming. It was observed that the aluminium had to be very hot before pouring into the steel mould in order to flow freely and not freeze too quickly. After about two minutes the filler and riser can be broken off the mould before the aluminium has had time to solidify completely. Extracting the casting from the mould can begin after five to seven minutes (and certainly no later than ten minutes) after pouring, or the aluminium will contract onto the mould bearing inserts, even though they have generous release tapers. Should this occur, allow the mould and casting to cool completely and then suspend the whole issue over a hot charcoal fire for about 15 minutes. The aluminium will expand more rapidly than the steel components and release will be possible.

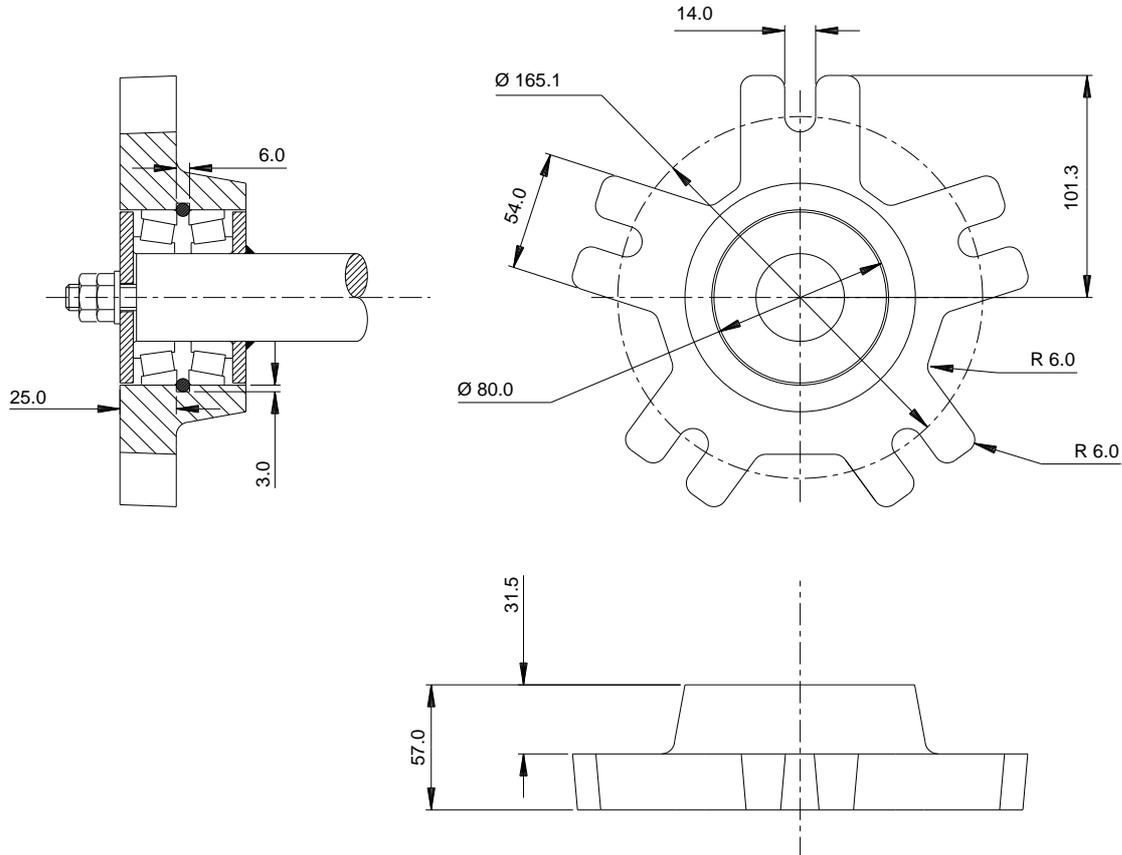


**Figure 22: Mk 4 aluminium hub - gravity die cast in steel mould.**

It may be argued that foundry facilities or raw materials do not exist in all African countries. This may or may not be the case, but where the materials are available the technology itself is not difficult and could be introduced.

### 6.3 Further developments.

Figure 23 shows an alternative sand-cast hub, which may be used with commercial tapered-roller bearings which are available at reasonable price in Nigeria. It exploits the bearings' high load capacity and allows machining of both bearing housings in one cut. A snap-ring, made from mild steel wire or similar and let into a groove in the bore, locates the bearing pair in the hub. The wheel studs are fitted into slots in the struts, saving a drilling and tapping operation.

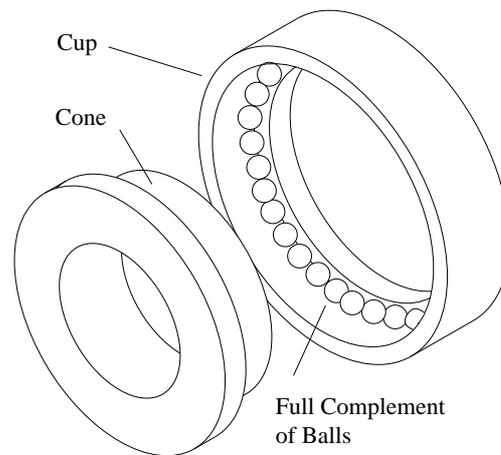


**Figure 23: sand-cast aluminium hub - for 6208 tapered roller bearings.**

## SECTION 7: BEARING MANUFACTURE.

### 7.1 Introduction.

The current Warwick axle and hub design being constructed at RAMAT Polytechnic utilizes three bearing alternatives, commercial taper roller, fabricated roller (Figure 7) and locally manufactured cup-and-cone ball bearings (Figure 24), the type specifically dealt with here. Cup-and-cone ball bearings, as used in bicycles, are one of the earliest examples of a rolling element bearing. It is a simple system that is adjustable and will carry both radial and axial loads.



**Figure 24: cup and cone ball bearings.**

Cup-and-cone bearings are made up of three parts: an outer race (the cup), an inner race (the cone), and the rolling elements (the balls). Commercial bearing balls have a very high finish and are heat treated to be hard enough (55 Rockwell C) to withstand the loads imparted to them when in use, this in turn requires the cup and cone races to be hardened.

Design criteria for the use of these bearings in the axle systems of animal drawn carts were as follows:

- 1) able to withstand maximum loads of approximately 250 kgf per bearing,
- 2) easy to fit, adjust and replace,
- 3) simple and cheap to manufacture.

Earlier versions of cup and cone bearings developed in Tanzania in 1988 were machined from solid bar and did not comply with the third, and perhaps, most important criteria above. Solid bar sections larger than 20 mm dia are hard to come by, and expensive, in most countries in Africa. Also machining these components requires the constant availability of expensive machine tools, a lathe, and the appropriate skilled labour to operate the machine. In order to alleviate this problem development proceeded with a programme for pressing the cups and

cones from 3mm thick mild steel plate.

## **7.2 Production.**

Bearing components must be consistent dimensionally in order to operate reasonably well and be interchangeable when worn. Such regularity should not be dependent on constant machine tool availability and a skilled labour input over a long production run of components. Even if facilities and personnel were available, costs would be high, as production rates would be low. A better approach to the problem is to develop a set of specialised tools, the function of which is to replicate bearing components speedily and faithfully, using unskilled labour.

Simple press tools for producing cups and cones can be made from mild steel to save costs and may be case hardened using the same process (described below) as for the cups and cones. Figure 16 gives the dimensions of the cups and cones to be produced with the press tools. The top tool is made to the internal dimension of the component whilst the bottom tool is made to the outside dimensions. Blanks for the cups and cones are made from the same material as the pressed steel wheels ie 3 mm steel sheet. These are annealed as described for the wheels. Each component blank is located centrally on the bottom tool whilst the top tool is forced down and into the bottom tool - pressing the blank into the tools and taking up their shape. The process takes very little time and requires minimum skill - although skilled input is required in the initial making of the press tools and to some extent in setting them up for use. Tools maintenance is minimal provided that checks are made on the components being produced from time to time, and wear on the tools is monitored.

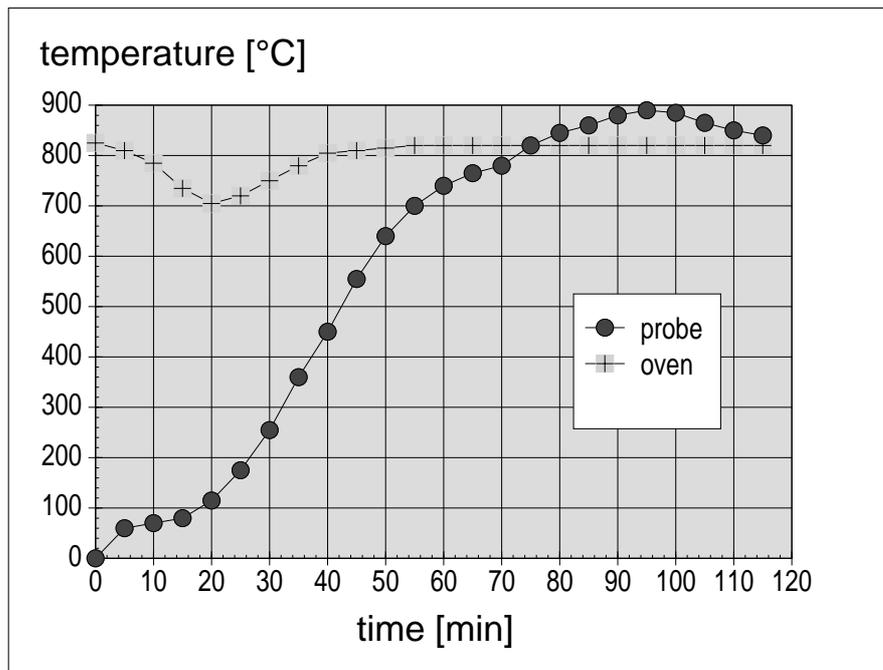
Bearings easiest assembled with heavy grease to hold the 20 × 8 mm diameter bearing balls in place. Adjust the bearing to run freely once the wheel is fitted.

Bearing components produced from pressing are of mild steel and will require heat treatment using a process called case hardening. The simpler aspects of heat treatment and the case hardening process are explained below.

## **7.3 Heat Treatment of Steel - General.**

Before proceeding it should be made clear that steel with less than 0.5% carbon cannot be hardened by the normal process of heating to 850/900°C and quenching in cold water or oil. Such low carbon steels are generally known as "mild steels". If in doubt take a very small sample, heat it to bright red and quench it in cold water. If the treated sample can be cut easily with a file then it is a mild steel, if however the sample is very hard and cannot be filed or cut, then it is almost certainly a high carbon steel.

To render steel soft or malleable, a reverse process of the above is applied - the steel is heated to 700/800°C, a dull red heat, and left to cool slowly - a process known as annealing. The blanks for the pressed cups and cones for the bearings and for pressed steel wheels are treated in this way.



**Figure 25: temperatures during carburisation of bearing components.**

## 7.4 Case Hardening - The Process.

This process is applied to articles of mild steel where a hard skin or surface is required (gears in an automotive gearbox for example) as opposed to hardening the components right through. The best results are obtained with steels containing from 0.1% to 0.2% carbon. Articles to be case-hardened are embedded in some form of carbon-rich material - in developing countries the most readily available material is probably wood charcoal, and this should be ground into a fine powder. The process is considerably improved if 1% by weight of sodium carbonate (**nb not 'bicarbonate of soda'**) is mixed with the charcoal as an activator.

Items to be hardened are packed, with the carbon rich mixture, in a steel or cast iron container not less than 4 mm thick. It is important that the container is as airtight as possible because air getting in will oxidise and waste the carbon (clay can be used to seal the lid). Also the container must be big enough to allow a space of about 25 mm between each component and the sides and top and bottom of the box. Carbon diffuses into the components and converts the outer layers into a steel that will harden, having a surface carbon content of about 0.9%. The depth of case depends upon the size of the article being hardened, the carbon rich material used, the length of time the process is continued and the temperature held during the process.

The box containing the articles to be carbonized must be heated to 850/950°C and the temperature maintained for a period of three hours. This can be achieved with the use of an electric furnace or a blacksmith's forge. Using a forge, the steel container must be kept bright red, covered with hot charcoal at all times and it should be rotated in the fire from time to time to ensure an even distribution of heat. Treatment is normally considered to start when the box reaches working temperature (visually a bright red) and at this temperature the depth

of case can be expected to increase at about 0.2 mm/hr.

After the allotted time the box should be removed from the furnace or fire and allowed to cool naturally. To harden the components they must be removed from the box and re-heated to 700/800°C (visually a dull red) and quenched in oil or water. Bearing components must be cleaned with a wire brush or emery paper before assembly into hubs. The charcoal mixture is re-usable but must have the volume made up with the addition of new charcoal powder/sodium carbonate mix. Figure 25 shows the temperature changes in a carburization box (measuring 230 × 100 × 100 mm and constructed from 6 mm mild steel plate) during the heat treatment of cup and cone bearing components.

Bearing cups and cones, heat treated for three hours, will be carburized to a depth of a little over 0.5 mm. Such a depth of case is required to withstand the pressure from the hardened steel balls when the bearing is under load. Charcoal case-hardening prolongs the life of the bearing components considerably and in itself is a *'key process'*, potentially of great value to rural and urban artisans and to small industries in developing countries.

## **SECTION 8: CART BODY MANUFACTURE.**

As discussed above, two cart bodies have been developed for construction in the current project. The body developed by the DTU for use with the DTU Borno Ox-Cart is made from sawn timber with simple fixings which are very easy and cheap to construct. Construction details of the oxcart body are detailed in Technical Release 24 attached as Appendix 9.

Also available is a design for a lightweight donkey cart. Construction of this cart utilises 50 mm × 50 mm light steel box section for the frame, with floor and sides made from wood. Construction details for this body are available in DTU Technical Release 23 included as Appendix 10. This design can easily be modified for use as an ox cart with small increases in material sizes and overall dimensions.

## **SECTION 9: TOOLS FOR DTU BORNO CART PARTS.**

### **9.1 Introduction.**

Earlier in this paper, details of the manufacture of the various components for the Borno ox-cart were described. Production of many of these parts depends upon the use of tools, dies, jigs and fixtures - generally known as special tools. These are used in order to ensure dimensional regularity, interchangeability, speed of production and general high quality of finish. This section of this document will describe how to construct these various special tools and as some of the tools are similar in their function, a general description of the tool will be given before a description of the variants needed for producing different parts. For example, making a hole-punching tool is explained in a way that can be applied to different punches of various sizes. The special tools dealt with are as follows:

- forming or bending tools for wheel-discs and cup-and-cone bearing components,
- punching or blanking tools for holes in the wheel discs, cup-and-cone bearing components and hub end-thrust washers,
- drilling jigs for holes in cast aluminum hubs,
- steel casting moulds for aluminium hubs.

It is recommended that the making of these tools should only be considered if it is expected that a significant number (say 100) carts are to be manufactured each year. For more limited production, traditional methods, such as drilling, cutting and filing can be employed. Of course press tools would still have to be made for the wheels and the cup-and-cone bearing components.

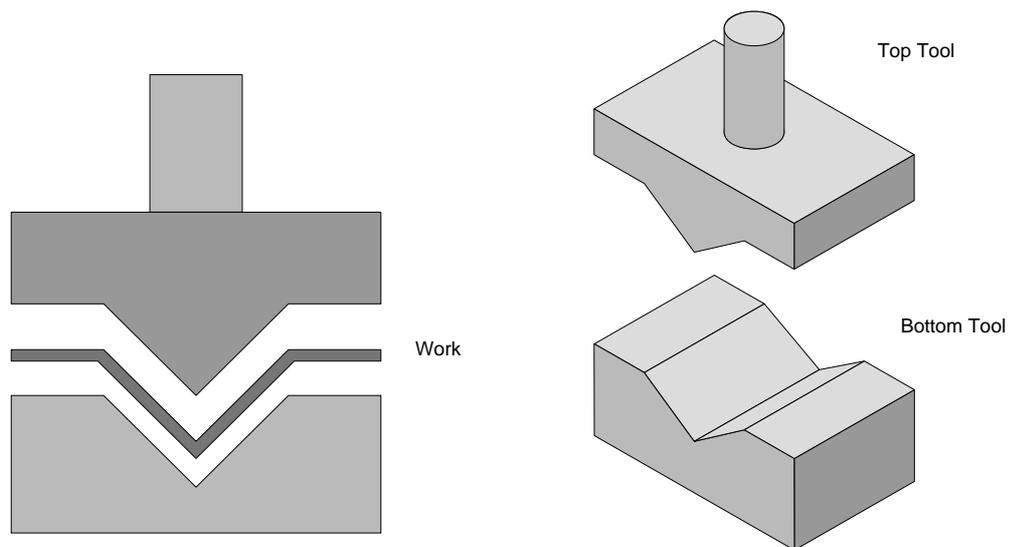
Regarding limited scale manufacture, the DTU is committed to developing other designs which can be made without special tooling and has made significant progress (as exemplified by the axle shown in Figure 7). Further development of this axle is necessary before it can be released for general use, but it is able to give up to 15 000 km in good conditions, and work is in hand to reduce still further the level of tooling required. New designs may even be able to avoid the need for drilling.

### **9.2 Forming or Bending Tools - General.**

It may be helpful to the reader to understand the pressing process and the importance of controlling pressing forces during the manufacture of the sorts of component discussed in the sections above. The following is an attempt to throw a little light on the subject for those not already well informed.

A hefty blow from a large hammer delivered onto a thin piece of steel will bend it or change its shape, usually not for the better, unless the person wielding the hammer happens to be very skilled. It will be even more difficult to bend a second piece of the metal to the same shape as the first. The problem is that the force of the blow from the hammer (and its position and angle) is not well controlled, because it is delivered by hand. Most of the problems of force

control are overcome by using a press which delivers the force in a straight line, usually vertically. The problem still remains however, that the material being pressed will have a tendency to form or flow along the least line of resistance, which may or may not be that intended. A simple form like a straight bend across a flat strip is easily controllable, whereas multiple bends close together may cause a problem because the stresses in the material pull in different directions. Such forces in the material can be controlled using press tools, which are designed to hold the material firmly in place and, under the force of the press, make all the bends at once. Figure 26 shows a simple bending tool which might be used to produce a V-bracket.



**Figure 26: simple press tooling example - here for a V bracket.**

Before pressing a blank must be made, but material stretch during pressing will cause dimensional changes which must be allowed for in the size of the original blank. It is possible to calculate the amount of stretch that will take place, but such calculations are not easy and will depend on the original state of the material - for instance if it has been annealed or not. The simplest method for determining the correct blank size is to run a series of pressing tests. By comparing the pressed components with the required design for a series of blanks, a reasonable estimate can be made of the necessary blank size.

The operation of the bending tools for wheels is to change the shape of the material being formed into that required. For this purpose the tools have to be sufficiently robust to withstand the pressing forces whilst the operation is taking place. Details of the simple tools for pressed wheels are shown in Appendix 3. The materials used are the lightest that may be expected to tolerate the pressing forces imposed when pressing wheels, and still give reasonable tool life. If available, heavier materials can be used with an obvious increase in cost and life. The important function is to form the rim and press the centre 200mm diameter

portion to the correct depth in relation to the rim. The exact shape of the coned or dished portion of each wheel half is not important, and so its exact shape is not controlled by the press tools. In practice it may take up a slightly rippled shape, but this will not detract from its strength or function.

When making the wheel discs, simply to press the centre portion down without controlling the rim would result in an irregular dish shape with a corrugated and ill defined rim. The very important function of the pressure ring is to hold the wheel disc in place and control the flow of the material. The wheel rim is held flat and in a horizontal plane by the pressure ring whilst the centre portion is pressed down to form the dish. The pressing of cups and cones for bearings is a very similar process to that of the wheels, and basic pressing methodology applies. Details of the press tools required are shown in Appendix 3.

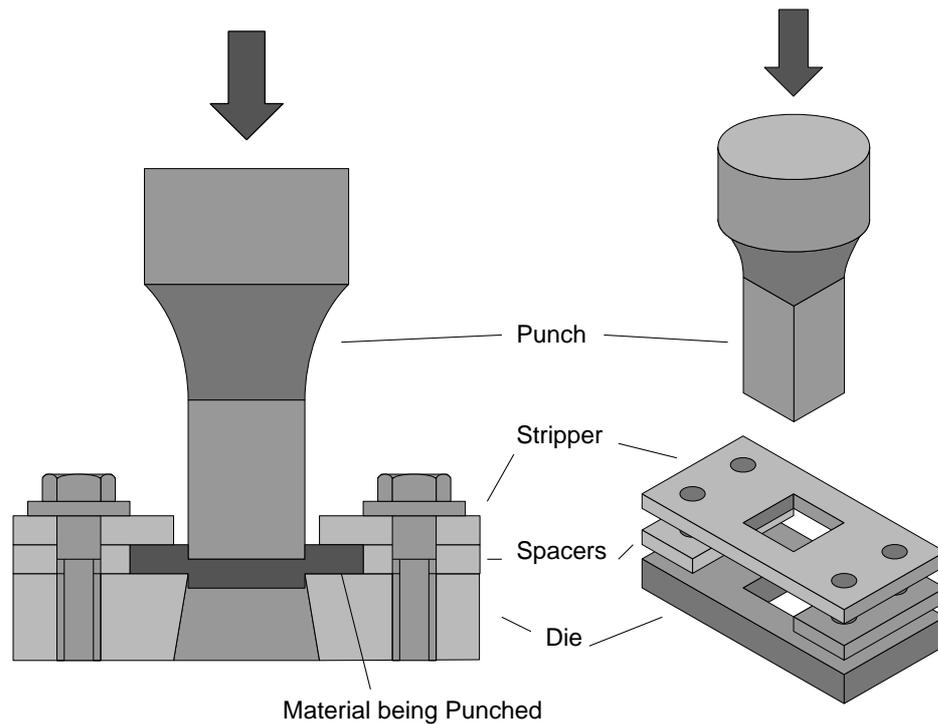
### **9.3 Punching or Blanking Tools - General.**

Correctly set blanking or punching tools produce an accurate hole or blank, (the 'blank' is the piece that falls out of the hole). Other advantages compared with drilling are that the finish is good and that the production time is short. Tools, once made are long lasting, and easy to service. The most important parts of the tool are the punch and die, both of which must be made of a high carbon steel and hardened (heated to 850/900°C and quenched in oil). Figure 27 shows the general arrangement of a simple punching tool. Hole or blank size is determined by the size of the die and not the size of the punch. A small clearance is required between the die and punch, as the material being punched is only cut for about one third of its thickness, the other two thirds being sheared or broken. This clearance is determined by the thickness of the material being punched - a good guide is to subtract 0.10 mm from the dimension of the punch, for every 1mm thickness of material being punched. It is of essential that the relative position of the punch and die be accurately controlled as otherwise damage will occur to both tools.

#### **9.3.1 Pressing Force for Blanking.**

The force required to punch holes, or cut out blanks of any size or shape, depends upon the total cross sectional area of metal to be cut, and the shearing strength per mm<sup>2</sup> of the material. It is usually expressed in tonnes force (tonnef) and is calculated by multiplying the total length cut by the thickness to obtain the sectional area in mm<sup>2</sup> (square millimetres), and multiplying the result by the shear strength of the material in N/mm<sup>2</sup>. A typical example with mild steel, which has a shear strength of 430 N/mm<sup>2</sup>, might be a blank 50 mm × 100 mm in 3 mm plate. This would need a force F of:

$$\begin{aligned} & \text{length of cut} \times \text{plate thickness} \times \text{steel shear strength.} \\ & = 300 \text{ mm} \times 3 \text{ mm} \times 430 \text{ N/mm}^2 \\ & = 387\,000 \text{ N} = 39.5 \text{ tonnef, (as 1 tonne force} = 10\,000 \text{ N)} \end{aligned}$$



**Figure 27: design of a blanking tool to produce a square hole.**

A similar example using imperial measurement would be:

rectangular blank  $2" \times 4" = 12 \text{ sq ins}$  (length of cut)  $\times 1/8"$  (thickness) =  $1\frac{1}{2}" \text{ sq ins}$  (area of cut)  $\times 30 \text{ tonf/sq in}$  (shear strength of mild steel) = 37.5 tonf.

The capacity of many presses is expressed in tons force (tonf), and materials are often sized in imperial measurement and so it is useful to have the Imperial formula handy. (In any case the reader will notice that there is only a small difference between tonnef and tonf and that 4" is nearly the same as 100 mm.)

## 9.4 Punching or Blanking Tools for Ox-Cart Manufacture.

In the manufacture of components for the Borno oxcart, punching tools are used for producing the following, ( $\emptyset$  means diameter):

### *wheel discs:*

1. eight (four  $\emptyset 14 \text{ mm}$  & four  $\emptyset 11 \text{ mm}$ ) wheel hub and bolt holes,
2. one  $\emptyset 32 \text{ mm}$  valve hole,
3. one  $\emptyset 113 \text{ mm}$  centre hub hole,

***hubs:***

4. bearing endplate protectors (these can be made from the discarded Ø 113 mm blanks from the centre hub hole),

***bearings:***

5. blanks for cups and cones.

Tools for punching the above items are constructed as illustrated in Figure 27. Details of the punching tools for the items 1 and 5 are shown under Appendices 4 and 5 of this report.

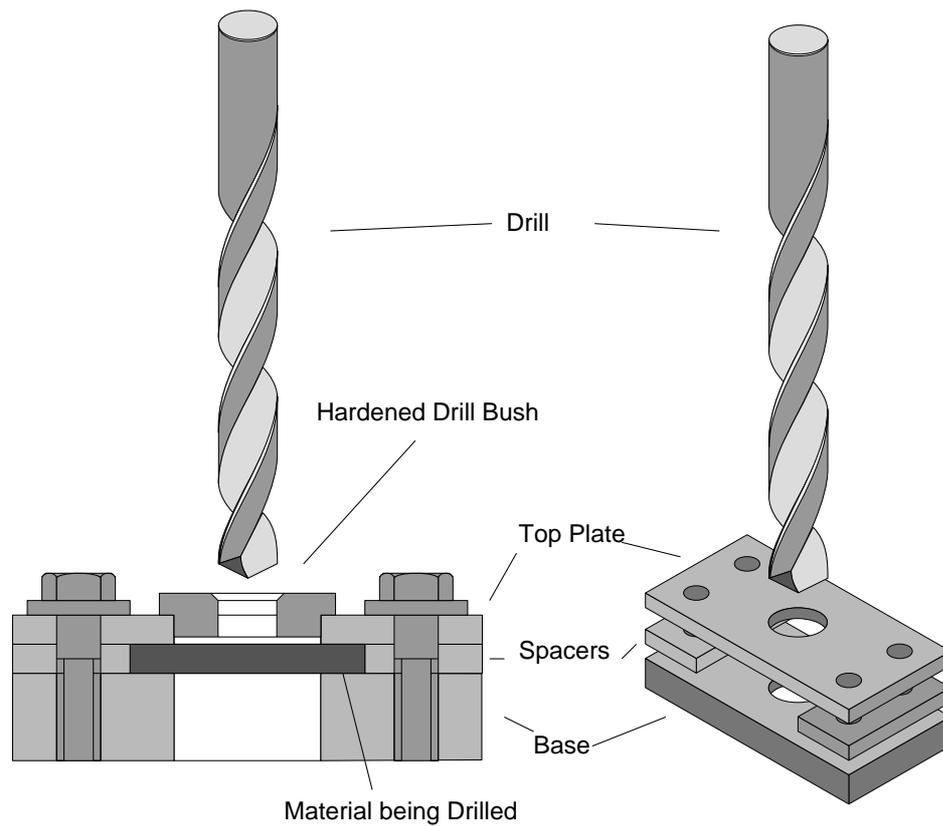
## **9.5 Drilling Jigs - General.**

A drilling jig is used for accurate placement of a hole or a series of holes. This is particularly important in production and for the interchangeability of parts. Accurate drilling of holes is a difficult exercise at the best of times. Though drilling appears simple and straightforward, it is full of pitfalls for the unsuspecting - for example accurate marking out, accurate centre punching, adequate holding of work and correct sharpening of the drill are all difficult, and any one, or a combination of the above, will cause inaccurate placement and size of the hole being drilled if badly done.

A drilling jig is made to locate over the component being drilled, and hold the component firmly in place whilst the drill is guided through a well fitting bush. Of course the jig itself has to be made accurately if it is to do the job correctly. The time taken in making a good drilling jig will be more than compensated for in the time saved with accurately drilled components.

When designing a drilling jig some thought has to be given to the method of inserting, holding, and removing the component. The jig has to have an open plan of construction to allow the swarf (cuttings that result from the operation) to clear from the jig and not block it up. An example of a simple drilling jig is shown in Figure 28.

If press tools are employed, only one drilling jig is required in the manufacture of the Borno ox cart. This jig is employed to locate accurately the four stud holes in the lugs of the cast aluminium hubs. Details are shown in Appendix 4 of this report. Ideally drilling bushes are made from high carbon steel and hardened, or they can be made from mild steel and case hardened as described earlier.



**Figure 28: simple drilling jig.**

## 9.6 Steel Casting Mould.

Details of the steel mould for casting aluminium hubs for the Borno Ox-Cart are shown in Appendix 6 of this report.



## **Appendix 1: Test results for aluminium cast in Nigeria.**

## **Appendix 2: Test results for Chinese Ball Bearings.**

## **Appendix 3: Pressed Steel Wheels: Dimensions and Tooling.**

(See also Appendix 4: Wheel Hole Punching Tools.)

## **Appendix 4: Wheel Hole Punching Tools**

## **Appendix 5: Cup-and-Cone Press Tools.**

## **Appendix 6: Aluminium Hub Casting Tools.**

## **Appendix 7: Drilling Jig for Aluminium Cast Hubs.**

## **Appendix 8: Axle Drawing for Wheel Hubs.**

## **Appendix 9: Wooden Ox-Cart Construction.**

## **Appendix 10: Steel and Wood Donkey Cart Construction.**

## **Appendix 11: Pipe and Roller donkey Cart Axles.**