DESIGN, FABRICATION AND TESTING OF A SUGARCANE FARM FURROWER

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DECLARATION

This thesis is my original work and has not been presented to any other university for a degree

28/6/2001

Date

Michael G. Muthini Kituu

This thesis has been submitted for examination with my approval as a University Supervisor.

28th June 2001

Date

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ABSTRACT

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Field studies were carried out to evaluate the performance of two furrowers that were in use for furrowing at Mumias sugar company: a double mouldboard furrower and a flat-plate furrower, using an undamped spring dynamometer. The results were utilised for guidance towards the design of a prototype furrower for Mumias Sugar Company. The prototype furrower was designed for better operational and power performance and tested relative to the mouldboard furrower and the flat-plate furrower. The goal was to minimise power requirements and maximise furrower performance, while improving workmanship and standardising the fabrication process. Future local manufacture at Mumias Sugar Company was the goal, for increased availability and lower cost of sugarcane farm furrowers.

A detailed standardised furrower manufacture process, with working drawings was developed. The furrower and its jigs were designed and fabricated. The furrower was tested for furrow formation and energy requirements. The tests were carried out against the Mumias sugar company mouldboard furrower and the Busia sugar company flat-plate furrower.

The mean draft for the prototype furrower was 1135.60N, for the mouldboard 1202.13 N and for the flat-plate it was 1287.38 N. Thus the prototype had least mean draft and the flat-plate had the highest mean draft. The mean moment for the prototype was 126.69Nm, for the mouldboard 122.40Nm and the flat-plate 136.12Nm. The prototype had a mean vertical force of 869.9 N. The same parameter for the mouldboard was 825.26N and for the flat-plate it was 819.99 N. The unit power consumption for the prototype lied between 0.92Wcm^{-2} and 1.78 Wcm^{-2}. The same parameter for the flat-plate lied between 0.68 W/cm^2 and 1.72 W/cm^2 while for the mouldboard it lied between 0.77 W/cm^2 and 1.41 W/cm^2.

The mean depth for the prototype in sand-bin ranged between 25.4cm and 25.8 cm. for the mouldboard the depth ranged between 27cm and 32.9cm and for the flat-plate it ranged between 31.5cm and 32.7 cm. Field studies mean depths were 25.8 cm for the prototype. 18.3cm for the mouldboard and 17.7 cm for the flat-plate furrower.

The prototype furrower showed qualities which made it better suited to resist bending even at increasing speed. Despite the increased power consumption quality of the prototype relative to the commonly used mouldboard furrower, the work quality recorded and the standardised design and manufacture process provided a real alternative to Mumias sugar company. The company had great desire to produce her own furrowers.

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Nairobi   Michael G. Muthini Kituu

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NOTATION AND COMMON ABBREVIATIONS

A	Cross sectional area (m^2).
ANOVA	Analysis of Variance
Autocad	Computer aided design programme
B	Regression coefficient, breadth of a structural member (mm), operating width (m)
B_1, b_2	Regression coefficient
B_a:	Angle iron breadth (mm).
B_b	Box section breadth (mm).
C	Regression coefficient.
C_f	Field capacity (ha/hr).
CPP3	Plate-rod system in frog-shank connection.
D	Draft (N), draft per bottom width (N/cm).
D	Depth of operation (cm), diameter (mm.), structural member depth (mm).
D_a	Angle iron height (mm).
D_b	Box section depth (mm).
d_f	Statistical degrees of freedom (dimensionless).
D_{sr}	Observed spring dynamometer reading (N).
D_s	Specific draft (Nm^{-2})
E_r	Shear modulus of rigidity (Nmm^{-2}).
E_f	Field efficiency (percentage, dimensionless).
ESS	Statistical sum of squares due to error
F	Force (N).
F_1	Horizontal force on shear bolt (N).
F_2	Horizontal force on pivot bolt (N).
f_{even}	Even values of f_i (defined below).
f_i	Ordinates on a Cartesian plane (I=1,2,3....n).
f_{odd}	Odd values of f_i
FP	Flat-plate
G_r	Torsional modulus of rigidity (N/mm^2).
I	Second moment of area of a structural member (mm^4).
ISI	Indian standards institute
K_1, k_2, k_3	Regression coefficients (dimensionless)
L	Moment arm (mm), length under stress (mm).
L_0	Original length of a structural member (mm).
L_1	Length of lower links (mm).
L_2	Normal distance between rear wheel axle and the tractor centre of gravity (mm).
LLP	Plate connecting tractor lower link to the furrower in prototype.
M	Mass (kg), moment (Nmm), Moisture content (%)
MB	Mouldboard
MS	Statistical mean sum of sample squares
N_s	Factor of safety.
P_h	Total implement draft (N)
P_s	Draw-bar draft (N), specific power (KWm^{-2}).
PT	Prototype
P_v	Total vertical force (N).
R	Wheel axle radius (mm), rank correlation coefficient.
R_f, R_r	Reactions on front wheel axle and rear wheel axle respectively (N).
RD	Drawing reference number.

S	Travel speed (m/s, Km/hr)
SASA	South African Sugar Authority
SCB	Block connecting the share to the landside in prototype.
SS	Statistical sum of sample squares.
SSB	Statistical sum of squares due to blocks
SST	Statistical sum of squares due to treatment
S_y	Material yield strength (Nmm^{-2}).
t_b	Box section material thickness (mm).
TSS	Statistical total sum of squares
V	Voltage (volts).
v_i	i^{th} regime of the furrowing speed: I=1, 2, 3 and 4 (m/s).
V_f	Vertical force (N).
V_c	Volume of a single component (cm^3).
V_s	Shear force (N).
W	Weight (kg), rated width of an implement (m).
W	Ploughing width (cm), width of a structural member (mm), integration width (m)
W_a	Apparent weight transfer (N).
W_{ac}	Weight added to the spring dynamometer (N).
W_b	Wheel base (mm).
W_f	Furrower weight(N).
W_c	Mass of a single furrower component (kg).
W_t	Tractor weight (N).
X	Constant, distance.
X_1	Constant (equal to 2 in most cases).
x, y	Indices of equation parameters.
Y_1	Transverse distance from central axis of a structural member (mm).
y_r	Perpendicular distance between P_c and rear wheel base (mm).
$\bar{y}$	Means of furrow depths.
Z	Section modulus of a structural member (mm^3), constant.
Z_{xx}, Z_{yy}	Structural member section moduli in the x and y axis respectively (mm^3).
α	Tractor wheel axle angular acceleration ($rads^{-2}$), angle (degrees).
β	Angle (degrees).
Δx	Change in horizontal displacement (mm).
Δt	Time taken to move through Δx:(s).
ε	Empirical constants.
Θ	The side angle at the trailing edge of mouldboard (degrees).
γ	Soil specific weight .
ρ	Soil bulk density (kgm^3).
ω	Angular speed of tractor wheel axle ($rads^{-1}$).
υ	Deflection .
σ, σ_t	Tensile stress and total stress respectively (Nmm^{-2})
σ_w, σ_y	Working stress and yield stress respectively. (Nmm^{-2})
τ, τ_{max}	Shear stress and maximum shearing stress respectively (Nmm^{-2}).

1 INTRODUCTION

1.1 Background Information

Sugarcane thrives under different soil types and conditions, varying from sandy, red clay loam to clay soils. Its growth requires a good supply of moisture, as its quality is characterised by a juicy stem. However it prefers well-drained soils. Cane performance is related to moisture availability (Mutanda, 1990) and temperature variations. The optimal temperature for sugarcane growth is about 35^0C. Lower and higher temperatures have shown a marked reduction in its germination and growth (Singh, 1988).

Moisture availability on one hand and poor drainage on the other influences the limitation to sugarcane production in Kenya. In lowlands where drainage is poor, sugarcane roots are unable to respire and soil toxicity results. About 90% of sugarcane crushed at Mumias Sugar Company are grown in the out-growers estates, which generally present upland soil conditions. Sugarcane growth exhibits apical dominance, and its development when planted at an angle to the surface is poorer than when laid flat, as all the buds do not develop into shoots. Sugarcane at Mumias Sugar Company is therefore grown by laying stem cuttings horizontally on the ground. For efficient cane planting and germination, furrows are required which also act as rainfall interception. However poor drainage must not result even as run-off is controlled.

1.2 The Problem

At Mumias Sugar Company, furrowing was mostly carried out using tractor drawn furrowers. A few out-growers farmers used animal power for furrowing. Three types of tractor powered furrowers in use at Mumias Sugar Company, were double mouldboard furrower, flat plate furrower and a disc furrower. The flat-plate furrower had over time presented poor performance at the company farms, while the disc furrower was rarely used due to high power requirements. The mouldboard furrowers in use had over time lost their originality rendering repair operations unpredictable. Successive repairs had in addition drastically altered the original designs of the mouldboard furrowers and this affected the power and operational performance with time. The reason why Mumias Sugar Company had resulted to manufacturing her own furrowers on station was because sugarcane furrowers were unavailable in the Kenyan market. Only light duty furrowers used in potato farming were available. The few original furrowers imported in the early seventies when they were affordable had failed due to old age. Over time, successive repairs and random replacement of various components made the furrowers shapeless and weaker. The modified furrower had poor performance, moved low quantities of soil and made rough furrows.

With the above developments, there was a need to design a prototype furrower and document its manufacturing process, within the professional skills and material resources of the company. The furrower design requirements and limitations were that the furrower would:-

a) Be fully mounted to achieve depth control, transportability and manoeuvrability,
b) Be simple in design with documented procedure for manufacture.
c) Be cheap to manufacture in comparison with the imported furrowers.
d) Have jigs and fixtures for uniformity of manufacture

A study carried out at Mumias sugarcane fields with the mouldboard and flat-plate furrowers aimed at gathering detailed furrowers performance information and furrower design data.

1.3 Hypothesis

The hypothesis of this study was that it was possible to design and develop a furrower for Mumias Sugar Company, which would perform better with respect to the operational requirements and power consumption. This would reduce the problems associated with furrower availability, and reduce the operating costs. It would reduce the risks associated with unavailability of the furrower and reduce overall costs of operation.

1.4 Research Objectives

The broad objective of the research was to design and develop a furrower for sugarcane farms at Mumias Sugar Company and test its power and operational performance quality in comparison to the existing designs. The specific objectives were:-

a) To determine the important furrower design parameters and their magnitudes based on field performance of the mouldboard and flat plate furrowers under Mumias sugar company field conditions.

b) To design and manufacture a prototype furrower, which would operate better than the existing furrowers with regard to prevailing soil, conditions and power requirements.

c) To test the prototype furrower for operational and power performance, against the existing mouldboard and flat-plate furrowers

2 LITERATURE REVIEW

2.1 Sugarcane Farming at Mumias Sugarcane Farms

2.1.1 Land Preparation

Mumias sugar company is located in a sugarcane growing area in Kakamega district and has a sugarcane belt covering Kakamega, Lugari/Malava and Bungoma districts of the Western province of Kenya. Mumias Sugar Company, the leading sugar producing company in Kenya, covers an area of 38,000 to 40,000 hectares (ha) of land under sugarcane production. The sugarcane zone is grouped into the company owned nucleus estates and the farmers owned out-growers estates. The nucleus estates have 3,400 ha of land, which produces 7% of the total sugarcane while the rest of the land is out-growers estates, and produces 93 % of the total sugarcane crushed. The maximum area available for ploughing, harrowing and furrowing which previously averaged 6000 ha annually rose to 11,000 ha in 1993/94, due to expansion of sugarcane producing area. Of the total area in the nucleus estates, about 10% are in lowlands.

Soils at Mumias sugarcane farms are classified into two major categories and a third minor one, which are, upland well drained loam soils deficient in nitrogen and phosphates, lowland poorly drained montmorillonitic soils and upland well drained poor soils having high gravel content. Cane stool destruction, ploughing, harrowing and furrowing is the order of land preparation operations at the sugarcane fields. Ploughing is carried out to an average maximum depth of 24cm with disc ploughs. Harrowing makes the seed-bed fine and involves chopping and destroying of the sugarcane stools, and inverting and mixing cane stool with soil for organic matter supply. Second and third harrowing operations are common, depending on the required seedbed quality.

Cane stool destruction takes place at the nucleus estates while at the out growers estates it is omitted partly due to high costs, and partly because the livestock grazes on the last ratoon. Out of the total area available for land preparation in the out-growers estates in the previous years, 4000 to 6000 hectares were ploughed by the company machinery, while private contractors mainly Mumias out-growers company ploughed 2000 ha annually.

The company machinery previously carried out all furrowing operations. At the time of this study, the company fleet was ploughing, harrowing and furrowing 8000 ha while Mumias Outgrowers company was preparing 3000 ha of outgrowers estates land. Only the company fleet prepared the nucleus estates land.

The costs of the land preparation at the company nucleus estates, Mumias sugar company were on the increase as reported by Kaumbutho et al., (1991), Katua (1992) and Kaumbutho et al., (1993). According to Kaumbutho et al. (1991) and Katua (1992), of the land preparation processes in the nucleus estates, harrowing was the most expensive, due to the use of crawler type of a tractor, whose power consumption was high (Table 2.1). In 1993, a reduction in operating costs was noted, which could be attributed to use of wheeled tractors for harrowing compared to the crawler drawn harrows. The power consumption for the crawler was always higher than the wheeled tractors power consumption. A new fleet of tractors for harrowing furrowing and ploughing had also been purchased, which must have reduced the costs of operation by reducing repairs and spare parts costs. The costs of operation for the years 1991/92, 1992/93 and 1993/94 rose consistently due to high depreciation, maintenance costs, old age and rising spare parts costs (Katua, 1992).

Table 2.1: 1991-94 Nucleus Estates Land Preparation Costs: Mumias Sugar Company

Activity		Ploughing	Harrowing	Furrowing
1991/92	KShs/ha	1956.30	2810.50	521.40
	KShs/hr	704.27	2276.50	598.20
	Rate (Ha/hr)	0.36	0.81	1.15
1992/93	KShs/ha	4379	3212.70	1772.80
	KShs/hr	1770.10	3316.20	1775.10
	Ha/hr	0.38	1.12	0.99
1993/94	KShs/ha	2521	972	735
	KShs/hr	3206	116	194
	Ha/hr	0.34	0.89	0.78

Source: Kaumbutho et al., (1991/92), Kaumbutho et al., (1993/94) and Katua (1992/93)

Table 2.2 indicates the costs of mouldboard furrowers as quoted to Mumias Sugar Company in the 1992/93 financial year. From the quotation file, Mumias sugar company (1993) a fabricated mouldboard furrower would cost KShs 97 500. Although local fabrication of furrowers would probably not necessarily reduce the costs of furrowers' ownership, it would enhance the availability of the furrowers and reduce the risks associated with their poor availability of the furrowers.

Table 2.2: Cost of 2-Bottomed Mouldboard Furrowers

Make and Model	Supplier	Price(KShs)
Dowdswell mold	Gailey & Roberts	1 915 690.00
Baldan Sls	Lima	108 850.00
Not Stated	Cane Land	136 660.00
Simba Mk III	Farm Engineering	383 250.00

Source: Quotation File (1992/93). Research and Development section. Mumias Sugar Company

Furrowing at Mumias sugarcane fields is done both in the nucleus estates and the out-growers estates using furrowers and involves making of furrows where seedcane is laid. In the poorly drained soils of the lowlands, the furrowers followed by a gang of disks make larger and deeper furrows.

2.1.2 Furrowers in Use at Mumias Sugar Company

Mouldboard furrowers at Mumias sugar company work on ploughed and harrowed land, cutting into pulverised soil and moving the soil sideways. The soil slides over the mouldboard surfaces before it is thrown sideways. A shin in front of the mouldboard helps in furrow formation, but its function is not well defined and could be done away with (MacIntyre, 1993). The double mouldboard furrower as seen from Fig 2.1 has a left and a right mouldboard, two landsides and a share. The left and right mouldboards were supported on a tool-bar through a standard and a rear rod. The system transmits loads from the soil via the mouldboards to the tool frame. At the lower edge is the share with a hard-faced edge for resisting wear. From earlier tests conducted on the equipment (Kamau, 1993) and reports by MacIntyre (1993), the mouldboard furrowers at Mumias sugar company performed as follows: -

a) Mouldboard furrowers brackets were not parallel and could not be clamped rigidly to the tool bar, a failure that led to the rapid twisting, misalignment and rapid loosening of the standard-toolbar system. This could have resulted from the overload of the brackets and their under-design. The effect led to fast wearing of the bolts and their holes. It was necessary to make brackets and standards of harder material than the bolts, which would wear at a lower rate than the bolts. As the bolts were cheaper to replace, this would reduce downtime and improve the operation (MacIntyre, 1993). The quality of the material to make them was not stated; hence the application of the recommendation needed further study.

g 2.1: A design of the mouldboard furrower

The standard was made of mild steel whose specifications were not stated, having replaced the original standard without design considerations, could not withstand high forces as it seemed weak and became unusable once bent. It was foreseen that a superior quality standard design would be more expensive.

c) The share, front point and the leading edge, initially made of hard steel, had been replaced with mild steel mouldboard point that wore fast. The overall effect was increased labour and spare parts costs. The angle of the share was steep, resulting in high suction and increased draft. The angle at the leading point required reduction for better penetration.

d) The mouldboards were made of mild steel, compared to the original design of hardened steel (MacIntyre, 1993). Wear was concentrated at the lower edges. The mouldboard material was 8mm thick mild steel. Old land-grader-blade material was recommended to be welded to the high wearing parts, which would improve wear resistance and life of the mouldboards. This was a difficult recommendation, as the grader blade could not take the shape of the edge without brittle failure. The mouldboard shape design required that a clean furrow free of clods be made. For sandy soils, the angle between mouldboards would be greater for reduced soil flow back. At the correct depth, it was necessary that the position of the rear outer edges of the mouldboard remained above soil and wider than the furrow, to push clods onto the ridge.

e) The frog was reduced to a small metal piece for securing the share to the landside and the mouldboard. It was noted that it could not offer reinforcement to the mouldboard.

Numerous furrower components existed in the original mouldboard furrower as seen in Fig 2.2. The failure of a single component could result in a weaker furrower, while more components increased the probability of failure. A reduction in the number of furrower components without reducing their replaceability was considered in this study. The flat plate furrower in Fig 2.3 had the following features: -

a) Simple and flat wings, unlike the curved ones for the mouldboard furrower,

b) Long, thin share that was far from the wings, which fed soil poorly to the wings,

c) Rough surface, with high soil resistance and poor scouring than mouldboard furrower.

d) Lift angle was large. This reduced the action of the wings on the soil. The long thin share went fully into the soil, but the wings floated above the soil. The correction to this was to elongate the top link, but there was a limit, beyond which the angle would still be large.

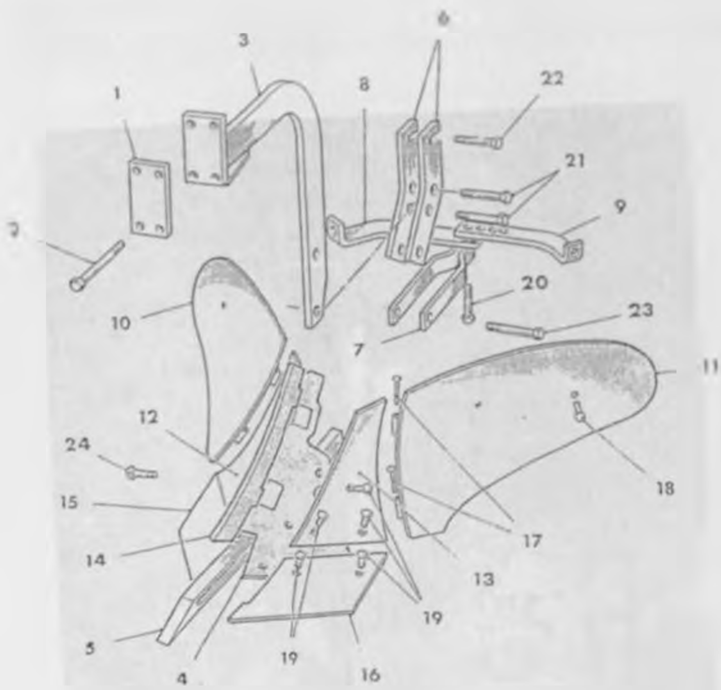

Fig 2.2: Exploded view of the components of an original mouldboard furrower design
Source: Ransomes, Sims and Jafferies (1986)

The names of the parts given in Fig 2.2 were as in Table 2.3

Table 2.3: List of Parts in Fig 2.2

1 =clamp plate	2 =bolt $^3/_8$ (4-off)	3 =stalk
4 =frog	5 =bar point	6 =adapter
7 =coupling	8 =left mouldboard stay	9 =right mouldboard stay
10 = left mouldboard	11 =right mouldboard	12 = left cutter
13 =right cutter	14 =shin	15 =left share
16 = right share	17 =pin	18 =bolt $^3/_8$x1
19 =bolt $^3/_8$x1$^1/_4$	20 = bolt $^3/_8$x2	21 =bolt $^1/_2$x2¾
22 =bolt $^1/_2$x2¾	23 =bolt $^1/_2$x2¾	

The performance of the flat-plate furrower was better in the dry season than in the wet season as it clogged up fast and had poor scouring in the wet conditions. The Mouldboard furrower had superior performance to flat-plate furrower in dry and wet seasons (MacIntyre, 1993).

Fig 2.3: Flat-plate furrower manufactured for Busia sugar company

2.1.3 Sugarcane Agronomy and Furrowing

In its growth sugarcane is sensitive to moisture changes and has a marked succulent juicy stem and dense canopy. Taylor and Yates (1988) developed equations relating sugarcane yield to moisture content, which demonstrated reduced sugarcane yield as moisture content reduced. In addition, sugarcane growth is sensitive to temperature variations and has an optimal temperature of 35^{0}C (Singh, 1988). Under Mumias sugar company scheme, young seed cane is cut from the nursery at the age of ten months. Any loss of seed-cane fluid due to desiccation could lead to low viability, with poor emergence and establishment of the cane on the soil.

There are two distinct sugarcane planting techniques namely hand-planting and mechanised furrow planting. Hand planting has two categories: dibble planting and non-mechanised planting. In the dibbling system, canes are planted in holes inclined at 30^0 to horizontal at a density of 5000 to 25000 canes per ha. At close plant densities, variation in seed cane population has no marked influence on the yield (Barnes, 1974). In furrow planting, seed-canes of three eye-buds on average are laid in the furrows with eye buds on the sides for uniform bud development. The canes are covered with the soil from the ridges. Seed-cane planting with an overlap of one or two buds is one of the placement methods used. The alternative is end-to-end lying of seed cane.

In sugarcane planting, setts are laid in furrows between 150 and 200 mm below the soil surface with good soil tilth underneath the crop, for root development. Soil cover for harsh conditions should be 10 cm, but not beyond 5 cm depth under favourable climate (Barnes, 1974). Heat is necessary for sugarcane germination and growth, while deep planting reduces soil temperature effects on the seed cane. Soil cover of 10-12 cm of soil at 12% moisture content, and a planting depth between 20 and 25 cm is adequate (Sharma and Singh, 1990). Soil physical conditions and depth of the soil available for the cane growth influence root system development. Werken et al., (1991) reported an increase of 5-10 tones per hectare of sugarcane with the use of furrows compared to the dibbling system of planting. Furrowing would enhance development of all buds into shoots. It would provide soil for the shoots as they grow and tiller. Moisture retention and availability would be higher in furrowing, while run-off would be checked. According to Werken et al., (1991) optimum sugarcane rooting depth would be 0.75m and furrowing would increase yield by 5-10 tones per ha of sugarcane, depending on cane variety and rainfall quantity.

Furrowing increases surface area, resulting in increased loss of soil moisture. Furrows should be narrow for water conservation. SASA (1977) recommended adequate ploughing to a depth between 20 and 25 cm, followed by 15-20 cm furrowing, as deeper shattering of the soil did not show significant increase in sugarcane yields. Uichanco (1981) reported supply of soil in deep planting and canes placement at 20-25 cm below soil surface, followed by a thin cover of soil above the cane as necessary. As the cane emerges and tillers, it requires further and continuous covering, for healthy secondary and tertiary shoots. This is achievable in furrow planting. In the furrow planting, plants become suited to withstand dry periods as moisture is conserved. In windy areas, plants become strongly anchored to withstand wind. Shallow planting and hilling up could cause lower yields and poor ratooning (Uichanco, 1981).

Some advantages of furrowing would be as follows: -

a) Soil supply: Furrowing cuts a groove in soil, sweeps the soil to the sides and forms ridges. The soil is used in covering seed cane during planting and supplying emerging shoots with soil on which the shoot-root system develops. Tillering also takes place on the soil.

b) Moisture conservation: Furrows in the field act as drains where water collects, which increase soil moisture available to the crop for a longer period.

c) Timeliness of planting: The process of cutting furrows, laying the seedcane and covering them with soil is faster than the dibbled planting.

d) Reduced compaction: Furrowing disturbs soil, reducing its level of compaction, which results in improved root penetration and better utilisation of soil moisture.

According to Lawrie and Neate (1960), seed-cane planted on ridges with 5 cm depth of soil cover, had outstanding germination while poorest germination was observed in furrow planting with 20 cm soil cover. Furrow planting with 8cm-soil cover had moderate performance. The performance of cane followed the germination trend. Probably 5cm- soil cover in the furrow planting could have given better cane performance (Lawrie and Neat, 1960).

2.2 Prototype Design Considerations

The prototype had the following design considerations: -

a) Economic constraints: The furrower would be cheap in design, within design budget.

b) Material availability: The furrower components material would be readily available, with a possibility of utilising the locally available high quality scrap land grader blades and mild steel available in the factory workshop and the country generally. Scrap land-grader blade material was necessary for the fast wearing parts since it was hard wearing. Mild steel available in the factory workshop and the country generally. Scrap land-grader blade material was necessary for the fast wearing parts since it was hard wearing. Mild steel was necessary for forging of the mouldboards and making other of components such as the shank and the tool carrier. However, land-grader blade material could only be applicable on straight sections, as it would suffer brittle failure on non-straight sections.

c) Technological capability: The design was limited by the local workshop capability and guided by designs in existence, which were the flat plate and the mouldboard furrowers.

Other considerations in the design were as given in sections 2.2.1 to 2.27.

2.2.1 Prediction of Forces on Mouldboard Surfaces

Work on the measurement of forces acting on mouldboard surfaces has been carried out over a wide range of mouldboard shapes and at different ranges of speeds. Suministrado et al., (1990), developed equations of forces on mouldboard surface using an orthogonal curvilinear system. Their work led to linear regression equations 1 to 4, relating draft D (N), vertical force V_f (N) and speed s (m/s).

For predicted values

$$D = 60.5 + 7.1S \tag{1}$$

while,

$$V_f = 22.2 - 1.7S \tag{2}$$

and for actual values,

$$D = 65.4 + 6.8S \tag{3}$$

while

$$V_f = 12.2 + 12.3S \tag{4}$$

Equations 1 to 4 showed that draft was under-predicted and increased with speed at a lower rate in comparison with actual values. From the equations vertical forces were predicted to decrease with velocity, but were practically found to increase with velocity. The equations could be used to predict draft, but their accuracy depended on the range of values under which they were developed, which was not stated by Suministrado et al., (1990). They also depicted that, at zero speed, the plough would experience some draft and vertical force, which would be difficult to explain. Perhaps the residual value would be related to cutting resistance and cohesive forces of the soil, which could be termed static draft. Qiong et al., (1986) developed mathematical equations for mouldboard plough draft prediction, using a curvilinear co-ordinate system. By their equations, draft was over-predicted by 18%, while vertical forces were substantially over-predicted. They developed a single equation relating draft *D* (N) to depth of operation *d (m)* and speed *s (m/s)* (with b_1 as 1.5 m^3/s^2, b_2 as 0.228 m for steel mouldboard and γ the soil specific gravity (kgm^{-3}). The equation was independent of trajectory motion of the soil particles over the mouldboard as,

$$D = \gamma d(b_1 + b_2 S^2) \qquad 5$$

Equation 5 by Qiong et al., (1986) could be applied to predict furrower draft since it was simple with a few unknowns, compared to other equations under the assumption that draft is additive. This would imply that draft on one surface of the furrower would be doubled to give total draft on one furrower bottom, and that no other interacting factors in the force analysis. Equation 5 depicted draft as independent of the width of cut. Qiong et al., (1986) did not give the width of cut for which the equation was developed. Furrowers bearing Simba, Ransome and Permitter brand names have 700mm as the width of cut (Simba, Permitter and Ransome Machinery Operating Manuals). Qiong et al., (1986), over-predicted the vertical force by 661.1%, while Richey et al., (1989), over-predicted it by 115.2% compared to measured values. Hence the equation could not be relied on for prediction of vertical forces. The effects of equations 1 to 5 in the design are discussed under section 2.2.6.

2.2.2 Mechanics of Soil-tool Interaction

Soil-tool interaction determine the size of the power source for adequate performance of a tillage implement. Draft, which is the force directly pulling the furrower is of major concern. The quality of the work done by the implement is of prime interest. When designing a tillage tool, soil-tool interaction and tractor-tool interaction are important input factors. Drawbar pull is the force required for pull an implement through the soil, and consists of draft, side force and vertical force components.

Gill and Vanden Berg (1967) stated draft as a factor of depth of operation, width, speed of operation and soil and tool factors. McKyes (1985) gave equations relating draft, traction force and vertical force to soil and design parameters. The draft in McKyes (1985) equation was dependent on traction force, and varied partly as the square of the depth of operation and partly with the depth. The depth of ploughing and hence depth of furrowing was crucial in draft prediction. A linear change in depth of operation was accompanied by an exponential change in draft.

The equations of prediction by McKyes (1985) were applicable in the determination of draft for a general soil tillage tool and did not relate to the mouldboard plough in specific. Their accuracy was limited to the range of values, over which they were developed, which limited their applicability in this study. Koolen and Kuipers (1983), suggested equations to predict draft *D (N)*, relative to depth of operation *d (m)*, width of operation *b (m)* and moisture content *M* (ratio, dry basis), (with k_1, k_2, k_3, z, γ, *c*, θ and ε as regression coefficients) on a mouldboard plough as shown in equations 6 to 8.

$$\frac{D}{bd} = k_1 - k_2M + k_3M^2 \qquad 6.$$

$$\frac{D}{bd} = z + \varepsilon^{\gamma d} \qquad 7$$

and

$$\frac{D}{bd} = z + c(1 + \cos\theta)S^2 \qquad 8$$

Equations 6 to 8 indicated an increase in draft with depth. For equations 7 and 8, the empirical constants would require experimental regression analysis, which made the equations inadequate for use in this study. Koolen and Kuipers (1983) did not define the normal speeds of operation. ASAE standards (1990) gave the typical ploughing speed as 1.94 m/s with a range between 1.39 m/s and 2.78 m/s, while Kepner (1976) gave the typical ploughing speed as ranging from 1.56 m/s to 2.47 m/s. ASAE standards (1990) presented equation for calculating draft *D* (N/cm) per bottom at a depth *d (cm)* for a mouldboard furrower at 1.88m/s in a silty clay loam as

$$D = 21.5d^2 \qquad 9$$

Equation 9 was for a specific speed and specific soil type and was considered inadequate for montmorillonitic clay soils available at Mumias sugarcane fields at the operating speed of 2.22 m/s.

Soil moisture would influence draft on a tillage tool moving through soil in several ways. For a soil cutting implement, increased moisture content would reduce cutting resistance (Hasan, 1983), thus reducing draft. Moisture increase would also increase sinkage, slip and traction resistance, which would eventually reduce soil trafficability. Thus moisture availability may not be advantageous depending on the level of moisture in the soil. Equation 6 showed a polynomial of draft in terms of moisture content. It indicated a decrease in draft as moisture content increased to 1, the decrease in draft being limited to a maximum moisture content of 1. As moisture content increased beyond 1, draft increased with moisture content. This could be explained by a combined effect of adhesion of the soil on the surface, friction between the surface and the soil particles and abrasion between the tillage tool and the soil particles. The weight of the soil bulldozed by the tool, sinkage, slip, and deformation effects of the tractor on the soil could also be contributing factors. Hasan (1983) stated that draft could be estimated if soil cohesion, soil-metal friction, soil-soil friction and the dimensions of a plough were known. Factors such as slip, sinkage, friction; adhesion, abrasion and cohesion of soil would increase draft more than the reduction of the cutting resistance, thus offsetting the reduction in cutting resistance by the moisture content. The state of soil compaction directly influences draft on a tillage tool.

Compaction has indicators such as bulk density and cone index. Hasan (1983) stated equations for draft prediction on a mouldboard plough, in which draft would increase partly with cone index and partly with the square of velocity. Cone index is proportional to bulk density. More energy would be required to cause soil failure under compaction while less force would be required for pulverised soils, typical of furrowing soils. For different tillage implements at different soil conditions, draft has been found to vary differently with the speed of operation. Generally draft on a mouldboard in operation would increase with speed. Wang and Lo (1970) suggested equations in which the draft of a mouldboard plough was related to plough characteristic length, which was subsequently related to the velocity.

Equations 1 to 9 were empirical. meant for predicting draft in ploughing. Their accuracy was limited to the range of values under which they were developed. The equations had coefficients, which required predetermining, using pre-design tests. The above two limitations made the equations unattractive for this study. The approach adopted in this study was actual measurement of furrowing forces before design and using the forces in stress analysis. Each of the factors affecting draft did not act in isolation. The separation of the factors in predicting draft would be a simplistic approach with unrealistic solutions, as the other factors would act simultaneously. A single equation relating all the factors to draft would be necessary in draft prediction.

2.2.3 The Soil Engaging Surface

Cut and try is a method used in the design of soil engaging surfaces. Recently research on efficient analytical and explainable methods of designing the soil engaging surfaces, for improved performance has been in progress. Simplicity in design of the surfaces was an input in this study, as the shape of the mouldboard is complex to quantify and explain.

In the development of soil engaging surface, Gyachev (1988) described a working surface as one that could be deformed into a plane by simple bending along its resultants, without plastic deformation of the individual parts of the surfaces. Cylinders and cones are working surfaces, while the sphere is a non-working surface. For a working surface, soil slices adhere completely to the surface (Gyachev, 1988). Deere (1984) stated that the manufacture of plough surfaces was dependent more on cut and try methods rather than analytical methods. The asymmetrical and complex curved shape of the plough precludes a precise mechanical analysis of interaction with the soil (McKyes, 1985). McKyes (1985) never gave parameters for use in design of the surface, or the performance criteria.

The study of practically developed forms of surfaces of plough bottoms would be useful in the design of new plough bottoms, but suitable methods of study have not been developed (Gyachev, 1988). These methods are subject to pre-design tests to determine the type of plough, the angles of approach and the ploughing speed for optimal performance of the plough bottom using model ploughs or furrowers.

The projected path of soil particle over the surface of the mouldboard estimates the position of the particles in the Cartesian {x, y, z} plane on a plough. Richey et al., (1989) cited computer graphics, which were used to study the shapes of surfaces and to design other surfaces. They used parallel vertical surfaces with coinciding grid holes. The surface established the y-z plane, while the horizontal grid rods gave the x-position of the surface.

Richey et al., (1989) gave a method of representing the soil engaging surface where measurement of eight descriptor points on the share and twenty-nine descriptor points on the mouldboard was necessary for describing the mouldboard surface. This was unfavourable in design work where there was no prototype available. A simple means of quantifying and qualifying the mouldboard was necessary in the present work, and could be taken as a cylinder or a cone as stated by Gyachev (1988). Thus the existing furrowers, and Gyachev's working surface theory were considered in this study. Suministrado et al., (1990) developed mathematical equations to predict trajectory motion over soil-engaging surface. They considered lift angle, angle of attack, velocities and acceleration in lateral, longitudinal and vertical directions. Qiong et al., (1986), cited equations to describe movement of soil over mouldboard, from Carson (1961). The equations had regression coefficients which could be obtained using values from a scratch surface, similar to those used by O'Callaghan and McCoy (1965) as stated by Richey et al., (1989). These values were unavailable, a factor which made the equations unsuitable for use in the current study.

In the mouldboard surface design, acceleration along the surface would be necessary to move soil over the crest. Kepner (1976) stated that an increased curvature from front to rear of the mouldboard would improve scouring. Gill and Vanden Berg (1968) stated that soil engaging surface curvature should increase from soil intake to outlet, to avoid soil build-up at intake. A conical surface would have either an increasing or reducing curvature along the surface. The expression for angular acceleration α (rads^{-2}) for a particle moving over a surface of radius *r (m)* with a velocity *V (m/s)* is expressed as

$$\alpha = r\omega^2 = \frac{V^2}{r} \qquad 10$$

Equation 10 would imply that a reduction in radius from intake to outlet would result in an increase in the angular acceleration over the surface. This would be achieved by a conical based mouldboard. The increased acceleration would increase rate of release of soil from the surface. It would reduce vertical force per unit time on the surface. It would probably improve on scouring of soil over the surface, increase the distance of throw of soil from furrow centre and hence make more stable furrows. For a mouldboard plough, a reduction in area over the surface would imply more side thrust. However, this effect would be eliminated in a double action effect of soil over the furrower.

2.2.4 Relation between Draft and Vertical Force

Vertical forces on tillage tools are present in tillage operation, and are responsible for the penetration of the implement into the soil. According to Kepner et al., (1979) the ratio of suction to draft depends on factors like soil type, soil conditions, depth of cut, share edge shape and sharpness and the speed of operation among other factors. Field test results gave the values of the ratio of suction to draft as ranging between 0.1 and 0.3 (Kepner et al, 1976). However, they did not elaborate on the design of the soil-engaging surface.

2.2.5 The Mouldboard and its Materials

John Deere (1984) and Kepner et al., (1976) described the basic mouldboard materials as:

a) Off-centre, soft-centre steel, which is 3-ply, with highly polished fine textured steel, for long wear and good scouring in sticky soils. Three layers with different thickness and carbon content hot rolled into a single tough sheet of metal exist, with the outer two layers having the highest percentage carbon content and responding to heat treatment.

(b) Chilled cast iron designed to withstand scratching and hard wear in sandy gravely soil.

(c) Solid steel, which would be a single sheet specially treated to provide a behaviour close to the 3-ply material and which would be shock resistant, with lower carbon content than the outer layers of the off-centre soft centre material.

Where soils are extremely sticky, Teflon would cover the front surface of the mouldboard for improved scouring, depending on the cost implications. Carbonising of the surface would improve the strength and resilience of the plate. None of these materials were available at Mumias sugar company at the time of this study. Mild steel was considered for use due to the low costs and ready availability, as it would reduce the cost of production, cost of operation and down time.

2.2.6 The Share and Landside

According to MacIntyre (1993) both the share and the landside in the Mouldboard furrower experienced high rate of wear during operation due to their position at the front leading edge and base of furrower. While the furrowers were in operation, the share had contact with soil particles, and experienced high abrasion from the abrasive Mumias Sugar company. Kepner et.al.,(1976) reported shares made from heat treated high carbon (C-1095) solid steel. For extremely abrasive condition hard and highly wear resistant chilled cast iron would be used although the material would experience brittle failure. A replaceable share would be necessary in heavy duty operations at Mumias Sugar Company.

The theory behind the design of the shank, bolts, mast tool carrier and the angle sections (irons) was merged with the actual design in the methodology for clarity and ease of synthesis by the reader. However, some literature on the parts was as discussed under section 3.2.

2.2.7 Applicability of Prediction Equations in the Design

In the theoretical analysis, it was not possible to identify a design force that would adequately be used in the design. Equations 1 to 5 had no regression coefficients, and gave forces that were low for design purposes, which subsequently gave low and unacceptable design values.

Equation 9 yielded reasonable values in design. The equation was however for determination of the draft on a 36cm furrower bottom operated at 1.88 m/s in a silty clay loam. Where the bottom would be beyond 36cm (in this study 70 cm) and the operating speed higher than 1.88 m/s (in this study 2.22 m/s) and the soil type different, the design forces would differ and hence the design would change. Equations 6, 7 and 8 had empirical regression coefficients whose determination would be as rigorous as determining design forces from field studies.

Regression equations would always be accurate over the range of values under which they have been developed. Beyond these values, the behaviour of the variables would be unknown. Thus the use of regression equations would probably introduce unpredictable errors. Their use would therefore not be highly recommended. This limitation would imply that equations 1 to 9, however accurate they would have been could not be best utilised to determine design forces. Thus direct field-testing would be necessary as a means for establishing the design forces. Gyachev's working surfaces, which included the cylinder and the cone, were considered in the design of the soil-engaging surface.

2.3 Furrower Performance Evaluation and Indicators

2.3.1 Loads Determination

Monitoring of the performance of the furrowers would require the measurement of forces and consequential loads. Development of devices for measuring forces has been in progress over time. While spring dynamometers emerged earlier than other modern devices, they offered difficulties due to the vibratory nature of their spring and hence the pointer. Damped spring dynamometers replaced the spring dynamometer where the damping improved readability but reduced sensitivity.

O'Dougherty (1975) described a multidirectional dynamometer design that could be used to measure draft and side forces. Howell and Paice (1989) described a data logging system, which was an integral part of the dynamometer described by O'Dougherty (1975). Singh et al., (1981) reported three basic types of dynamometers. These included mechanical dynamometers that were good for static loads. There were hydraulic dynamometers that were good for hitched implements but not highly sensitive and with leakages, in addition to inconveniences in attaching to the tillage tools. They also had octagonal ring transducers, which were superior to the other two types above. Gebresenbet (1989) described the design and analysis of octagonal ring transducers. The transducers could measure tillage forces in lateral, longitudinal and the vertical directions of movement of the tillage tool, and a moment in the lateral direction as well as monitoring the speed and depth of operation.

In this study, due to unavailability of the strain gauge dynamometer at the early stages, a spring dynamometer was used for preliminary force measurements in the Mumias sugarcane farms. In final testing, an electronic load cell capable of recording draft, side forces, vertical forces, in addition to a moment, speed and depth was available and was used in sand-bin studies. The speed logging mechanism however was un-operational at the time of the study. Equations relating to structural design were merged with the design in the methodology.

2.3.2 Operating Speed

Speed of operation would influence tillage forces and determines the final soil condition, hence the importance of its measurement. Suministrado et al. (1990) used a battery powered simple electronic assembly with an automatic speed recording print out to determine speed of operation. Owende (1995) described a speed monitoring device in which speed was monitored from axle mounted sprocket, through a chain drive mechanism. He used a speedometer and a D.C. Tachogenerator for speed recording. A simple procedure in the measurement of speed would be to measure the time taken to cover a measured distance. The speed *s* according to Tranter and Lambe (1984) is expressed in terms of change in distance Δx (m) and change in time Δt (s) as.

$$S = \frac{\Delta x}{\Delta t} \qquad 11$$

2.3.3 Specific draft and Field Capacity

According to ASAE Standards (1990) an implement specific draft D_s (N) is given by

$$D_s = \frac{\text{Draft}}{\text{Furrow Area}} \qquad 12$$

and the specific power $P_s(Wm^{-2})$ would be given by

$$P_s = D_s \times \text{Speed} \qquad 13$$

The field capacity C_f (ha/hr) of the furrower operating at speed S (Km/h), with a rated width W (m) and field efficiency E_f would be given by

$$C_f = \frac{SW}{10}\left(\frac{E_f}{100}\right) \qquad 14$$

2.3.4 Soil Micro-profile

The furrow relief is a measure of soil disturbance necessary in evaluating the performance of the furrower and any other tillage tools. A relief metre, (Fig 2.4) similar to the seed row roughness metre developed by Tessier et al., (1989) would be employed for this

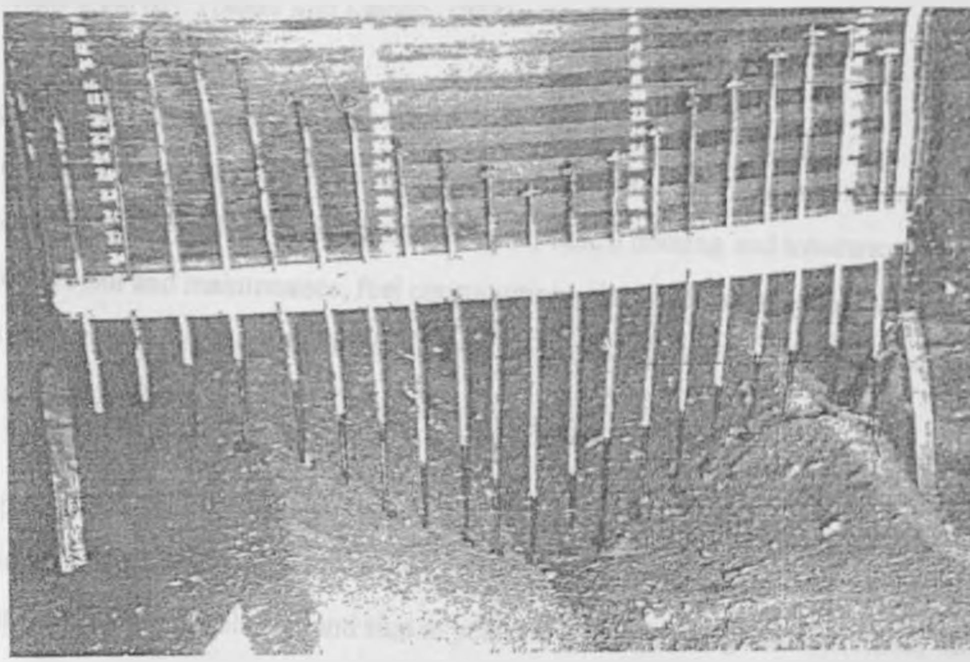

Fig 2.4: Soil micro-profile metre used at Kabete sand-bin Tests

The results would give comparatively, the shape of cross-sections of the furrow made by different furrowers and quality of furrows. The area of a furrow is nec^^ssary in evaluating the performance of the furrowers. It could be given by a cross-section of the projection of the furrower in operation. By integration, the area A under a curve of function *f(x)* bounded by ordinates [a, b], for an increment *dx* in the ordinate direction, is given by

$$A = \int f(x)dx \qquad 15$$

Consider an unknown function of a curve. Let its ordinates range be divided into n intervals of equal widths, h. If the heights of the ordinates are expressed as f_0, f_1, f_2, ...f_n. then, according to Jeffrey (1979), then

$$A = h(\frac{1}{2}(f_0 + f_n) + f_1 + f_2 + ... + f_{n-1}) \qquad 16$$

which is the Trapezoidal rule. A more accurate formula for approximating the area under a curve of unknown function, with the ordinate range [a. b] divided into even intervals would be given by

$$A = \frac{1}{3}h[(f_o + f_n) + 2\sum f_{even} + 4\sum f_{odd}] \qquad 17$$

Equation 17 is the Simpsons rule and has been found to be more accurate in the estimation of the area under a curve (Tranter and Lambe, 1984).

2.3.5 Agricultural Implements Costs

The cost of use of any implement is divided into two sections, namely ownership and operating costs. Ownership costs include depreciation. interest, taxes, housing and insurance. Operating costs include repair and maintenance. fuel consumption, oils and lubricants, labour, and cost of the prime mover for driven or mounted implements. For the furrower, oils and lubricants would not apply in cost analysis.

Ownership costs

Depreciation: Several methods would apply in depreciation calculations. Among the methods are straight line, declining balance, and sum of years' digits. The straight-line method, which is most commonly used, would give depreciation D_p as

$$D_p = \frac{P - S_v}{L} \qquad 18$$

where

P= Principal amount or buying price.
S_v = Salvage value, in most cases taken as 10% of P, (Kepner, 1976),
L = Machine life (years).

Interest is calculated using the expression

$$R = (P - S_v)\left[\frac{\left(\frac{i}{n}\right)\left(1+\frac{i}{n}\right)^{Ln}}{\left\{1+\frac{i}{n}\right\}^{Ln} - 1}\right] + \frac{si}{n} \qquad 19$$

where

R = equal payments due at the end of each compound period, n times a year,
P =Principal amount,
i =interest rate as compounded n times a year,
L = life of investment (in years),
S = Salvage value, in most cases taken as 10% of P, (Kepner, 1976).

Taxes, housing and insurance are given as a percentage of the principal as 1%, 0.75% and 0.25% respectively (ASAE, 1990). They all add up to 2% of the principal.

Operating Costs

Repair and maintenance: This is calculated from the formula

$$C_{rm} = P(RF1)\left(\frac{h}{1000}\right)^{RF2} \qquad 20$$

Where

C_{rm} =Annual Repair and maintenance costs
RF1 and RF2 are factors obtainable from D495 (ASAE, 1990),
P = Principal amount,
h = accumulated use of machine in hours.

Other costs include fuel costs, which would either be determined by use of empirical formulae or from actual field tests.

3 METHODOLOGY AND MATERIALS

3.1 Assessment of the Mouldboard and Flat-plate Furrowers

3.1.1 Spring Dynamometer Calibration

The evaluation of the performance of the mouldboard and the flat-plate furrowers was carried out before the prototype furrower design. An un-damped spring dynamometer of 49050N capacity was utilised in the pre-design furrowers' performance. The dynamometer was calibrated using a pulley of 5 tons capacity. Weights below 49050 N were used to avoid damaging both the pulley and the dynamometer.

Tractor front weights available up-to a maximum of 43948.8N, were utilised for the calibration data acquisition. Table 3.1 gave the data obtained from the calibration tests, which was a data of weight added to the spring dynamometer W_{as} (N) and the spring dynamometer reading D_{sr} (N). From Table 3.1, Fig 3.1 was plotted which was a plot of dynamometer reading against the weights added to the dynamometer. The plot gave a straight line, with a regression equation and rank correlation coefficient inscribed in the plot in Fig 3.1.

Table 3.1: Spring Dynamometer Calibration Forces

W_{as} (N)	1962	3139.2	3924	5886	7848	8927.1	10006.2	17658	21778.2
D_{sr} (N)	1962	3041.1	3924	5984.1	7848	9123.3	9908.1	18148.5	22072.5
W_{as} (N)	21876.3	21974.4	26094.6	30018.6	31980.6	33942.6	35021.7	36100.8	43948.8
D_{sr} (N)	23256	24034.5	25996.5	29920	31882.5	34089.75	35070.8	36297	44145

Using regression analysis as explained by Little and Hill (1989) the data fitted the equation inserted in Fig 3.1, which would be essential in converting dynamometer readings into actual furrowing forces.

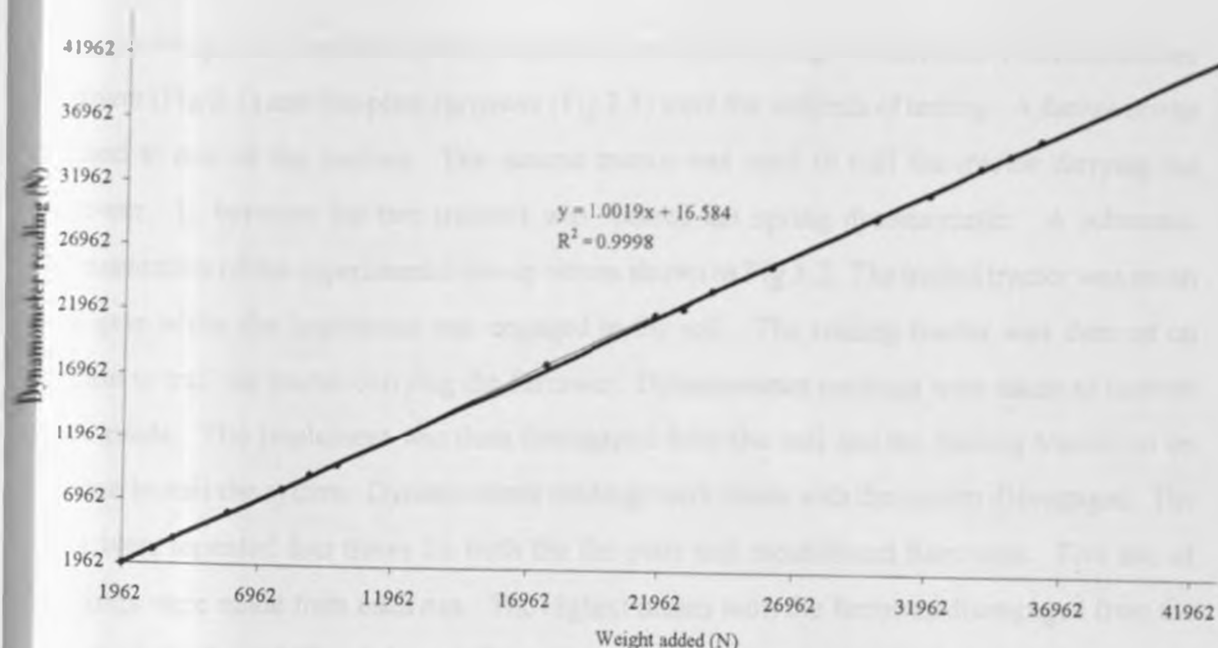

Fig 3.1: Spring Dynamometer Calibration Curve

3.1.2 The Furrowing Tests

The pre-design furrowers assessment studies carried out at the nucleus sugarcane estate farms of the company were aimed at:

(a) Comparing the performance of the existing flat-plate and mouldboard furrowers with respect to furrow formation and furrowing forces,

(b) Estimating the required furrowing forces,

(c) Developing an insight into the conditions under which furrowing was done, in relation to moisture content, bulk density, ploughing and furrowing depths, soil micro profile and the speeds of furrowing.

The tests were carried out at the F56 nucleus estate farm, which had a slope of 2%, as evaluated by Masiga (1990). The field with a slope of 2% was the only near flat field available at the time of study. Since the same orientation was used with reference to all tests, no variation in forces was expected to result due to the slope. Both the mouldboard and flat-plate furrowers were tested.

The pre-design furrower assessment tests were carried out using two tractors. The mouldboard furrower (Fig 2.1) and flat-plate furrower (Fig 2.3) were the subjects of testing. A furrower was hitched to one of the tractors. The second tractor was used to trail the tractor carrying the furrower. In between the two tractors was secured the spring dynamometer. A schematic representation of the experimental set-up was as shown in Fig 3.2. The trailed tractor was set on free gear while the implement was engaged in the soil. The trailing tractor was then set on motion to trail the tractor carrying the furrower. Dynamometer readings were taken as furrows were made. The implement was then disengaged from the soil and the trailing tractor set on motion to trail the system. Dynamometer readings were taken with the system disengaged. The tests were repeated four times for both the flat-plate and mouldboard furrowers. Five sets of readings were made from each run. The highest means with the furrower disengaged from the soil for both the uphill and down hill loading positions were subtracted from the forces at the respective loading positions with the furrower engaged in the soil, to give the actual furrowing forces.

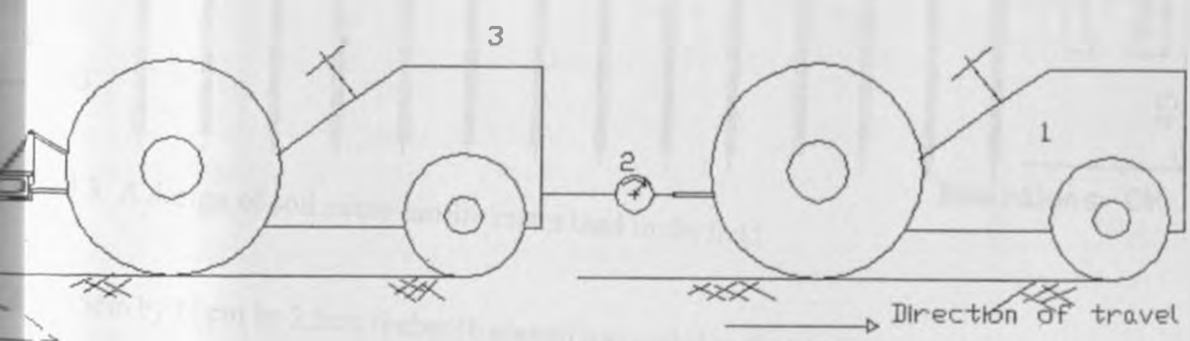

Fig 3.2 Pre-design tests experimental set-up showing tractors and the furrower arrangement. The leading tractor was on gear while the rear tractor and the furrower were trailed. 1: trailing tractor, 2: dynamometer, 3: trailed tractor, 4: furrower

A furrow micro-profile metre (Fig 3.3) was developed for soil micro-profile measurement. The material used in the development included: -

a) two planks of timber of 1.5m by 8cm by 2.5cm each,

b) two planks of timber of 15cm by 10cm by 2.5cm,

c) Two planks of timber of 10cm by 4cm by 2.5cm,

d) Fourteen wooden pins each 45cm long and 1.25cm diameter with tops of 0.5cm length and 1.3cm diameter,

e) Three bolts of 1.25cm diameter and 6cm length, with each carrying a wing nut.

Two pieces of timber 1.5m long were nailed together into a timber structure of 1.5m by 8cm by 5cm. Fourteen through holes were drilled for 1.25cm bolts at a distance of 10cm from each other, starting from one end along the joining line. On the broad surface of the structure, three equidistant through holes for 1.25cm bolts were drilled with centre-line bisecting the surface.

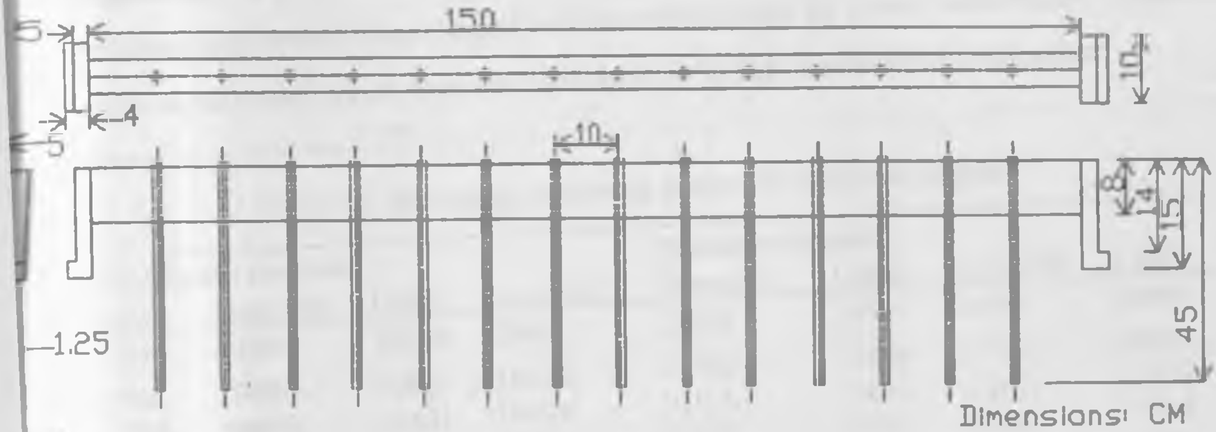

Fig 3.3: A design of soil micro-profile metre used in the field

The 15cm by 10cm by 2.5cm timber (b above) was nailed to the 10cm by 4cm by 2.5cm timber in (c) above) such that the 10cm lengths of the two planks formed a right angled edge, to make a one end stand. The other remaining pieces (in (b) and (c) above) were similarly joined to make a mirror image of the stand already made, which would be the opposite end stand. Each of the two stands above were longitudinally bisected by a vertical line into two equal parts. The timber structure of 1.5m by 8cm by 5cm (a, above) was secured to the stands such that the line of their joint was in line with the line bisecting the stand. Only one of the long timber planks (1.5m x 8cm x 2.5cm) was nailed to the stands. The 6cm long bolts were fitted in the three holes and the pins supporting the 1.5m by 8cm by 5cm structure were removed, such that one timber plank was supported to the other by the bolts.

Once the furrower made a furrow, the micro-profile metre was placed across the furrow. The nuts were loosened slightly, then the metre was tapped slightly to allow the depth pins to drop and take the shape of the furrow. The nuts were tightened to make the grip on the rods firm. The furrow micro-profile readings were obtained by measuring the depth of depth pins across the furrow. Once plotted the depth pins readings gave the variation of the furrow depth across the furrow, which would be a measure of the furrow micro-profile. Four sets of readings were taken per furrow. The mean of each point was then calculated and used to plot a graph of the profile.

3.1.3 Pre-design Furrowers Assessment Tests and Findings

The pre-design test results, which were as in Tables 3.2 to 3.4, were discussed under the methodology as they preceded the design. They were a pre-requisite to the design and were considered appropriate when merged with the methodology for flow of information. From the results, the downhill forces were not considered for design for the following reasons: -

Table 3.2: Pre-design furrowing forces (N): Furrower engaged

Mouldboard furrower				Flat-plate furrower			
Uphill	Downhill	Uphill	Downhill	Downhill	Uphill	Downhill	Uphill
23544	23544	22504	20601	22504	20601	21582	20601
22504	19620	20601	18658	21582	17658	21533	19620
21533	18658	21631	19620	21533	19620	22073	17658
22504	20601	21582	20601	22073	17734	22504	17734
21533	18658	21631	18658	21582	17658	21582	20601

Table 3.3: Pre-design furrowing forces (N): Furrower disengaged

Mouldboard				Flat Plate			
Downhill	Uphill	Downhill	Uphill	Downhill	Uphill	Downhill	Uphill
3924	5886	1962	1962	981	3924	3924	3924
2943	6376.2	2943	3924	1962	5886	981	5886
2943	3924	3924	2943	981	5886	981	3924
3924	7357.5	3924	3435.4	981	7848	1962	3924

(a) In draft measurements, a trailed tractor rolled freely without engaging a gear. Where there was a slight slope, the trailed tractor had a tendency to accelerate in rolling due to gravity. To reduce this effect, its brakes were applied when the tendency was noted. This resulted in high inertial forces on the trailing tractor and hence high dynamometer readings. Where such a tendency was noted, the forces were disregarded.

(b) Forces at the engaged position on the downhill motion were low, due to the free rolling of the tractor. Free rolling at the engaged position was less than the free rolling at the disengaged position, due to the effect of the inertia of the engaged furrower. The difference would thus be misleading.

Table 3.4: Net pre-design test forces (N)

Mouldboard furrower				Flat plate furrower			
Uphill	Downhill	Uphill	Downhill	Downhill	Uphill	Downhill	Uphill
17658	20201	16618	17258	16618	18639	15696	18639
16618	16277	14715	15315	15696	15696	15647	17658
15647	15315	15745	16277	15647	17658	16187	15696
16618	17258	15696	17258	16187	15772	16618	15772
15647	15315	15745	15315	15696	15696	15696	18639

Analysis of Variance (ANOVA) was carried out on the forces to find out whether there was any significant difference in the forces made by a particular furrower, and among the forces made by different furrowers. Table 3.5 gave the sample calculations to obtain the ANOVA table.

Table 3.5: Calculations leading to ANOVA

	Mouldboard Furrower				Flat Plate Furrower				Totals
	Uphill	Downhill	Uphill	Downhill	Downhill	Uphill	Downhill	Uphill	
	17658	20201	16618	17258	16618	18639	15696	18639	141327
	16618	16277	14715	15315	15696	15696	15647	17658	127622
	15647	15315	15745	16277	15647	17658	16187	15696	128172
	16618	17258	15696	17258	16187	15772	16618	15772	131179
	15647	15315	15745	15315	15696	15696	15696	18639	127749
Totals	82188	84366	78519	84123	79844	83461	79844	86404	656049

The following terms were applied in the analysis of variance

B_j=sums of the forces (N) in the columns in Table 3.1.5 (82188, 84366...86404),

T_i= sums of the forces (N) in the rows in Table 3.1.5 (141327, 127622...127749),

G=Total sum of all forces (N) in Table 3.1.5 (= 656049)

y_{ij}=the individual forces (N) within the table (17658, 20201..18639),

Σ=summation, n_t= number of blocks (columns) in Table 3.5 (=8),

n_b= number of rows in Table 3.5 (=5).

The following computations were obtained for the ANOVA

$\Sigma\Sigma(y_{ij})^2$=10812236871, $\Sigma(B_j)^2$ = 53848945999, $\Sigma(T_i)^2$ =86216494439

Total sum of squares (TSS) was given by

$$y_{ij}^2 - G^2 = 552229610.975 \qquad 21$$

Sum of squares due to blocks (SSB) (columns) was given by

$$\frac{(B_j^2)}{n_b} - \frac{G^2}{n} = 9781939.775 \qquad 22$$

Sum of squares due to treatments (SST) or furrowers (rows) was given by

$$\frac{\Sigma(T_i^2)}{n_t} - \frac{G^2}{n} = 17054544.85 \qquad 23$$

Now statistical total sum of squares, TSS was given by

$$TSS = SSB + SST + ESS \qquad 24$$

Where ESS is the sum of squares due to error. Substituting the above values, ESS was evaluated as 25393126.35. Table 3.6 was evaluated as the ANOVA table for these forces.

Table 3.6: ANOVA

Source of Variation	Df	SS	MS	F_{ratio}	F_{crit} 5%	1%
Due to treatment	4	17054544.85	4263636	4.701	2.71	4.07
Due to blocks	7	9781939.775	1397420	1.541	2.36	3.36
Due to error	28	25393126.35	906897.4			
Total	39					

There was no enough evidence to conclude that there was significant difference between the furrowing forces within the blocks since $F_{crit\,(5\%)}$ and $F_{crit\,(1\%)}$ were greater than the F_{ratio} . However there was enough evidence to conclude that there was a highly significant differences between the furrowing forces among the furrowers since $F_{crit\,(5\%)}$ and $F_{crit\,(1\%)}$ were less than the F_{ratio}. The highest measured force was 23544 N on downhill motion. These forces were considered inappropriate for design purposes. The forces considered for the design were steady state forces. The force identified for design was the difference between the highest uphill force with the furrower engaged (neglecting the inertial forces stated above), which was 22504 N, and the highest mean of the forces on the uphill motion with furrower disengaged, which was 5886 N. The difference was 16618 N, a half of which was 8309 N and was considered as the force acting on a single furrower bottom. The regression equation inscribed in Fig 3.1 was applied to convert this force to actual force as follows

$$y = 1.0019x + 16.584 = 1.0019(8309) + 16.584 = 8341.37N \qquad 25$$

Table 3.7 gave the values of the means of pre-design furrow readings as taken during the preliminary assessment of the performance of the furrowers. Actual readings were as given in Table A1 and Table A2 of Appendix 1. From Table 3.7, Fig 3.4 was plotted. The mouldboard furrower had a mean maximum depth of 24 cm while the flat-plate furrower had a mean maximum depth of 19.8cm. The flat-plate furrower presented depths below the expected 22cm furrowing depths.

Table 3.7: Means of pre-design furrow relief dimensions (cm)

Distance Across Furrow	Flat-plate	Mouldboard
10	-2.2	-1.5
20	-3	-3
30	-0.7	-4.1
40	-2.9	-7
50	-6.2	-12.8
60	-13.1	-19
70	-16.4	-24
80	-19.8	-18.2
90	-18.2	-11
100	-13.4	-7.6
110	-13.4	-2.3
120	-1.2	-1.2
130	-1.4	-1
140	-2.2	-1.2

Fig 3.4 demonstrated soil micro-profile curves for mouldboard and flat-plate furrows. From Fig 3.4, the mouldboard furrow curve projected below the flat-plate furrow curve, which indicated it made deeper furrows than the flat-plate furrows. Mouldboard furrow curve tails development indicated that the furrower threw soil further than flat-plate furrower did.

The flat-plate furrows, though shallow, were wide which could imply that the wings were sweeping a shallow soil depth, while the knife went deep into the soil. The knife could not however feed the soil to the wings. Apart from the low depth of soils swept, the distance of throw for the flat-plate was low. This could be attributed to the scouring of soil over mouldboard surface compared to flat-plate surface. Its shape and the rough surface characteristics hindered soil movement over the flat-plate, hence it's bulldozing of soils. Perhaps high draft requirement on the flat-plate resulted from poor soil scouring and bulldozing.

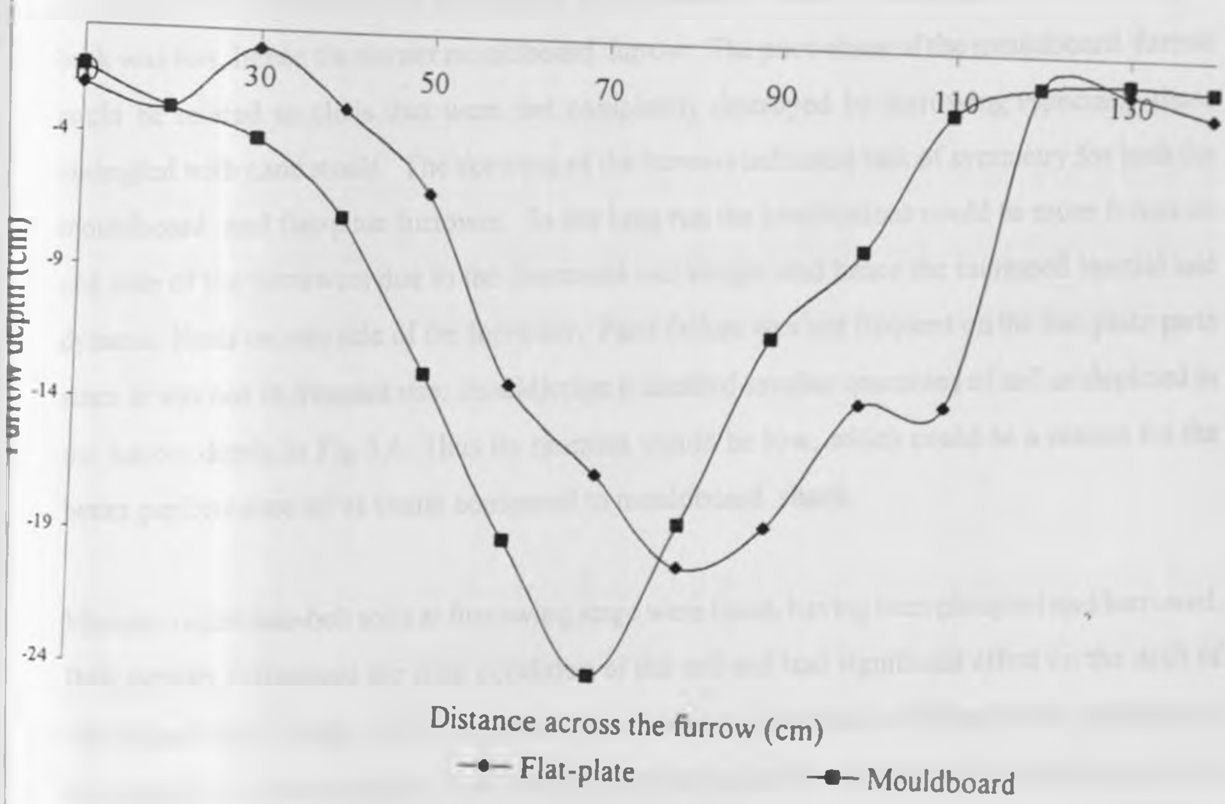

Fig 3.4: Pre-design Soil Micro-profile Curves

The furrow relief curves lacked symmetry for both mouldboard and flat-plate which could have indicated lack of symmetry about the shank centre line for the mouldboard and flat-plate furrowers. Imbalanced forces must have been experienced on the sides of the furrower. This was perhaps the reason for the rapid bending and twisting of the mouldboard shank, a common mode of failure for the mouldboard shank. The flat-plate furrow was narrow and shallower than the mouldboard furrow, which implied that less soil was carried by the flat-plate. The quantity of soils dictated the magnitude of inertial and dynamic loads induced on the surface of the furrower. Thus forces induced on the flat-plate were less than forces induced on the mouldboard, and hence the more damage on the mouldboard shank relative to the flat-plate shank.

From Fig 3.4, mouldboard curve was skewed to the left, while flat-plate curve was skewed to the right. From the manner in which the mouldboard and flat-plate curve tails were shaped, mouldboard threw soils far off beyond the 1.5m distance. Possibly mouldboard furrow soil flow back was low, hence the deeper mouldboard furrow. The poor shape of the mouldboard furrow could be related to clods that were not completely destroyed by harrowing especially those entangled with cane stools. The skewing of the furrows indicated lack of symmetry for both the mouldboard and flat-plate furrower. In the long run the implications could be more forces on one side of the furrowers due to the increased soil weight and hence the increased inertial and dynamic loads on one side of the furrower. Parts failure was not frequent on the flat-plate parts since it was not in frequent use. In addiction it handled smaller quantities of soil as depicted in the furrow depth in Fig 3.4. Thus its moment would be low, which could be a reason for the better performance of its shank compared to mouldboard shank.

Mumias sugarcane-belt soils at furrowing stage were loose, having been ploughed and harrowed. Bulk density influenced the final condition of the soil and had significant effect on the draft of any tillage tool. Ndugo (1991) reported Rhozikhovs explanation on the use of the gamma rays attenuation for measurement of soil density with the principle that light soils would allow more rays to pass through. The handling of apparatus could be risky and costly and was unavailable at the time of this study.

A simpler method is gravimetric technique, in which soil samples are collected in containers of known weights and dimensions, and weighed when wet. They are oven dried at 105^{0}C for 24 hours and dry weights taken. The dry weight of soil samples, taken as a ratio of the volume of the container gives the bulk density of the soil sample. The method is simple, inexpensive and accurate for properly collected soil samples. The disadvantage is that harrowed soil is highly disturbed during sample collection. The simplicity of the method, and availability of material at the time of study, made it superior over other methods and was used in this study for measurement of the bulk density and moisture content.

Liu and Evett (1984) explained a simpler procedure in which a sample is placed in a container of known weight and weight of the container and the soil sample taken. The samples are oven dried and weights of the soil and the container taken, from which the moisture content is evaluated. However, the mass could take long before achieving a constant weight, in addition to oxidising the organic matter and results in loss of soil constituents. Oven-drying soil for 18 to 24 hours at 105°C would be adequate. The gravimetric technique is employed both in the measurement of bulk density and moisture content. Once dry and wet weights are taken, the difference between the wet and the dry weights expressed as a percentage of the dry weight gives the moisture content. The core sampler technique was adopted here.

Table 3.8 gave the values of the moisture content and bulk density four sample taken. From Table 3.8, the bulk density of the soil lied between1.43 g/cm^3 and 1.88 g/cm^3 with a mean bulk density of 1.68 g/cm^3. The soil moisture content lied between 13.6% and 19%, with mean moisture content of 16.8 %. These soils were dry and pulverised, resulting in soil flow back. They would require further pushing on furrow crest to be more stable.

Table 3.8: Bulk density and moisture content for pre-design tests soils

Sample Number	Dry Bulk Density g/cm^3	% (Dry Basis) Moisture Content
1	1.57	19
2	1.68	17.3
3	1.88	13.6
4	1.43	16.3
5	1.85	17.7

3.1.4: Basic Pre-design Conclusions

The following conclusions were drawn based on the pre-design tests and analysis:-

The mouldboard furrower had a mean maximum depth of 24cm, which was within the expected 22-24cm of furrowing. The flat-plate furrower had an average furrowing depth of 19.8cm, which fell short of the furrowing depths.

a) The design force was established as 8347.86N per furrower bottom.

b) The furrowing forces did demonstrate significant difference among the two furrowers at 5% level of significance. However, there was no significant difference between the furrowing forces for furrows made by a particular furrower.

3.2 Prototype Furrower and Its Design

3.2.1 Background Information

The performance of a tillage tool is dependent on various factors, which are grouped into three major categories as follows:

a) Tool-Tractor Interaction Factors: Of interest would be slip, compaction, sinkage and draft capability, related to tractor weight, implement weight, draft requirements, soil moisture content, bulk density and soil type among other factors. Implement weight and draft requirements would dictate the size of tractor to be matched with the implement designed.

b) Soil-Tool Interaction Factors: These would include soil bulk density, soil texture, moisture content, speed, depth and width of operation. Of interest are depth and width of operation, as the rest are either soil factors or implement operation factors.

c) Tool Factors: These would include tool geometry and dimensional relationships.

Fig 3.5 illustrates in a flow diagram form the design process adopted in this study. It demonstrates a chart that is specific for the prototype design. From the start of the design to the left side of the chart would be determination of soil tool parameters. These would include tillage forces, operating depth, moisture content and soil bulk density among others.

On the right hand side would be the machine design parameters such as the material strength in tension and shear under various loads. The design theories and their applicability in design would be necessary. Below the first decision box on the right hand side, an action is depicted, where the design would take place. The design would involve use of the soil-tool parameters and the machine design parameters to design the various components of the furrower. The furrower design would be followed by its fabrication, assembly, performance evaluation, and the results and conclusions. So far the process has gone up-to measurement of soil-tool parameters and forces useful in the design shown on the left side of Fig 3.5. The right side of Fig 3.5, up-to tool design was incorporated in and discussed under structural design (section 3.2.2).

3.2.2 Structural Design

Fig A.01 in the Appendices indicates the various parts of the implements that were to be designed. The shank, bolts, the mast and the angle irons, which had failed frequently in the previously unprofessionally modified furrower design, would be redesigned structurally. Several theories developed by different authors were considered in the design. Mahadevan and Reddy (1987) recommended values of factor of safety (N_y), for different loading conditions that could be used in the design of the machine components (see Table 3.9).

Table 3.9: Recommended Values of N_y

Material	Steady loading	Varying loading
Steel	4	8
Wrought iron	4	7
Soft metals and alloys	6	9
Cast iron	5 to 6	8 to 12

Source: Mahadevan and Reddy (1987)

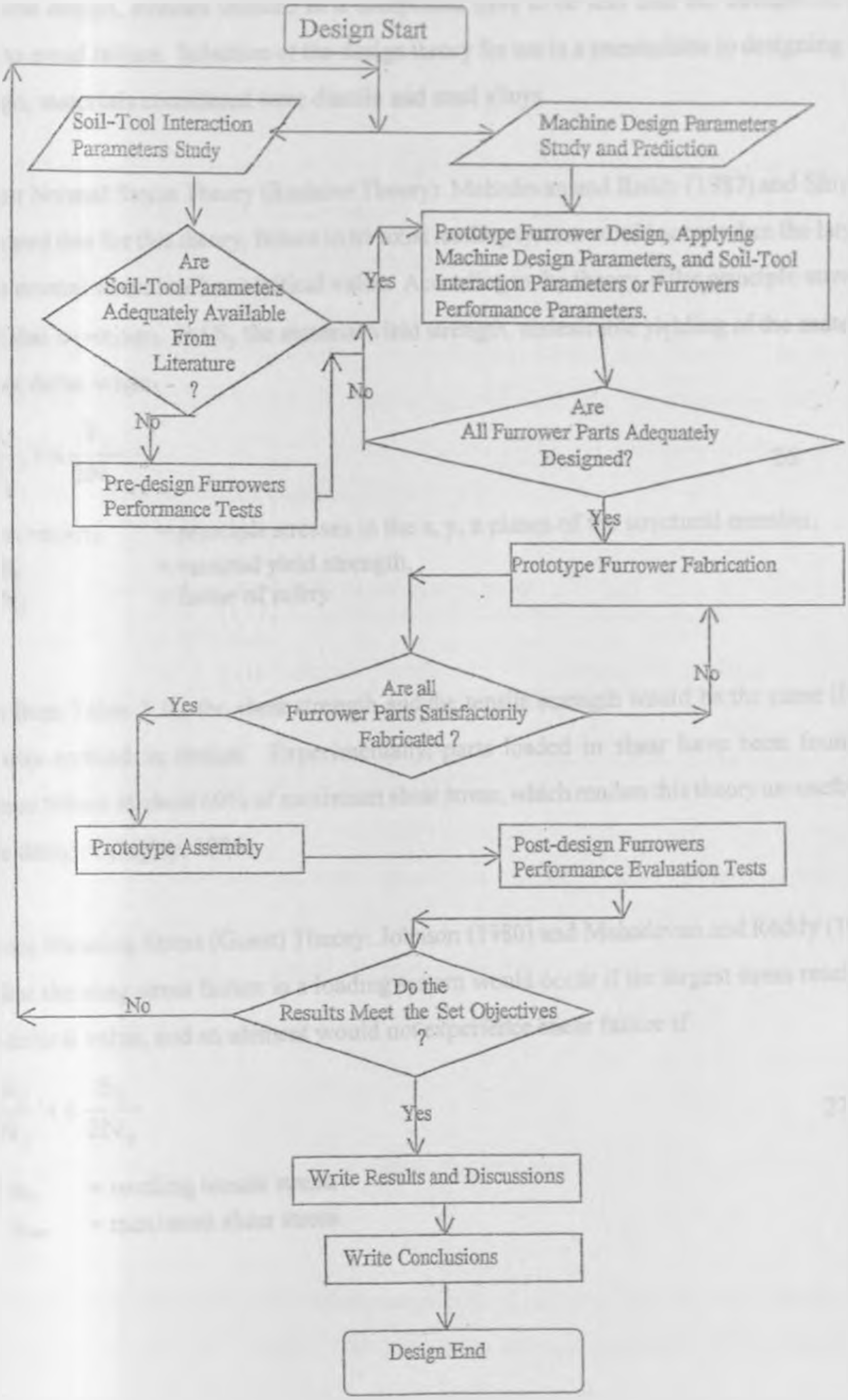

Fig 3.5: Approach adopted in prototype design

In structural design, stresses induced in a component have to be less than the strength of the material to avoid failure. Selection of the design theory for use is a prerequisite to designing. In this design, materials considered were ductile and steel alloys.

Maximum Normal Stress Theory (Rankine Theory): Mahadevan and Reddy (1987) and Shigley (1986) stated that for this theory, failure in tri-axial loading system would occur when the largest principle normal stress reaches a critical value. According to the theory, if the principle stresses are such that $\sigma_1>\sigma_2>\sigma_3$, and S_y the material yield strength, undesirable yielding of the material would not occur when

$$\sigma_1 = \frac{S_y}{N_y}, \tau \leq \frac{S_y}{2N_y} \qquad 26$$

Where $\sigma_1>\sigma_2>\sigma_3$ = principle stresses in the x, y, z planes of the structural member,
S_y = material yield strength,
N_y = factor of safety

As seen from Table 3.10, the shear strength and the tensile strength would be the same if this theory was applied in design. Experimentally, parts loaded in shear have been found to experience failure at about 60% of maximum shear stress, which renders this theory un-useful for accurate design (Shigley, 1986).

Maximum Shearing Stress (Guest) Theory: Johnson (1980) and Mahadevan and Reddy (1987) stated that shearing stress failure in a loading system would occur if the largest stress reaches a certain critical value, and an element would not experience shear failure if

$$\sigma_w \leq \frac{S_y}{N_y}, \tau \leq \frac{S_y}{2N_y} \qquad 27$$

Where σ_ω = working tensile stress,
τ_{max} = maximum shear stress.

Equation 27 indicates that

$$\tau_{max} = \frac{\sigma_w}{2} \quad 28$$

Equation 28 gave the maximum shear stress that could be used in design for shear resistance of various furrower components. Guests theory is safer to use than the Rankine theory as the stresses predicted would be lower than the experimental failure stresses.

Distortion Energy Theory or Shear Energy Theory (Henckey-Von Mises Theory): The theory is considered the best for ductile material, having replaced the Saint Venants theory (Maximum strain-energy theorem), which is out-dated (Shigley, 1986). A summary of the equations governing these theories was tabulated as in Table 3.10.

Table 3.10: Comparison of theories of failure

Type of Load	Theories of Failure			
	Rankine	Saint Venant	Guests'	Henckey-Von Mises
Tension	$\sigma = S_y$	$\sigma = S_y$	$\sigma = S_y$	$\sigma = S_y$
Shear	$\tau = S_y$	$\tau = 0.77S_y$	$\tau = 0.5S_y$	$\tau = 0.577S_y$

Source: Mahadevan and Reddy (1987)

Four categories of uni-axial stresses exist, namely bending stress, axial stress, torsional shear stress and transverse shear stress. For a cantilever of depth d (mm) with a rectangular cross-sectional area A (mm) with a concentrated transverse load F (N) acting close to the free end (Fig 3.6), according to Shigley (1986), the shear stress τ (Nmm^{-2}) at a depth y_1 is

$$\tau = \frac{F}{2I_x}\left(\frac{d^2}{4} - y_1^2\right) \quad 29$$

and the maximum shear stress τ_{max} occurs when y_1 is zero and is

$$\tau_{max} = \frac{3F}{2A} \quad 30$$

Given F (which was measured), and with the knowledge of τ_{max} (available in design handbooks), evaluation of A was possible. Shigley (1986) stated that the maximum bending stress σ_b caused by a bending moment M about the fixed end of a structural member of length L, breadth b and depth d occurs at the free end and would be

$$\sigma_b = \frac{My}{I} \qquad 31$$

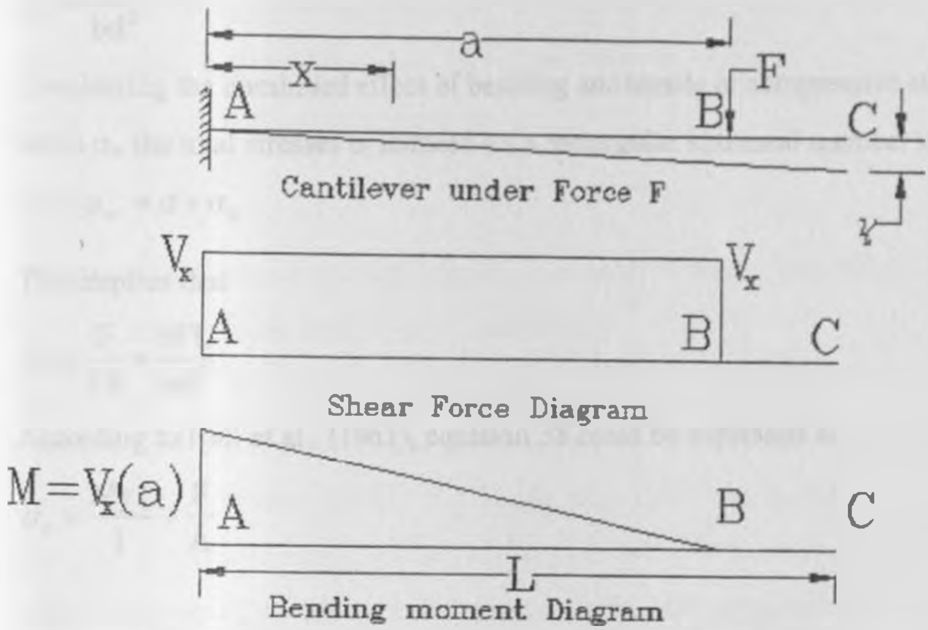

Fig 3.6: Transverse Loads and their Bending Moments on a Cantilever:

At a distance x from the point of support, the shear force (V_x)= force (F), and between points B and C, the shear force is zero. At a distance x from the point of support, the bending moment $M=V_x(a-x)$. The moment M due to force F acting at length L from the pivot of the shank is

$$M = -FL \qquad 32$$

The second moment of area I of a structural member with a depth d and a breadth b, is

$$I = \frac{bd^3}{12} \qquad 33$$

The section modulus Z of the structural member could replace I as

$$Z = \frac{M}{\sigma_b} \qquad 34$$

Where σ_b is the bending stress induced by the bending moment M. The value of Z for a rectangular structural member is given by.

$$Z = \frac{bd^2}{6} \quad 35$$

Thus the bending stress is given by

$$\sigma_b = \frac{6FL}{bd^2} \quad 36$$

Considering the combined effect of bending and tensile or compressive stress σ_s and working stress σ_w the total stresses σ_t induced on a rectangular structural member would be

$$\sigma_t = \sigma_w = \sigma + \sigma_b \quad 37$$

This implies that

$$\sigma_t = \frac{F}{Lb} + \frac{6FL}{bd^2} \quad 38$$

According to Hall et al., (1961), equation 38 could be expressed as

$$\sigma_t = \frac{My_1}{I} + \frac{F}{A} \quad 39$$

Consider a cantilever with a shear modulus of rigidity E_r and a torsional modulus of rigidity G_r carrying a load F at the free end. The total deflection υ_L which would include deflection due to shear, according to Case and Chilver (1986), would be given by

$$\nu_L = \frac{4FL^3}{E_r bd^3}\left[1 + \frac{3E_r}{8G_r}\left(\frac{d}{L}\right)^2\right] \quad 40$$

From equation 31 to 40, the values of z and υ_L for the shank could be evaluated if all other factors were known. For a shank made of 070M20 British Standards (BS) steel, a design yield stress S_y of 200 N/mm^2 (Shigley, 1986) was established. Taking N_y for steady loading as 4 according to Mahadevan and Reddy (1987) and increasing it to 6 to take care of yielding by bearing, the working stress σ_w, from Henckey-Von Mises theory became

$$\sigma_w = \frac{\sigma_y}{N_y} = \frac{200}{6} = 33.33Nmm^{-2} \quad 41$$

Shearing stresses resulted from the force acting on the furrower. By Henckey-Von Mises theory (Table 3.10),

$$\tau_w = 0.577\sigma_w = (0.577)(33.33) = 19.25Nmm^{-2} \quad 42$$

From equation 38, (F was taken as 8341.37 N, as evaluated from pre-design tests) and τ_{max}, the area of the shank became 433.32mm^2 . Using the equation

$$A = bd \qquad 43$$

and taking 25 mm, the design thickness of the mouldboard shank, as the design thickness for the present shank, d was evaluated as 17.33 mm. This value was unrealistically low for the shank depth. The tensile stress was given by

$$\sigma = \frac{F}{A} = \frac{8341.37}{25L} \qquad 44$$

Taking the tensile stress as 33.33 Nmm^{-2}, L became 10.01mm. This resulting length of the shank was similarly unrealistically low in shank design.

Consider the flow of pulverised homogeneous soil past a surface to be analogous to the flow of a fluid past the same surface. It is possible to relate mechanics of fluid flow to mechanics of soil flow past the soil-engaging surface, which in this case is the mouldboard. Francis and Minton (1984) stated that the mean velocity of flow of a fluid through a stream is concentrated at a mean height of 0.37 of the height above the datum. Douglas (1985) stated that the force of a fluid on a curved surface would be concentrated at a third of the effective height of the projection of the surface on a vertical plane. At high speeds of operation, typical of furrowing, homogeneous soils would behave like fluids.

The height of the lower links to attain a horizontal movement of the mouldboard was measured as 700 mm above ground. The draft was assumed concentrated at one-third of the height of the mouldboard, which was 153.3 mm above the bottom according to Douglas (1985). Subtracting 153 mm, which was the height of the point of concentration of draft above the ground, the moment arm was 547 mm. Thus the moment M became

$$M = (8341.37)(547) = 4562729.99\text{Nmm} \qquad 45$$

which gave the value of z as

$$Z = \frac{bd^2}{6} = \frac{M}{\sigma_w} = \frac{4562729.99}{33.33} = 136895.596\text{mm}^3 \qquad 46$$

Since b was chosen as 25 mm, d became 181.25 mm, which was a reasonable value in the design.

For combined bending and tensile failure, total stress was given by

$$\sigma_t = \sigma_b + \sigma_s = \frac{6FL}{bd^2} + \frac{F}{Lb} \qquad 47$$

Since the value of b was taken as 25 mm, taking the value of σ_t as 33.33Nmm^{-2} gave the value of d as 182.94 mm. The design value of d was taken as 200 mm which was the actual design depth for the existing shank.

Mahadevan and Reddy (1987), gave the values of E_r and G_r for carbon steel as 202X10^3 N/mm^2 and 78.5 X 10^3 N/mm^2. Manipulating equation 40 gave the deflection as 1.52X10^{-1}mm. The percentage allowable elongation according to Shigley (1986) was 20% for a length L_o given by

$$L_o = 5.65A^{-\frac{1}{2}} \qquad 48$$

The cross-section for this deformation was evaluated as 54.93 mm^2. The shank cross-section would have an area of 25 by 200 (=5000) mm^2. Thus the shank deflection would not exceed the design requirements.

Since the relationship between the force F on a bolt of diameter d and cross sectional area A and the induced shear stress τ is

$$\tau = \frac{\text{Shear Force (F)}}{\text{Area (A)}} \frac{F}{\frac{\pi d^2}{4}} \qquad 49$$

then the bolt diameter d is given by

$$d = \sqrt{4\frac{F}{\pi \tau}} \qquad 50$$

The failure of the bolt could be by its bending or the bending of the bolted member. According to Shigley and Mischke (1989), the bending moment M acting on a bolting member of thickness t is approximately given by

$$M = \frac{Ft}{2} \qquad 51$$

The bending stress is given by

$$\sigma = \frac{M}{z} = \frac{Ft}{2Z} \quad 52$$

Where z = bolting member section modulus

= Stress induced in the bolting members due to force F.

Equation 52 is rarely used in design (Shigley, 1986). The effects of bending would be reduced by stepping up the safety factor (N_y). N_y was taken as 4, for steady loading (Mahadevan and Reddy, 1987). The above theory was used in the design of the bolts.

The force on the shear bolt was evaluated assuming the shank was pivoted at the pivot bolt (position K, Fig 3.7). Fig 3.7 represented schematically the shank and the forces acting on it, which would be supported by the shear bolt.

The vertical force V_f was taken as 30% of the draft D, (Kepner et al.,1976). The weight carried by the shear bolt would be the weight of the furrower less the weight of the mast, box section and the angle sections. Assuming an iron (or iron alloys) density of $7810kgm^{-3}$, the mass became 116.53kg per furrower bottom. The weight per furrower bottom became 1143.16N. The values of lengths in Fig 3.7 were, L_j =532mm, L_k =200mm, x_1 =141mm, x_2 =28mm, x_3 =150mm, x_4 =20mm, W_f = 1143.16N, V_f =2502.41N and D=8341.37N. All the possible equations of forces in Fig 3.7 were obtained as in equations vii to ix in Appendix 2. There were three equations which had four unknowns. For solutions of the equations, some assumptions would be necessary. When the tractor-furrower system was in operation, the support bolt was assumed to carry all the vertical forces, which included weight and vertical forces due to draft, since it was higher in position than the shear bolt. Thus V_j was zero. By Newton's third law of motion,

$$V_k = W_f + V_f = 1143.16 + 2502.41 = 3645.57N \quad 53$$

and

$$F_j + F_k + D = 0 \quad 54$$

Taking moments about point K, then

$$D(L_k + L_j) + V_f(x_1 + x_3) + W_f(x_3 + x_2) + F_j(L_k) = 0 \quad 55$$

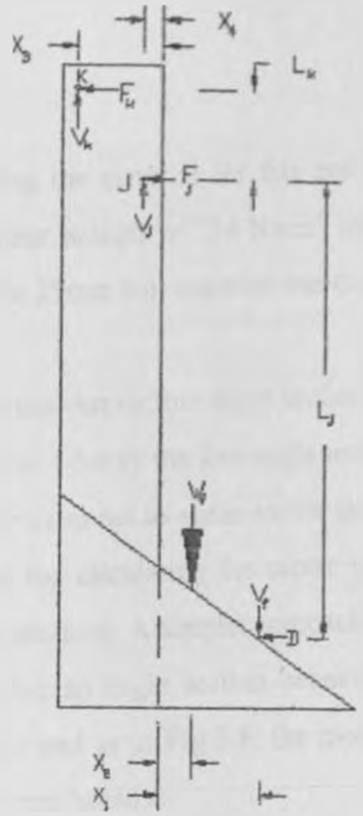

Fig 3.7: Diagrammatic representation of forces acting on the shank and implement

Substituting for the values in equation 55 gave the value of F_j as –35187.84N, the negative sign implying that the force was acting in the opposite direction (from that shown in Fig 3.7). Considering SAE 1045 Annealed carbon steel material with a shear strength of 180 N/mm^2 for medium carbon steel bolt design as given by Mahadevan and Reddy (1986), the size of bolt to resist shear failure under 35187.84N load was calculated as

$$\frac{\text{Force F}}{\text{Area A}} = \frac{35187.84}{\pi \frac{d^2}{4}} = 180\text{Nmm}^{-2} \qquad 56$$

The value of d was evaluated as 15.78mm. For the safety of the furrower, the maximum size of the shear bolt from the material was taken as 16mm

A pivot bolt stronger than the shear bolt was required to support the operation. As stated by Mahadevan and Reddy (1987), N_y was taken as 4 for steady loading. Substituting for F_j and D in equation 54, F_k was obtained as 26846.47N. The pivot bolt was under two forces V_k (equation 53) and F_k, whose resultant R_k was calculated as

$$R_k = \sqrt{F_k^2 + V_k^2} \qquad 57$$

and became 27090.80N. Taking the material for this bolt as S.A.E 10.25 annealed water quenched carbon steel with a shear strength of 234 Nmm^{-2} (Mahadevan and Reddy, 1987), the diameter became 24.28mm. The 25mm bolt material was considered adequate for pivot bolt.

The shank was supported to the tool-bar by four angle sections (Fig A.01 in Appendix 3). It was pivoted at points D and E to the tool-bar by the four angle sections. The angle sections had to be stronger than the shear bolt for them not to shear earlier than the shear bolt. Mahadevan and Reddy (1986) stated formulae for calculating the centre of mass y, section modulus z and moment of inertia I for various sections. A simpler approach as stated below was used to design the support angle sections. For an angle section behaving as a cantilever and carrying a concentrated load F at the free end as in Fig 3.8, the moment at the free end was given by equation 32 and the induced stress became

$$\sigma = \frac{M}{Z} = \frac{My}{I} = \frac{FLy}{I} \qquad 58$$

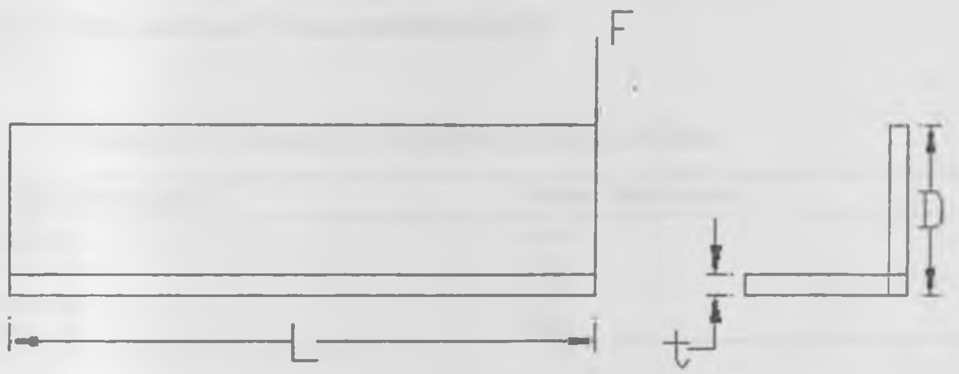

Fig 3.8: Loads on angle sections

From equation 58, the value of Z would be evaluated. According to Kepner et al., (1976), the vertical force on a mouldboard surface was 30% of draft. The draft on a single bottom furrower was 8341.37N. The vertical force was evaluated as 2502.41N. The weight of the furrower acting on the angle sections was its weight less the weight of the box section, the angle sections and the mast. This weight per unit furrower bottom was evaluated from Table 3.11 as 1235.72N. The forces were taken as in Fig 3.8 and values in Table 3.11 were evaluated indicating loads on the angle sections and the corresponding moments.

Table 3.11: Loads on angle sections

Force	Draft	Suction	Weight	Total moment	Moment on one upper angle section
Magnitude(N)	8341.375	2502.41	1235.72		
Moment Arm(cm)	67.7	15	2.8		
Moment (Ncm)	564710.82	37536.15	3460.02	605707.094	302853.05

Using 0.70M20 BS steel with a yield strength of 200 N/mm^2 (Shigley, 1986), and taking N_y as 4 for steady loading (Mahadevan and Reddy, 1987), the working stress became 5000 N/cm^2. The size of the section was calculated as

$$z = \frac{M}{\sigma_w} = \frac{302853.047\ \text{Ncm}}{5000\ \text{N}/\text{cm}^2} = 60.57\ \text{cm}^3 \qquad 59$$

Kraut (1984) and Shigley (1987) gave summarised tabulated values of z for various sizes of angle sections which could be used to obtain the values of B, D and d from the values of z as shown in Table 3.12. These were used in angle sections design.

Table 3.12: Values of Z for Sizes of Angle Sections

Size of angle Section (mm)	Section Modulus (cm^3)
152 x 102 x 9.5	54.4
127 x 127 x 15.9	63.3
127 x 127 x 12.7	51.8
150 x 150 x 10	56.9

From Table 3.12, angle section of size 127 by 127 by 15.9 mm was considered appropriate for the design. It was thus evident that the angle sections of sizes 75 by 75 by 10 mm that were in use were under-designed.

For a thin walled rectangular box with thickness t_b, depth D_b and breadth B_b as in Fig 3.9, Case and Chilver (1986) gave the section moduli for the axes shown as

$$Z_{xx} = D_b t_b (B_b + \frac{1}{3} D_b) \quad 60$$

and

$$Z_{yy} = B_b t_b (D_b + \frac{1}{3} B_b) \quad 61$$

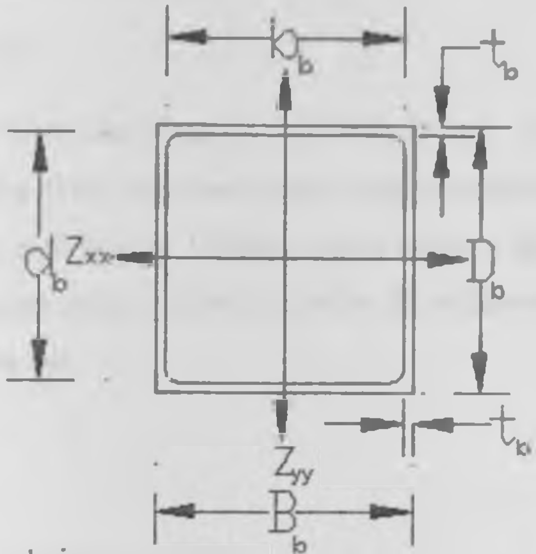

Fig 3.9: Box section in tool-carrier design

Mahadevan and Reddy (1987) gave Z values for a box section as

$$Z = \frac{(B_b D_b^3 - b_b d_b^3)}{6 D_b} \quad 62$$

Table 3.13 below summarises the calculations for the moment emanating from forces acting on the box section, which included draft, vertical force and furrower weight. The draft was 8341.37N, while the vertical force was 30% of the draft , in this case 2502.41N. The weight used in box section design was that of material supported by the box section, and was 1750.71N per furrower bottom.

Table 3.13: Loads on Box Section

Source of Moment		Lever arm (mm)	Moment (Nmm)
Force (N)	Magnitude		
Draft	16682.74	549.7	9170503.387
Suction	5004.82	185	925892.19
Weight	3501.42	28	9 8039.76
Total			10194435.34

Taking 070M20 steel with a yield strength of 200N/mm^2 (Shigley. 1986. Mahadevan and Reddy. 1987) and a factor of safety of 4 for steady loading. (Mahadevan and Reddy. 1987). available at Mumias sugar company. the working tensile stress σ_w became 50 Nmm^{-2}. Considering equations 60 and 61 and a square cross-sectioned box section.

$$Z_{yy} = Z_{zz} = D_b t_b (D_b + \frac{D_b}{3}) = \frac{4}{3} D_b^2 t_b \qquad 63$$

The value of M from Table 3.13 was given as 10194435.3Nmm. which gave Z as 203888.71mm^3. Applying equation 63 for a 6mm box section (readily available at Mumias Sugar Company), the value of D_b was evaluated as 159.6mm which could be taken as 160 mm. Considering equation 62 and a square cross-sectioned box section. D_b and d_b could replace B_b and b_b respectively. It could be shown that

$$d = D_b - 2t_b \qquad 64$$

Thus

$$Z = \frac{D_b^4 - (D_b - 2t_b)^4}{6D_b} = \frac{8(D_b^3 - 18D_b^2 + 144D_b - 432)}{D_b} \qquad 65$$

The value of Z from Table 3.13 and equation 34 was evaluated as 196908.88 mm^3. and equation 65 simplified to

$$D_b^3 - 18D_b^2 - 25342.09D_b - 432 = 0 \qquad 66$$

By iterations. equation 66 above was evaluated as 168.5mm. which could be taken as 170 mm. Thus the size of the box section was evaluated as 170 mm x 170 mm x 6 mm of 1.6m length.

Fig 3.10 shows the tractor- furrower system with the forces on it while Fig 3.11 shows a free-body diagram of the furrower and the mast with the forces acting on it. extracted from Fig 3.11. Taking moments about point G. equation 67 was obtained as

$$W_f(x_1 - x_2) - F_h h_h + V_f(x_1) + Dh_d = 0 \qquad \mathbf{67}$$

Where x_1 and x_2 were taken as in Fig 3.7. h_h was measured as 473mm. h_d was calculated assuming that the force D acts on one-third of furrower height. and the distance between G and V_f was calculated from dimensions of box section. The value of h_d was measured as 582mm.

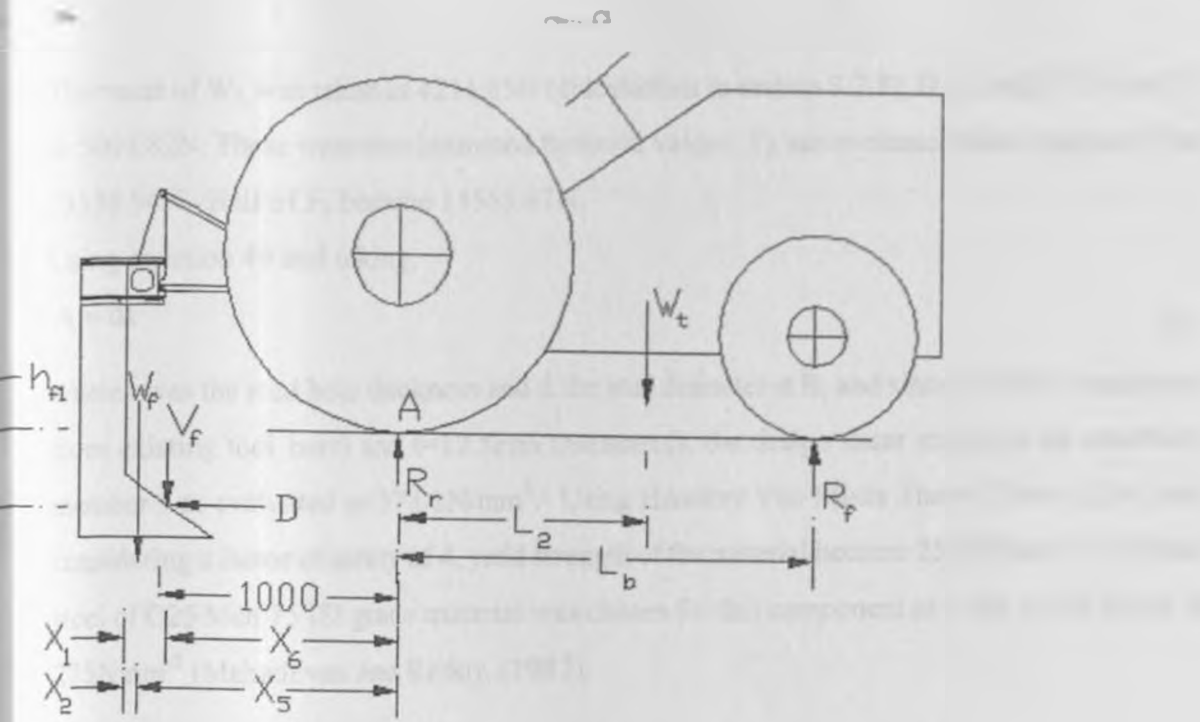

Fig 3.10: Tractor-furrower system with acting forces

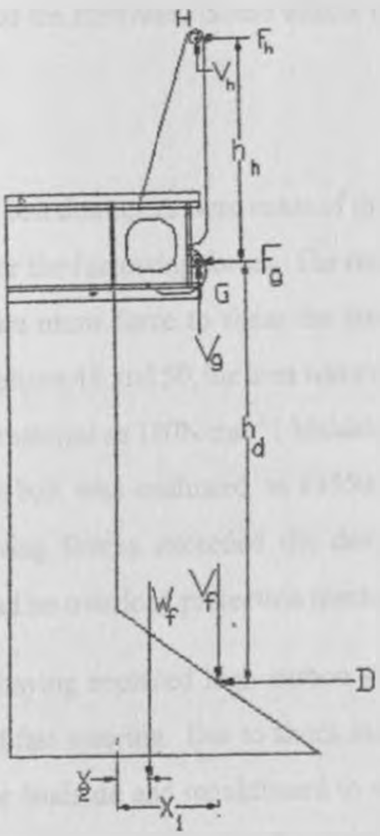

Fig 3.11: Forces on the furrower and mast

The value of W_f, was taken as 4211.05N (calculations in section 3.2.8), D as 16682.75N and V_f as 5004.82N. These were two-bottomed furrower values. F_h was evaluated from equation 67 as 23130.94N. Half of F_h became 11565.47N.

Using equation 49 and taking,

$$A = dt \qquad 68$$

where t was the stud hole thickness and d the stud diameter at B, and since d=25mm (measured from existing tool bars) and t=12.5mm (measured), the design shear stress for the structural member was evaluated as 37.01N/mm^2. Using Henckey Von Mises Theory (Table 3.10), and considering a factor of safety of 4, yield strength of the material became 256.56Nmm^{-2}. A carbon steel of C25 Man 75 ISI grade material was chosen for this component as it had a yield stress of 275Nmm^{-2} (Mahadevan and Reddy, (1987).

3.2.3 Effects of Modification of the Furrower on their Performance

Since the initial mouldboard design was reported as suitable for the furrowing operation, (MacIntyre, 1993), later modifications must have introduced changes which were unfavourable for the functional performance of the furrower. Some effects of the modifications introduced were as follows

a) The shear bolt and pivot bolt diameters were made of the same size, a change that made the shear bolt stronger for the furrowing forces. The resultant effect was that the shank yielded. It would require more force to shear the bolts. The shear bolt had 25mm diameter. Applying equations 49 and 50, the area was evaluated as 490.87 mm^2. Taking the shear strength of the material as 180N/mm^2 (Mahadevan and Reddy, 1987), the force F required to shear this bolt was evaluated as 83350.9N. The bolt could not shear immediately the furrowing forces exceeded the design forces. Thus the modified mouldboard furrower had no overload protection mechanism

b) A share of mild steel, having replaced high carbon steel, was incapable of resisting abrasion. It experienced fast wearing. Due to shock loading, it underwent bending and easily separated with the landside and mouldboard to which it was welded. The share was long, could not feed the mouldboard with soil adequately and its length made it unstable. The original frog was replaced with a short piece, which offered poor support and could not offer any reinforcement to the mouldboards. The mouldboards thus bent backwards. A reinforcing rod connecting the mouldboards behind the shank was bending while in operation. It was necessary to reinforce the mouldboards by the frog as initially intended.

c) The angle sections (irons) used in the modified mouldboard design was 75X75X10 mm. According to Kraut (1984), the section modulus of the angle sections would be $13.36X10^3$ mm^3, which would be less than the failure section modulus. The angle irons were thus bound to fail. Their failure brought about poor and loose connection of the shank to the angle irons and the tool-bar.

3.2.4 Mouldboard Design

The design of prototype soil engaging surface (mouldboard) based on the existing furrowers favoured a curved surface. This was because the curved surface had superior performance to a flat-plate. The mouldboard however had its limitations due to the noted failure inform of bending of the soil engaging surface, poor performance inform of unstable furrow formation in addition to the earlier described failures of the furrower. Equation 10 implied soil would accelerate over the surface as the radius reduced from intake to outlet. This reducing curvature from intake to outlet was considered for design as it had the following advantages: -

a) Increased angular speed of throw of soil out of the furrower, hence reducing clogging, with a possibility of improving scouring.

b) Improved distance of throw and therefore making more stable slopes.

c) Improving the rate of throw would reduce the amount of soil on the mouldboard per unit time, hence reducing the vertical force on the furrower.

Scouring, soil flow-back and soil overflow were important aspects of mouldboard design consideration in this study. The average maximum depth of the furrow was 24cm below soil surface and mean minimum depth was 22cm. The height of soil above the ground was assumed to be 24cm. Under the assumption that the soil scooped from the furrow would be deposited on the ridge, soil particles would rearrange and take positions corresponding to their positions before furrowing, with the height from furrow crest to the trough as 48cm. Due to rearrangement of the soil particles, soil weight, adhesion and friction, this height could not be realised practically.

The highest point of the soil particles would be lower than 48cm, from the furrow trough. The design height was taken as 46cm, which would be 2cm lower than the theoretical ridge top from the bottom. The average width of cut from the pre-design trials was 70cm per bottom of the furrower. The following angles (as in Fig 3.12) were taken as design angles for the furrower as in a typical mouldboard.

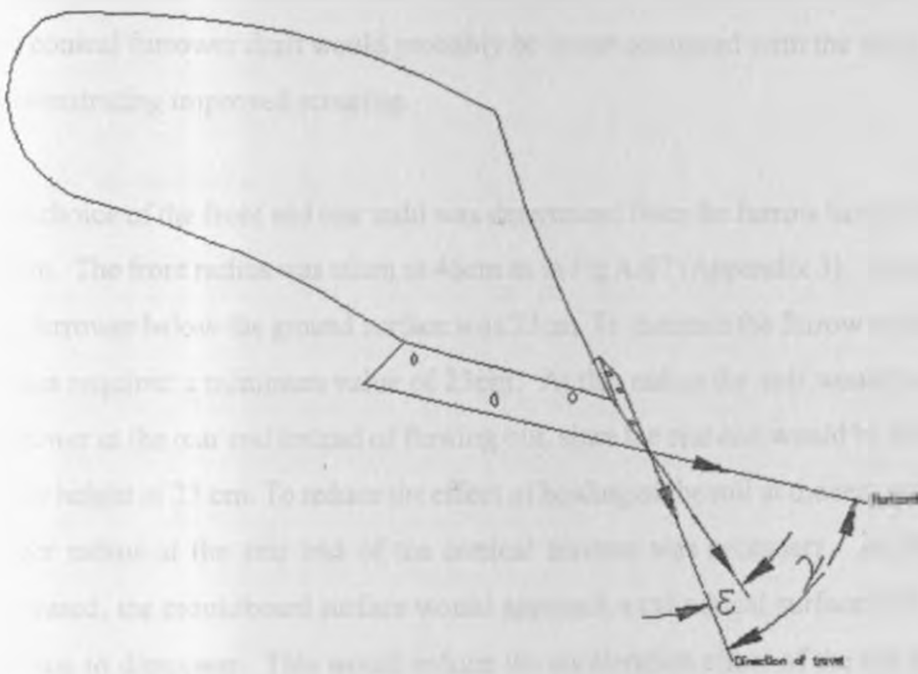

Fig 3.12: Typical plough mouldboard

a) The initial angle between the intersection of a tangent plane to the surface and the horizontal, and the direction of the travel (γ) was taken as the angle of attack and was assigned 42^0, though it changed along the furrow surface.

b) The initial angle between the tangent plane and horizontal plane (initial lift angle ε) was taken as 12.7^0.

In the design of the mouldboard, the shape was dictated by the height of soil movement. Previous furrowers had their lower mouldboard edges curving in-wards, which favoured soil flow-back, common in dry harrowed soils. For soil to be lifted up and thrown side ways, it would be picked up and moved evenly over the surface from a horizontal or a near horizontal direction. It would be moved through the curved surface, into a near vertical position before outlet. The design consideration was such that the soil engaging edge was near horizontal and the curvature developed evenly. This was the design using a conical based surface of revolution. It contrasted with a cylindrical based surface of revolution where the development of curvature was considered abrupt, from near horizontal to near vertical position. The gradual development of the curvature, the conical furrower draft would probably be lower compared with the other furrowers' drafts, demonstrating improved scouring.

The choice of the front and rear radii was determined from the furrow height, which was taken as 46cm. The front radius was taken as 46cm as in Fig A.07 (Appendix 3). The theoretical depth of the furrower below the ground surface was 23cm. To maintain the furrow height at 46cm, the rear radius required a minimum value of 23cm. At that radius the soil would be supported on the furrower at the rear end instead of flowing out, since the rear end would be almost semi -circular at the height of 23 cm. To reduce the effect of holding of the soil at the rear end of the furrower, a larger radius at the rear end of the conical frustum was necessary. As the rear end radius increased, the mouldboard surface would approach a cylindrical surface with the conical shape tending to disappear. This would reduce the acceleration effect of the soil along the furrower surface. A 30cm radius was picked for the rear radius. The jig had a length of 742 mm. The 742mm length of the mouldboard was necessitated by the projection of the mouldboard on the ground, which had a length of 800cm. This was the overall length of projection of the mouldboard on the ground, from the front tip of the mouldboard to its rear tip (wing).

3.2.5 Fabrication of the Furrower

In the mouldboard fabrication, a jig was made first, in order to achieve the mouldboard reproducibility and spare parts replaceability, for mass production. One half of a cone plate, sufficient for the jig was fabricated (Fig A.07). A half of the jigs surface was used to make one mouldboard (Fig A.02A and Fig A.02C). The reflection of one mouldboard was made from the other half as in Fig A.02B and A.02C in Appendix 3. Two mouldboards, one a reflection of the other made one furrower bottom (Fig A.01). The mouldboard angle of attack was 42^0 in the horizontal direction, which was within the recommended range of 37^0 to 43^0 (Kepner et al., 1976) for a plough design. Using the above dimensions, the mouldboard drawn in Fig A.03 was developed. From drawing development, using AutoCAD, the plates for the fabrication of the mouldboards as shown in Fig A.03 were designed.

Frogs necessary for securing the mouldboards to the shank were also designed with frog radii being more than the mouldboard radii by the mouldboard thickness, for proper meshing of the mouldboard and the frog. The edges of the frog were made 10 cm less than the edges of the mouldboard. In addition to the securing of the mouldboards to the shank, the frogs reinforced the mouldboard, increasing their deformation resistant. Thus it was necessary that the frogs cover about 60% of the area of the mouldboard. The same thickness of mild steel was used to make both the mouldboard and the frog.

The jig was designed and developed from the mouldboard dimensions shown in Fig A.02B, and Fig A.03. The outlines of the mouldboard and frog plates on the jig plates were developed and marked on the plates as shown in Fig A.02A, Fig A.02B, Fig A.02C and Fig A.02D obtained from curves of development. On the jig plates, the outlines of the mouldboards and the frogs were marked. The corners of the plates were filleted with fillet radii (FR) shown in Fig A.02B and Fig A.02D. A half cone jig of dimensions shown in Fig A.02B with fixtures was fabricated.

The plates for the jigs were marked as shown in Fig A.02A and Fig A.02C and cut along the lines marked for the Jig plates. The plates were rolled into the conical shape of the dimensions shown in Fig A.07, using a rolling machine. Reinforcement and fixtures were welded to make them deformation resistant during forging and to increase their ability to hold the work. Hot working was used in the mouldboard and the frog forging. The frog and mouldboard plates were heated to red-hot. Once hot, the plates were fed into the respective jigs and held on position using clamps fitted along the plate's outlines and then forged.

After forging of the mouldboards and fabrication of the other components, they were assembled to give the prototype furrower in Fig A.01 and Fig 3.13, and the implement was ready for testing. Only a single furrower bottom was fabricated in accordance with an available electronic dynamometer capacity, which was 10kN. Tests were to be carried out using the electronic dynamometer. Two blocks by which the dynamometer would be secured between the implement and the tractor were shaped using a milling machine. Their dimensions were as shown in Fig A.05B. One of the blocks was attached to the furrower tool bar, while the other was attached to a bigger three-point linkage tool bar. In between the two blocks was the dynamometer as shown in Fig A.04.

The landside was attached to a landside extension by two 8mm bolts and protected by protective planks as shown in Fig A.06. The landside was in turn secured onto the shank by two 12mm bolts. The landside and its extension were made from high carbon steel, available at Mumias sugar company in form of scrap grader blades. The landside was intended to secure the share-mouldboard assembly to the shank, a function that would be extremely different from its function in mouldboard ploughs. Bolts, countersunk at the soil-engaging surface attached the frog and mouldboard to each other. They were secured to the shank through two rods and two webs, one on either side of the shank. The landside was supported to the shank and the share through bolts. Due to its small size, the landside was connected to the share through 8mm bolts. The bolts were weak to support the operations on their own. They were protected by planks welded above and below them on the landside. The planks took the stresses induced in the bolt. The planks took all the stresses induced in the bolts. A web and rod at the rear side of the furrower connected the frog to the shank. The shank was connected to the tool-bar via angle irons, by two bolts, a 25mm pivot bolt and a 16mm shear bolt. The angle irons were bolted to the tool bar using four 25mm bolts as shown in Fig A.01.

The number of units making the prototype was reduced compared with mouldboard furrower (Fig 2.1), and the replaceability of the furrower components was not reduced, since the components were bolted. At the lower front edge of the conical mouldboard was the share. The mouldboards were tucked in the share. This reduced the resistance of the soil flow over the surface of the mouldboard. From the design, Table 3.14 gave the approximate weights of the various components of the furrower. The approximated weights in Table 3.14 were calculated assuming the density of steel as 7.81gcm^{-3} and the acceleration due to gravity as 9.81 ms^{-2}. The volumes of the various components making the furrower were determined from cross-sectional area and thickness and the masses were determined from the relation:-

Mass = DensityxVolume

Table 3.14: Furrower Components Weights

Components	Volume	Mass	Quantity	Total Mass
Shank	4482.78	35.145	2	70.29
Mouldboards	1792.57	21	4	84.00
Frogs	1109.69	13	4	52.00
Landsides	234.93	1.83	4	7.34
Share plates	221.26	1.73	4	6.93
Box section	6644.4	51.89	1	51.89
Upper angle iron	1679.9	13.12	4	52.49
Lower angle iron	1685.99	13.17	4	52.67
Mast	607.81	4.75	2	9.49
LLP(Fig A.06)	219.1	1.71	4	6.84
Share landside block (P1 in Fig	471.46	3.68	4	14.73
Shaft-plate(P3 in Fig A.06)	262.54	2.05	4	8.20
Web	636.8	2.49	4	9.95
Bolts	1498.34	11.7	All	11.70
Total Mass				438.52

In the fabrication of the prototype furrower. Mumias Sugar company did not consider surface polishing as cost effective for the prototype design. The concept of surface polishing was deferred until a period of mass production. The surface polish measures would consider the off-centre-soft centre steel, the chilled cast iron and the solid steel as discussed under section 2.2.5. Surface polishing would improve scouring of the surface and hence reduce the draft requirements and improve performance.

3.2.6 Resulting Prototype Furrower

From the design work carried out, a mouldboard jig and a frog jig were fabricated as shown in the Fig 3.13 which shows the two jigs combined. The material used in making of the jigs was 12.5mm thick mild steel. The conical based mouldboard furrower as shown in Fig 3.14 was fabricated. A single furrower bottom was fabricated for performance monitoring. The fabrication included a tool bar as shown in Fig 3.15, which carried the mast. The furrower weighed 183 kg, together with a tool bar of dimensions 100X100 by 6mm box section of 200mm length (and a dynamometer attachment block for testing only). It had removable landsides welded to the share. The furrower bottom without the tool carrier weighed 143 kg and had an effective length of 693 mm. height of 460 mm and width of 700 mm at the rear end of the mouldboards.

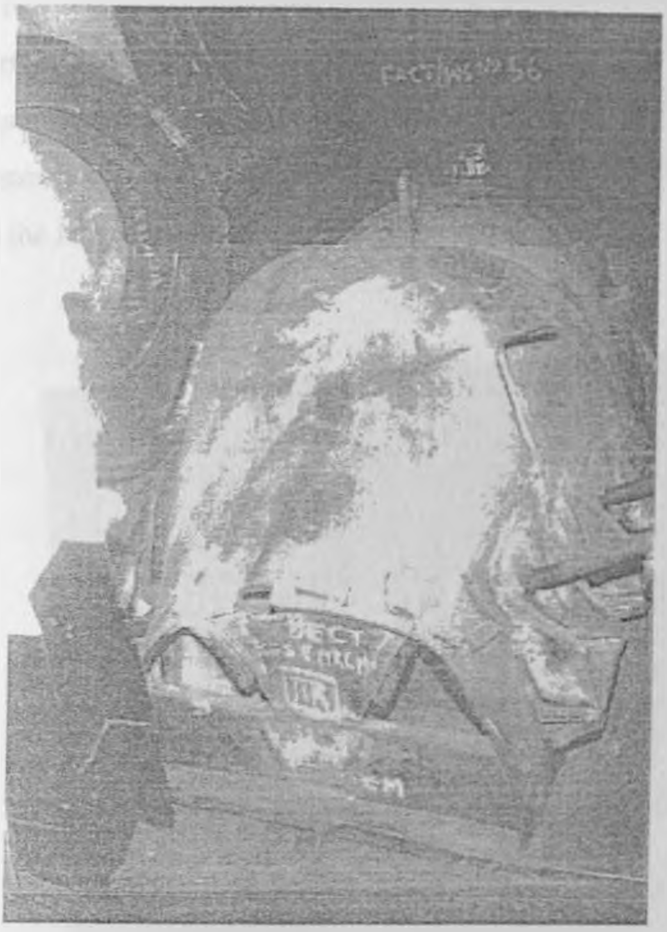

Fig 3.13: Prototype frog and mouldboard jigs

3.2.7 Furrowers Costs

The costs of the furrowers were done by first establishing the principal costs of furrowers. The principal cost of the prototype furrower was evaluated as follows. -

i) Material costs, which included shank, mouldboards, box section, angle iron, share and landsides, bolts and nuts and welding rods, was KShs 38500.

ii) Cost of 87 labour-hours of skilled labour at KShs 100/= per hour was KShs 8 700, while 63 labour-hours of unskilled labour at KShs. 70 per hour cost KShs 4 410.

Total cost for material and labour in the production of a single bottomed prototype furrower became KShs. 51610.00. The same cost in production of a two bottomed furrower, assuming that the costs were additive would be KShs 93220.00. The costs evaluated included the costs of fabricating a dynamometer attachment block, both in material and labour-hours. The cost of making a two-bottomed furrower would practically be less than KShs 93220.00, as the costs are not additive from one bottomed furrower costs to two-bottomed furrower costs. KShs 93220.00 was considered the investment capital for the prototype furrower while KShs 97500.00 (pg 5) was considered the investment cost of the mouldboard furrower. With the above data, operating and ownership costs for the furrowers would be evaluated.

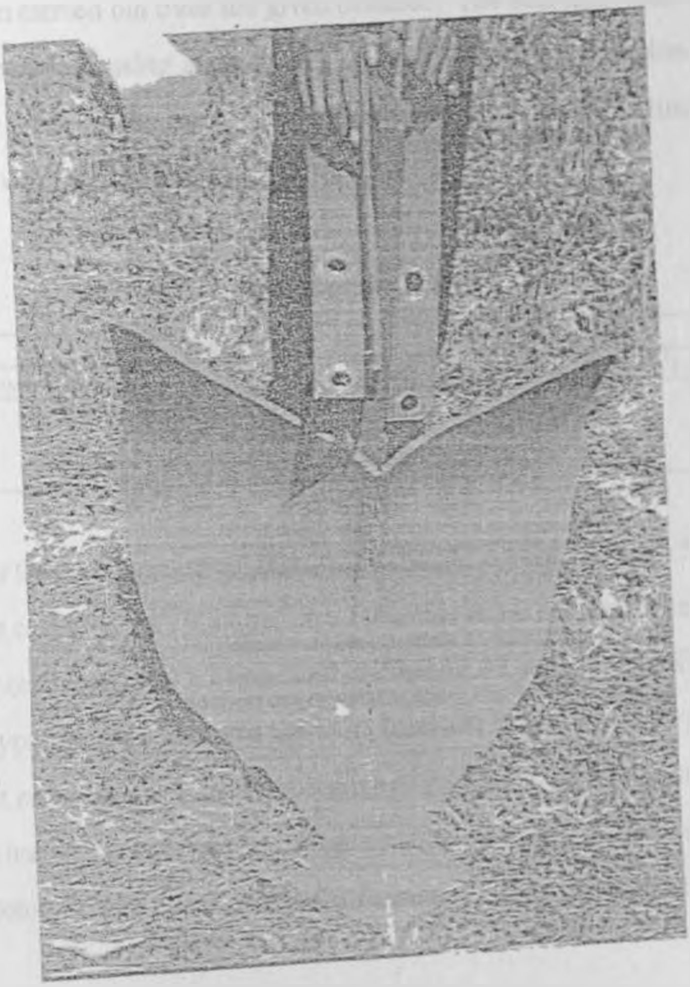

Fig 3.14: Prototype furrower

Accumulated use of the implement was taken as 2000 hours spread over 4 years period. The interest rate was taken as 36% per annum (commercial banks rates). Salvage value was taken as 10% of the principal (Kepner, 1976). RF_1 and RF_2 were 0.22 and 2.2 respectively (ASAE, 1990).

Fuel consumption was evaluated from actual field operations carried out over a 120m distance. The time taken to cover the distance, against the fuel used were taken and tabulated in Table 3.15. At the start of the operation with a furrower, the tractor with the furrower engaged were set on a flat ground. The tractor was shaken well with the fuel tank open to expel any trapped air. The fuel tank was topped up, and the hour-meter reading of the tractor was recorded. The furrowing process was then carried out over the given distance. The fuel tank was refilled with diesel at the end of the operation, using a measuring cylinder. Refilling was done carefully, shaking well to expel any gases in the tank. The process was repeated three times for each tractor. The data obtained was tabulated in Table 3.15.

Table 3.15: Fuel Consumption data

Furrower	First reading			Second reading			Third reading		
	Time (s)	Fuel (cm^3)	Rate	Time	Fuel	Rate	Time	Fuel (cm^3)	Rate
Prototype	86	130	5.44	88	132	5.4	84	126	5.4
Mouldboard	88	127	5.19	91	130	5 14	90	130	5.2
Flat-plate	84	133	5.7	86	133	5.57	94	144	5.5

The mean consumption for the prototype, mouldboard and flat-plate were 5.41L/hr, 5.18L/hr and 5.59l/hr respectively. At a cost of Kshs 19.84 per litre (Mumias sugar company purchase rate), the cost of the operations became Kshs107.14 per hour, KShs102.77 per hour and Kshs 110.9/hr respectively for the prototype, mouldboard and flat-plate furrowers. The purchase price for the flat-plate furrower was not established. This was because its performance was poor and power consumption too high. Its use was not certain and it was considered inferior. Thus, cost analysis was considered for the prototype and the mouldboard furrowers. Table 3.16 gave the various costs evaluated.

Table 3.16: Costs of Owning and Operating Prototype and Mouldboard Furrowers

Costs		Prototype	Mouldboard
Ownership costs	Depreciation	41.95	43.88
	Interest	11.67	12.11
	Taxes, Housing and Insurance	3.73	3.9
	Subtotal	57.35	59.89
Operating costs	Repair and Maintenance	2.51	2.63
	Fuels	107.14	102.77
	Oils and lubricants (15% of Fuels	16.07	15.42
	Subtotal	125.72	120.82
Totals		183.04	180.71

The cost of the prototype became Kshs 183.04 per hour, and Kshs 180.71 per mouldboard furrower hour. The low cost for the mouldboard relative to the prototype could be related to the broad surface area of the prototype, and the higher soil quantities it held relative to the mouldboard.

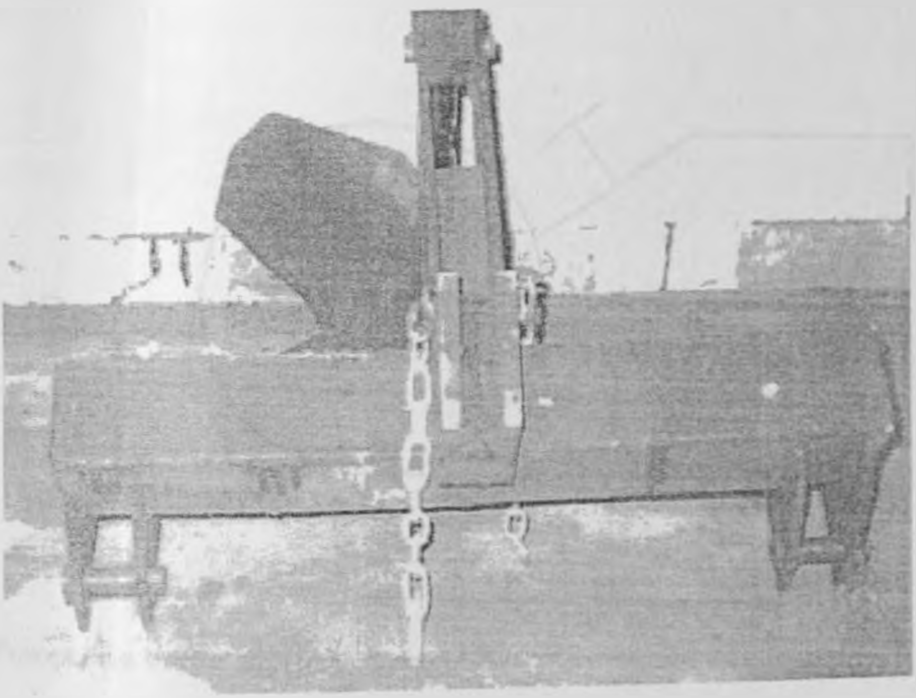

Fig 3.15: Prototype mouldboard furrower mast

3.2.8 Implement-Tractor Interaction Analysis

The weight of an implement W_f relative to tractor weight W_t and the tractor virtual hitch position, the wheelbase (L_b) and its centre of gravity influence the tractor-implement stability. Consider a tractor-implement system in equilibrium, carrying draw bar pull P (Fig 3.16). If y_r is the perpendicular distance between P and A and L_2 the perpendicular distance between W_t and R_r, the ground reaction at the front wheel R_f, according to Liljedahl et al., (1989) could be given by

$$R_f = \frac{W_t L_2 - P y_r}{L_b} \qquad 70$$

To avoid loss of steering, according to Liljedahl et al., (1989) the value of P should not exceed a maximum value P_m given by

$$P_m = \frac{W_t L_2}{y_r} \qquad 71$$

Which would occur if R_f, the front wheel axle reaction would become zero. Liljedahl et al.,(1989) gave equation 72 relating the apparent weight transfer W_a, y_r and L_b as

$$W_a = \frac{P y_r}{L_b} \qquad 72$$

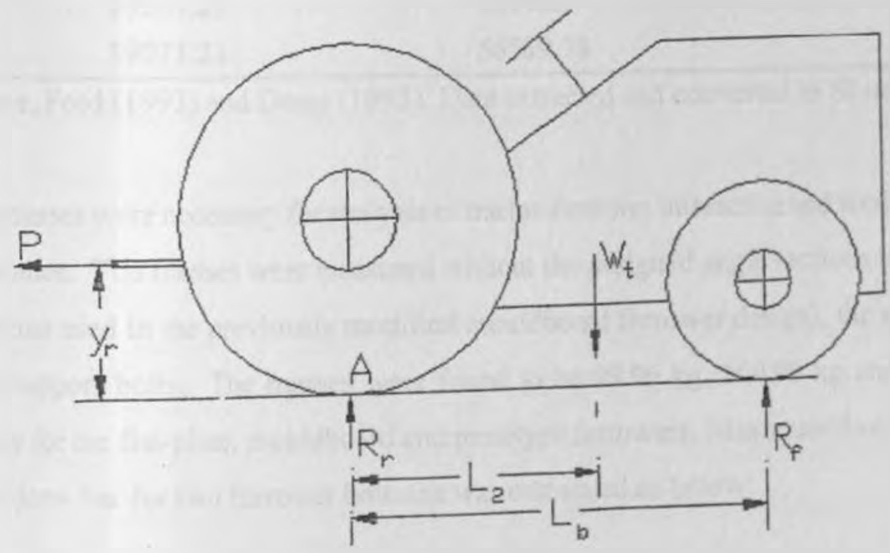

Fig 3.16: Forces on a tractor implement system

Py_r refers to the moment created by the implement hitched to the tractor. The static weight (W_s) supported by the front wheel of a tractor in equilibrium conditions, would be equivalent to the ground reaction on the front wheel R_f and would be given by

$$W_s = R_f = \frac{W_t L_2}{L_b}$$

When W_a exceeds W_s, steering control is lost. Table 3.17 gave data collected from Ford 6610 and John Deere 3040/3140 tractor operators manuals (Ford, New Holland, and John Deere. Deere and Company). R_{rm} and R_{fm} are the maximum rear and front wheel weights on the tractor respectively, and R_{fi} and R_{ri} the maximum front wheel and rear wheel axle weights attainable using liquid balasting. The data was utilised in tractor-furrower stability analysis. Ford (1993) stated that the front wheels must always support between 10% and 20% of the tractor weight at all times to minimise loss of steering.

Table 3.17: Tractor Data for Tractor- Furrower Sizing

Tractor	Ford 6610 (80 Hp)	John Deere 3040/3140 (100 Hp)
R_{fi}(N)	28036.98	24525
R_{ri}(N)	48069	50325.3
L_b(mm)	2253	2600
L_1(mm)	1000	1000
L_2(mm)	889	1040
R_{fm}(N)	13871.34	24211.08
R_{rm}(N)	25201.89	32078.7
W_t(N)	39073.23	56289.78

Data Source, Ford (1993) and Deere (1993): Data extracted and converted to SI units

Furrower masses were necessary for analysis of tractor-furrower interaction and were taken using a beam balance. The masses were measured without the designed angle sections (but with the angle sections used in the previously modified mouldboard furrower design), the mast and the shear and support bolts. The masses were found to be 99.96 kg, 100.96 kg and 143.38 kg respectively for the flat-plate, mouldboard and prototype furrowers. Maximum force expected at the tractor draw bar for two furrower bottoms was calculated as below:

Weight of a single furrower bottom measured 143.46 kg, (which included the mass of the angle sections in the previously modified furrowers). The angle sections of 75x75x10mm and 400mm length measured 4.37kg each, hence four of them had 17.49kg. The furrower mass without the furrower angle sections was 125.96kg. Two such furrower bottoms had 251.93 kg. This was the mass without the angle sections, the box section and the mast.

The box section of 170x170x6 mm, and 1.6m long had a volume of 6297600 mm^3. Plates of 120mm square plates of 6mm thickness whose volume was 346800mm3 covered its ends. Thus the total volume of the material in the box section became 6644400mm^3. Considering a density of 7810kg/m^3, the mass of the box section became 51.89kg.

Four angle irons of 127 X 127 X 15.9 mm of 450 mm length, each carrying two support bolt holes and a pivot hole of 25 mm diameter had a volume of 6720763.78mm^3. The other four angle irons of 127 X 127 X 15.9 mm of 400mm length each carrying two support bolt holes of 25mm and one shear bolt hole of 16 mm had a volume of 6739195.32mm^3. The mass of the angle sections became 105.12kg.

The volume of shear bolt and its nut was 35.63 cm^3, while the volume of pivot bolt and its nut was 75.96 cm^3, thus the total volume of eight securing bolts with nuts was 637.59 cm^3. The total volume for the support bolts, shear bolts and pivot bolts was 749.17 cm^3 per furrower bottom, and for the two bottoms it was 1498.34 cm^3. Assuming the bolts were made of steel of 7.81 g/cm^3, the mass of the bolts was calculated as 11.70 kg,
The volume of the plate connecting the lower links and the box section (LLP) was 218950.064mm^3. Four such plates had a volume of 875800.25mm^3. The mass of the plates thus became 6.84 kg.

The volume of the mast was evaluated as 607.81cm^3 per piece. Two such pieces had a volume of 1215.62cm^3. Thus the mass of the mast became 9.49kg.
The mass of the furrower material was evaluated as 436.97kg. This compared very well with the design masses obtained and tabulated in Table 3.14 which added up to 438.52kg. The difference could be due to errors introduced by approximations (to some decimal points), which must have either increased or reduced the calculated mass

The greater of the two masses, which was 438.52kg was taken as the mass of the furrower. Its weight thus became 4301.88N.

Draft per unit furrower bottom, was 8341.37N. Thus on a two bottomed furrower, draft was evaluated as twice the draft on a single furrower bottom, which became 16682.74N. Suction per unit furrower bottom was evaluated 30% of draft and it became 2502.41N, and 5004.82N fo a two bottomed furrower.

For a tractor in static equilibrium (Fig 3.17), sum of all the vertical forces would equal zero. Similarly the sum of all the horizontal forces would equal zero.

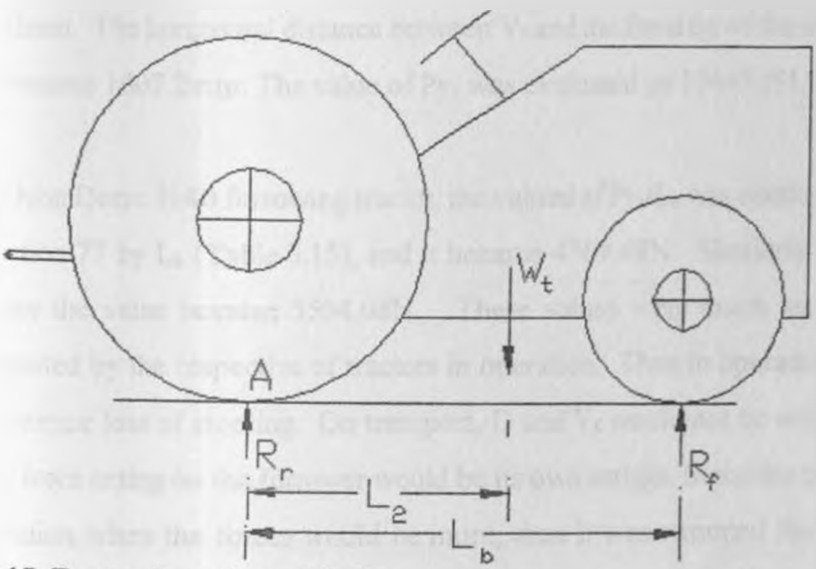

Fig 3.17: Tractor in static equilibrium

Thus

$$R_r + R_f - W_t = 0 \quad 74$$

Taking moments about point A, for a John Deere tractor,

$$W_t L_2 - R_f L_b = 0 \quad 75$$

For John Deere 3040 tractor, the static weight on the front wheel W_s, would be given by

$$R_f = \frac{W_t L_2}{L_b} = \frac{(5738)(1040)(9.81)}{2600} \quad 76$$

Which gave the value of R_f as 225159N. Thus R_r became 33773.87N. Similarly Ford 6610 tractor, R_f became 15417.7N and R_r became 23655.5N. The conditions for loss of steering control were given earlier. From equation 70 giving the condition of loss of steering. Fig 3.11 and 3.17, Py_r would be the sum of moments of the forces acting on the furrower about A (Fig 3.11). The values of x_5 and x_6 were evaluated from AutoCAD drawings as 1227mm and 1042mm respectively. The value of H_d was similarly evaluated as 135.7mm. The sum of the moments due to the implement about point A when the implement is in operation would be

$$Py_r = D\,H_d + W_f\,X_5 + V_f\,X_6 \qquad 77$$

The length of the lower link was 1000mm. Horizontal distance from the eye of the lower link to the tip of the shank was 223mm. W_f was 28mm ahead of the front tip of the shank. Thus X_5 was 1195mm. The horizontal distance between V_f and the front tip of the shank was 215.8mm. Thus X_6 became 1007.2mm. The value of Py_r was evaluated as 12445451.14Nm.

For John Deere 3040 furrowing tractor, the valued of Py_r/L_b was obtained by dividing the value in equation 77 by L_b (Table 3.15), and it became 4769.49N. Similarly for Ford 6610 furrowing tractor the value became 5504.08N. These values were much less than the static weights supported by the respective of tractors in operation. Thus in operation, the tractors would not experience loss of steering. On transport, D and V_f would not be acting on the furrower. The only force acting on the furrower would be its own weight. Since the tractors would be stable in operation when the forces would be more, then it was assumed that they must be stable on transport under fewer forces. The implement would experience loss of steering if P_s (Fig 3.18) would exceed P_m whose steps of calculations were given below. It was assumed that all the forces were acting at the drawbar end. From Fig 3.11 and 3.12, equation 78 could be derived as

$$P_v = V_h + V_g = W_f + V_f \qquad 78$$

The draft D for a two-bottomed furrower, which would be equal to P_h would be given by

$$D = 2x8341.37 = 16682.74N \qquad 79$$

and the sum of forces would imply that

$$R_r + R_f = V_f + W_t = 9306.70 + W_t \qquad 80$$

For the tractor to experience loss of steering, R_f would be zero. This would imply that

$$R_r = 9306.70 + W_t \tag{81}$$

For Ford 6610 tractor the value of R_r would be 48349.26N and 65565.81N for John Deere 3040 tractor. To establish steering stability, equations 69 and 70 were stated. Considering forces acting on the rear wheel as in Fig 3.11 and Fig 3.18, total vertical force (P_v) was the sum of V_f on the mouldboards and the furrower weight (W_f),

$$P_v = V_f + W_f = 5002.82 + 4301.88 = 9306.7N \tag{82}$$

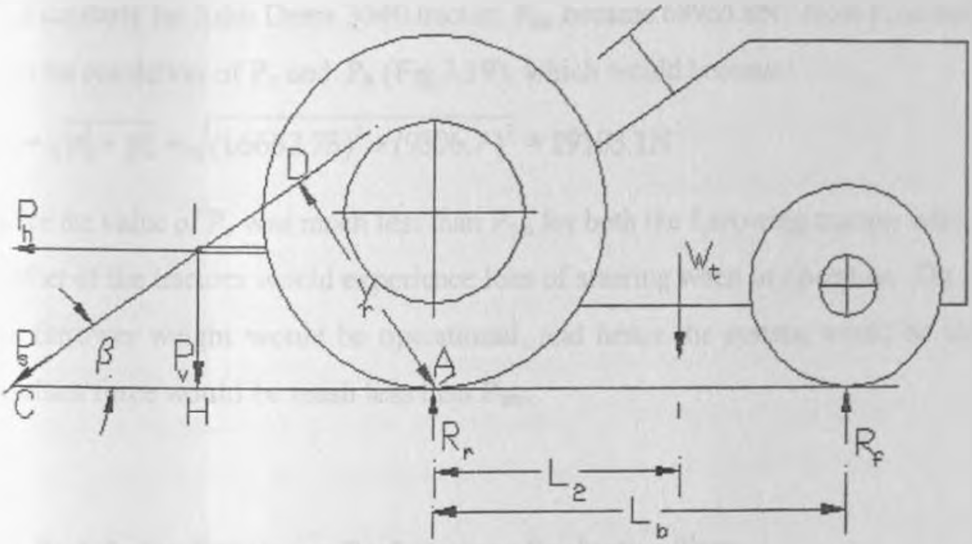

Fig 3.18 Forces on the Tractor and drawbar

Thus, the ratio of P_v to the total implement draft P_h, would be related to angle β, the angle between the resultant of P_v and P_h, and the ground, by

$$\tan\beta = \frac{P_v}{P_h} = \frac{9306.70}{16682.74} = 0.5579 \tag{83}$$

and β, was evaluated as 29.16^0. Since HI=414 (Ford, New Holland, John Deere, Deere and Company), HC became

$$HC = \frac{414}{\tan 29.16} = 742.12\text{ mm} \tag{84}$$

and AC became 1742.12mm, while y_r was evaluated as

$$y_r = AC \sin\beta = 848.85\text{ mm} \tag{85}$$

Thus taking moments about point A (Fig 3.18). and since the total force P_s which is a resolution of D_r and P_v could be expressed as

$$P_s = \frac{L_2 W_t}{y_r} \qquad 86$$

At the point where steering control would be lost, the value of P_s which would be maximum could be referred to as P_{sm}. For Ford 6610. P_s was evaluated as

$$P_{sm} = (3983)(9.81)\left(\frac{889}{848.85}\right) = 40921.54 \text{ N} \qquad 87$$

and similarly for John Deere 3040 tractor, P_{sm} became 68965.8N. Now P_s on both the tractors was the resolution of P_v and P_h (Fig 3.19), which would become

$$P_s = \sqrt{P_h^2 + P_v^2} = \sqrt{(16682.75)^2 + (9306.7)^2} = 19103.1\text{N} \qquad 88$$

Since the value of P_s was much less than P_{sm} for both the furrowing tractors while in operation. neither of the tractors would experience loss of steering when in operation. On transport, only the furrower weight would be operational. and hence the system would be stable since the resultant force would be mush less than P_{sm}.

3.3 Post-design Furrowers Performance Evaluation Tests

3.3.1 Sand-Bin Tests

3.3.1.1 Electronic Transducers Data Acquisition

The performance evaluation tests were intended for comparison of the performance between the prototype. the mouldboard and the flat-plate furrowers. A spring dynamometer used during the pre-design tests in Mumias sugar company fields trials was sensitive to 50 kg or 495 N. It experienced vibrations and needed two tractors to operate. hence it could not measure forces accurately and it wasted power. An octagonal ring transducer with a capacity of 10 kN was used to monitor the performance of the furrowers in a sand bin. The objective of using a sand-bin was to test the implement under controlled and uniform conditions, which included:-

a) the uniformity of the sand.

b) moisture content which would be independent of the atmospheric conditions.

c) Soil bulk density, which would be independent of time and space.

The electronic transducers were developed collaboratively between the Agricultural Engineering Department of the University of Nairobi, Kenya, and the Swedish University of Agricultural Sciences (SUAS), Upssala, Sweden. It had a provision for different rates of logging and an automatic draft, vertical force, moment, speed and depth monitoring mechanisms. The Implement was secured to the tool bar through the load cell as shown in Fig A.04. The implement-tool bar system was then secured to the tractor through the three point linkage. Before carrying out actual tests, zero reference readings on the transducers were obtained by placing implement on a level ground and logging data for 30 seconds. The system was then transferred to the sand-bin for data acquisition. Draft, moment and vertical force were simultaneously taken by real voltage time data logging. This was repeated for the three furrowers. In between tests, harrowing was carried out twice to ensure soil uniformity. A PROLEC-TRA 9000 computer software package as explained in Prolec-Tra Users' Manual (1993) was used to off-load the logged data to a computer and for data formatting and analysis. ASCII formatting converted the data into a spreadsheet for further analysis. In the monitoring of the performance of the furrowers, various measured parameters were logged as signals in volts and later off-loaded to a computer for analysis. In the load-cell design, calibrations had been carried out. The calibration data in Table 3.18 was obtained.

Table 3.18: Electronic Load-Cell Calibration Data

Draft (N)				Vertical Force (N)				Moment (Nm)			
Loading		Off-Loading		Loading		Off-Loading		Loading		Off-Loading	
F_d	V_d	F_d	V_d	F_d	V_d	F_d	V_d	F_d	V_d	F_d	V_d
79.40	-0.003	79.40	-0.003	79.40	-0.0002	79.40	0.00	8.853	0.0005	8.853	0.0005
2709.57	0.059	2709.59	0.060	2709.59	0.0695	2709.59	0.0702	302.12	0.0377	302.12	0.0390
4052.76	0.171	4052.76	0.1752	4052.76	0.1919	4052.66	0.1912	451.88	0.1045	451.88	0.1047
5026.20	0.2464	5026.20	0.2527	4561.90	0.2382	4561.90	0.2360	508.65	0.1297	508.65	0.1300
6011.88	0.3362	6011.88	0.3297	5071.04	0.2842	5071.04	0.2840	565.42	0.1550	565.42	0.1577
7026.11	0.4085	7026.11	0.4133	5580.18	0.3295	5580.18	0.3292	622.19	0.1797	622.19	0.1800
8008.68	0.4862	8008.68	0.4862	6089.32	0.3733	6089.32	0.3742	678.96	0.2043	678.96	0.2060
				6598.46	0.4210	6598.46	0.4215	735.73	0.2313	735.73	0.2320
				7107.59	0.4667	7107.59	0.4670	792.50	0.2610	792.50	0.2590
								849.27	0.2840	849.27	0.2840

Data Source: Kaumbutho and Gebresenbet. (1993)

The data in Table 3.18 was used to plot graphs in Fig 3.19 to Fig 3.21, whose regression equations were as inscribed in the graphs. From the plots, hysteresis was considered insignificant and only the loading equations were developed and considered for conversion of the voltage signals from the logger to the required performance loads. In the analysis of the logged data, zero reference readings for each of the components recorded by the electronic load cell were subtracted from the sand-bin test results to get the actual readings. The equations inscribed in Fig 3.19 to Fig 3.21 were applied using a spreadsheet to calculate actual forces and moments from the logged voltage. The calculated parameters were used to evaluate the performance of the three furrowers by plotting graphs of the various components measured against time

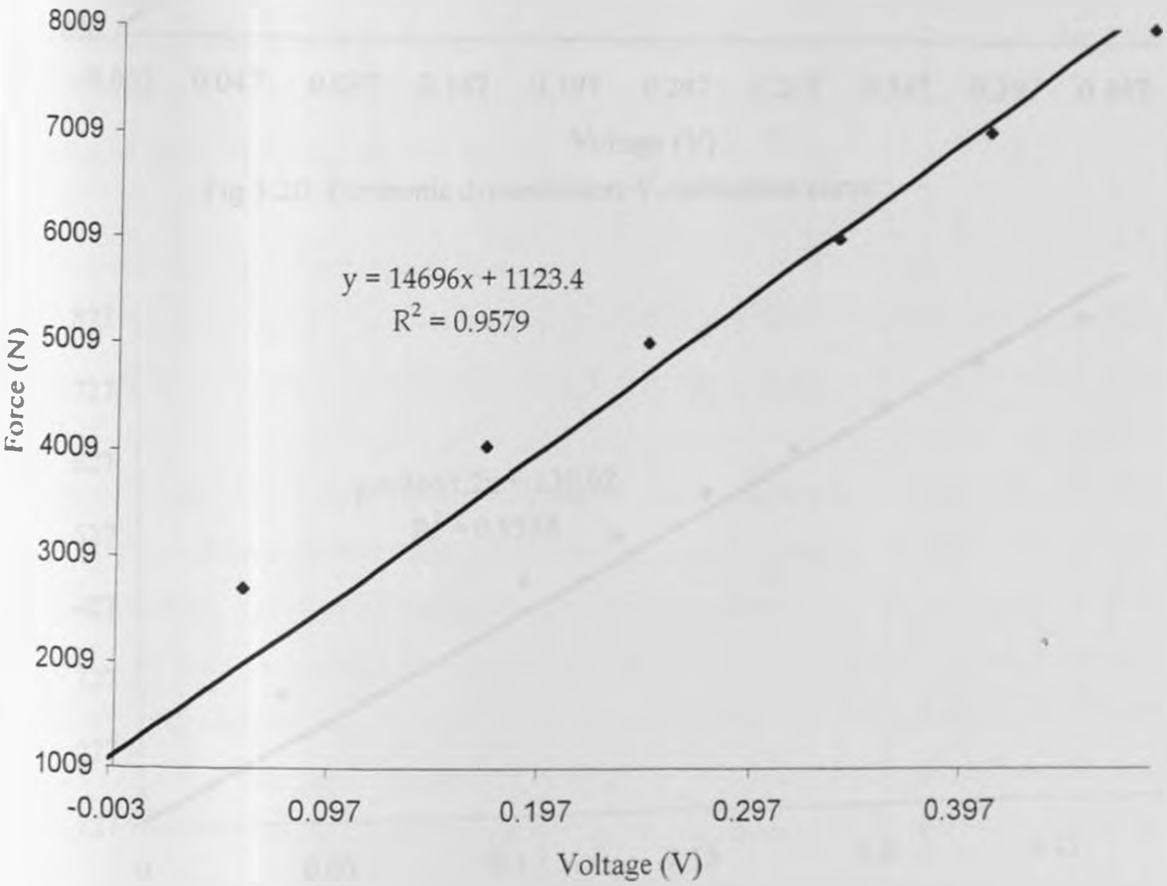

Fig 3.19: Electronic Dynamometer Draft Calibration Curve

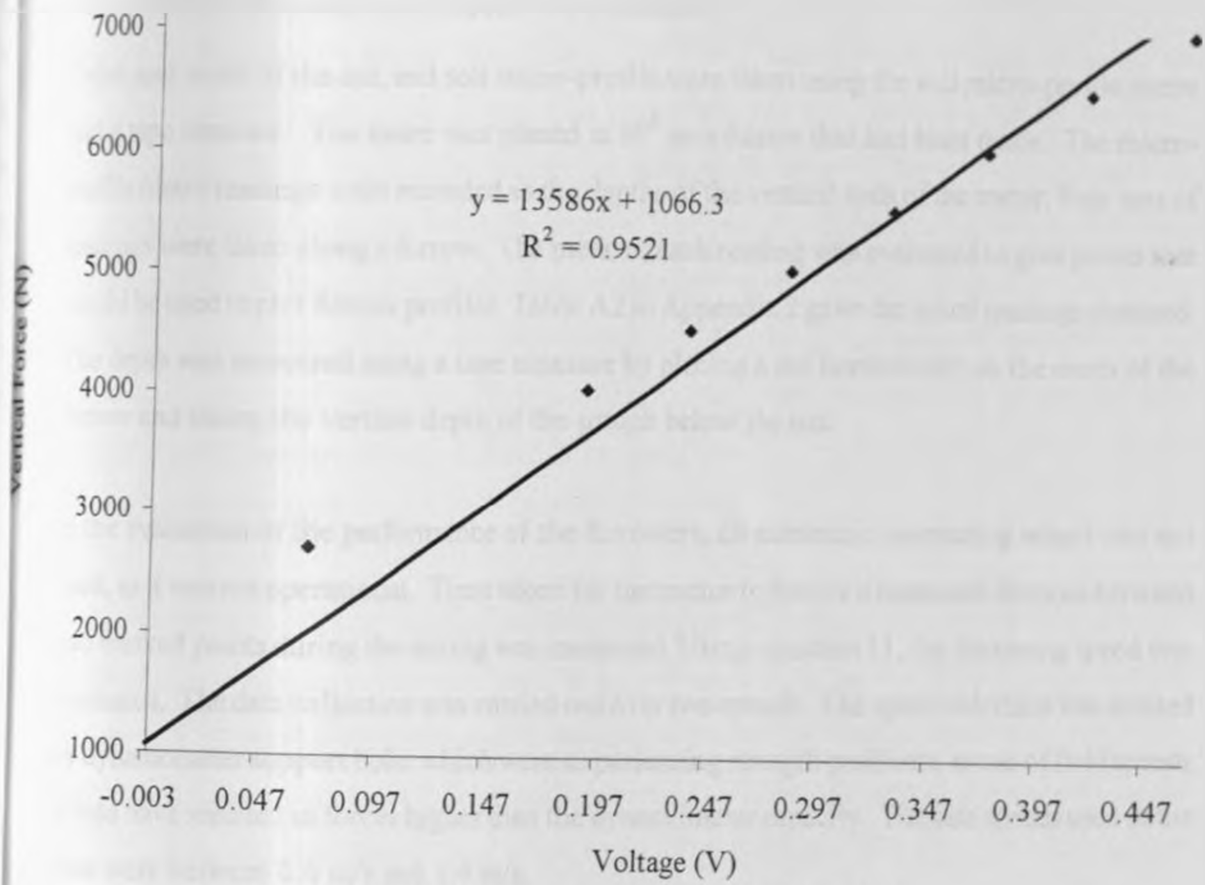

Fig 3.20: Electronic dynamometer V_f calibration curve

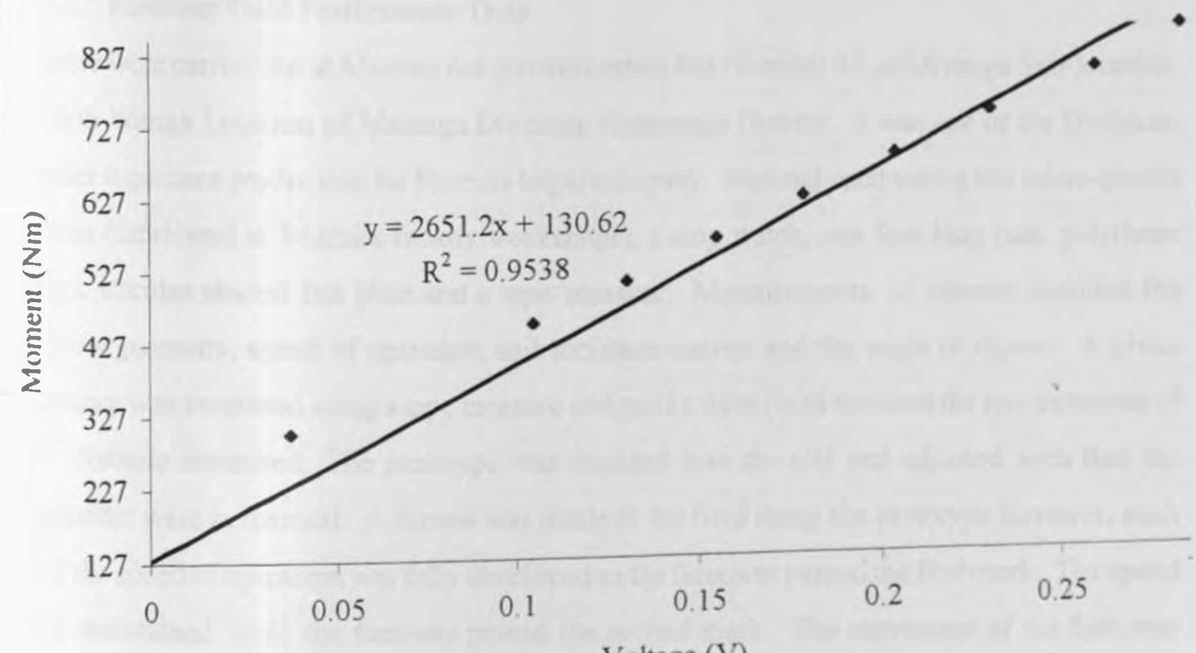

Fig 3.21 Electronic-dynamometer moment calibration curve

3.3.1.2 Furrow Parameters and Speed Measurement

Depth and width of the cut, and soil micro-profile were taken using the soil micro-profile metre and a tape measure. The metre was placed at 90^0 on a furrow that had been made. The micro-profile metre readings were recorded as the depths of the vertical rods of the meter. Four sets of readings were taken along a furrow. The mean of each reading was evaluated to give points that would be used to plot furrow profiles. Table A2 in Appendix 2 gave the actual readings obtained. The depth was measured using a tape measure by placing a rod horizontally on the crests of the furrow and taking the vertical depth of the trough below the rod.

In the evaluation of the performance of the furrowers, an automatic monitoring wheel was not used, as it was not operational. Time taken for the tractor to furrow a measured distance between two marked points during the testing was measured. Using equation 11, the furrowing speed was evaluated. The data collection was carried out over two speeds. The speed selection was limited by dynamometer support bolts which were experiencing strength problems, as use of field speeds would have resulted in forces higher than the dynamometer capacity. The safe speeds used in the tests were between 0.6 m/s and 1.4 m/s.

3.3.2 Furrower Field Performance Tests

These were carried out at Mumias out-growers estate field number 41, at Miyanga Sub-location, North Wanga Location of Matungu Division, Kakamega District. It was one of the Divisions under sugarcane production for Mumias sugar company. Material used were a soil micro-profile meter (fabricated at Mumias factory workshops), a stop watch, one foot long rule, polythene bags, circular shaped flat plate and a tape measure. Measurements of interest included the furrow geometry, speed of operation, soil moisture content and the angle of repose. A given distance was measured using a tape measure and marks were fixed between the two extremes of the distance measured. The prototype was engaged into the soil and adjusted such that the landsides were horizontal. A furrow was made at the field using the prototype furrower, such that the speed of operation was fully developed as the furrower passed the first mark. The speed was maintained until the furrower passed the second mark. The movement of the furrower between the first and the second marks was timed to enable evaluation of operating speed.

A soil micro-profile meter (Fig 3.3) whose depth measuring rods had not protruded at the lower edge of the lower horizontal bar, was placed at 90° to the direction of travel of the furrower on the furrow made between the marks. The meter had its nuts loosened to allow the depth measurement rods to drop and conform to the shape of the furrow. The nuts were tightened to maintain rods firm in position. Along the furrow, four sets of readings were obtained. The mean of each reading on the meter readings was evaluated and used to plot furrow profiles. Table 3 in appendix 1 gave the actual readings of the micro-profile meter. The depths of the rods below the lower wedge of the horizontal bar were measured and recorded. The process was repeated three (3) times and all measurements tabulated. The measurements were repeated for both mouldboard and flat-plate furrowers.

Soil samples were collected in polythene bags from four different positions in the field. Samples of 100g mass were collected and packed in polythene bags such that they could not lose moisture. They were then taken to soil analysis laboratory at Mumias sugar company. The samples wet masses were taken and recorded as (m_{ws}). The samples were oven dried for 18 hours at 105°, then their dry masses (m_{ds}) were taken. The wet basis moisture content (M_{wb}) was evaluated as

$$M_{wb} = \frac{M_{ws} - M_{ds}}{M_{ws}} \qquad 89$$

The angle of repose would dictate the stability of soil in furrow formation. If the angle the slope makes with the horizontal would be less than the angle of repose, the slope becomes stable. On raising the slope angle to values greater than the angle of repose, the furrow formation becomes unstable.

The method utilised by Ross et al (1987) was employed to determine the angle of repose (φ) of the soil at the time of operation. A sample of the soil collected from the field at the field moisture contents was dropped from height *h* to a horizontal plate such that the point of release was vertically above the centre of the plate of diameter *d*. The soil that was highly pulverised was dropped slowly until soil issued by the sides of the plates. The set up was as in Fig 3.23.

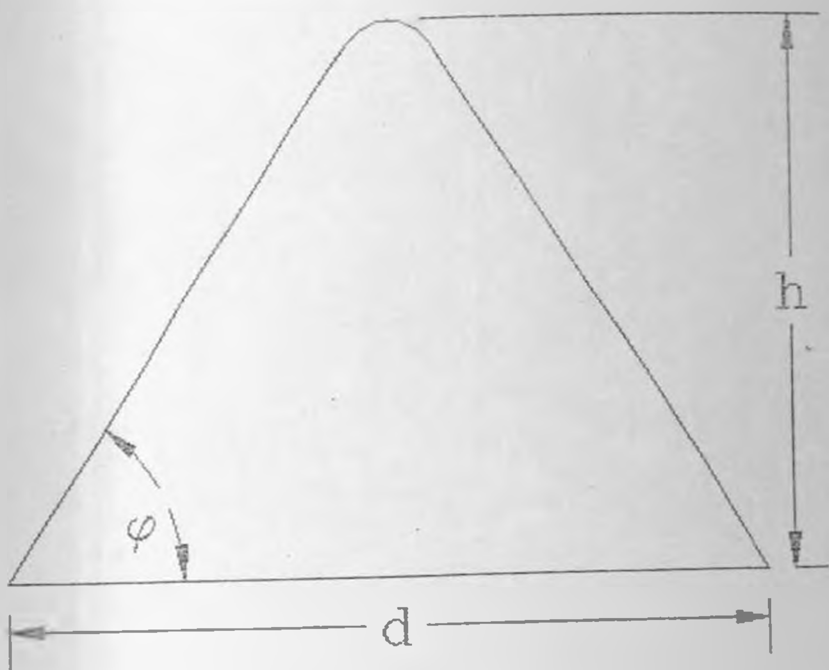

Fig 3.23: Angle of Repose Determination

The angle of repose (φ) was evaluated as

$$\varphi = \tan^{-1}\{\frac{2h}{d}\}$$

90

4 RESULTS AND DISCUSSION

4.1 Sand-Bin Furrowing Performance Evaluation Test Results

4.1.1 Sand-Bin Test Results

Once the logged voltage from the transducers was converted into forces and moments, the plots in Fig 4.2, Fig 4.3 and Fig 4.4 were obtained. The mean values for the (forces and moments) loads and their ratios were evaluated as in Table 4.1.

Table 4.1: Logged loads and their ratios

Furrower		Draft, N (D)	Moment, Nmm (M)	Vertical force, N (V)	M/D	V/D	M/V
Flat-plate	v_1	1269.74	134.68	811.34	0.11	0.64	0.11
	v_2	1315.21	119.66	808.59	0.09	0.61	0.09
	v_3	1229.39	136.36	787.26	0.11	0.64	0.11
	v_4	1335.18	145.78	872.77	0.11	0.65	0.11
Mouldboard	v_1	1192.33	106.66	809.06	0.09	0.68	0.09
	v_2	1135.95	126.5	761.17	0.11	0.67	0.11
	v_3	1247.93	127.44	864.62	0.10	0.69	0.10
	v_4	1232.32	129.02	866.2	0.10	0.70	0.10
Prototype	v_1	1234.93	130.36	836.37	0.11	0.68	0.11
	v_2	1234.93	130.36	836.37	0.11	0.68	0.11
	v_3	1054.24	121.89	1006.57	0.12	0.95	0.12
	v_4	1218.53	124.15	796.29	0.10	0.65	0.10

Table 4.2 shows the actual widths and depths of furrow taken during the furrowing tests. The operating speeds for each furrower were as inserted in Table 4.2. Four sets of readings were taken for each furrower test. To evaluate the specific draft and specific power, the furrow area was required. The furrows made in the sand-bin appeared triangular in shape(Fig 4.1) and the area of a triangle could be taken as a good estimator of the furrow area. The width and the depth of the furrows were measured and entered in Table 4.2. The area of the furrow was estimated as half the product of depth and width of the furrow. The area of each furrower was evaluated and entered in Table 4.3. The specific draft for each furrower unit was calculated using equation 13. Table 4.3 gave the specific power, which was obtained as a product of specific draft and speed. Table 4.3 also shows the furrowers specific draft and specific power

Table 4.2: Mean furrow measurements (cm) from sand bin tests

Furrower		Depth reading					Width readings				
		1st	2nd	3rd	4th	Mean	1st	2nd	3rd	4th	Mean
Prototype	V_1	29	25	22.5	22.5	24.6	72	72	66	67	69.3
	V_2	30	28	27.5	23	27	74	73	73	67	7.18
	V_3	24	27	26.5	25	25.4	68	71	73	70	70.5
	V_4	24	25	26	27.5	25.5	71	71	71	73	71.5
Flat-plate	V_1	30	33	34.5	31.8	32.2	73	74.5	74.5	74	73.9
	V_2	33	32	36.2	32.5	33.3	76	77	78	79	77.4
	V_3	22	29	32	31.8	28.6	66	73	73	72	71
	V_4	31	36	35.5	35	34.4	80	80	81	77	79.5
Mouldboard	V_1	25	27	31.5	29	27.9	58	61	71.5	64	63.6
	V_2	21	23	26.5	25	26.4	54	53.5	55	53	53.2
	V_3	30	31	35.5	35	32.9	74	72	76	79	72.3
	V_4	31	32	33.7	35.7	33	74	74	77	76	75.1

The tests were carried out over two testing speeds, 0.6m/s and 1.2m/s. Each test was repeated twice within each testing speed ((V_1 and V_2) and (V_3 and V_4)). The actual testing speeds obtained using a stopwatch and a tape measure were as in the fifth column of Table 4.3.

Table 4.3: Mean Values of Logged Draft and Specific Power

Furrower	Draft (N)	Area (cm^2)	Draft/Unit Area (N/cm^2)	Speed (m/s)	Specific Power (W/cm^2)
Flat-plate	1269.764	1176.6	1.08	0.63	0.68
	1315.21	1283.75	1.02	0.69	0.70
	1229.39	1015.3	1.21	1.42	1.72
	1335.18	1367.4	0.97	1.34	1.30
Mouldboard	1192.33	928	1.28	0.60	0.77
	1135.948	662.5	1.71	0.70	1.20
	1247.93	1189.33	1.04	1.36	1.41
	1232.32	1192.95	1.03	1.35	1.39
Prototype	1234.93	753	1.64	0.56	0.92
	1234.93	770.5	1.60	0.71	1.13
	1054.236	895.35	1.18	1.38	1.63
	1218.53	911.63	1.34	1.33	1.78

The ratios of the furrower loads at a particular speed were evaluated and tabulated in the table. The ratio of vertical force to draft ranged from 0.61 to 0.95 with a mean of 0.74 for the prototype furrower, from 0.67 to 0.70 with a mean of 0.685 for the mouldboard furrower and from 0.61 to 0.65 with a mean of 0.63 for the flat-plate furrower. The ratios of the vertical forces to drafts were therefore highest with the prototype, followed by the mouldboard and the flat-plate.

The weights of the furrowers increased in the order of flat-plate, mouldboard and prototype (99.6kg, 100.96kg and 143.38kg respectively, for a single furrower bottom carrying four angle sections designed to work with the previously modified mouldboard furrower). Vertical force would be directly proportional to weight. In addition, the quantity of soil held by the prototype due to its broad surface would be more than that held by mouldboard and flat-plate. The mouldboard held more soil than the flat-plate, as the flat-plat was more afloat on soil than the mouldboard due to the long knife, which could not allow the plates to go deep into the soil. The quantity of soil held by the surface also bore a direct proportionality with the vertical force. These could explain the trend in the ratios of vertical forces for the three furrowers.

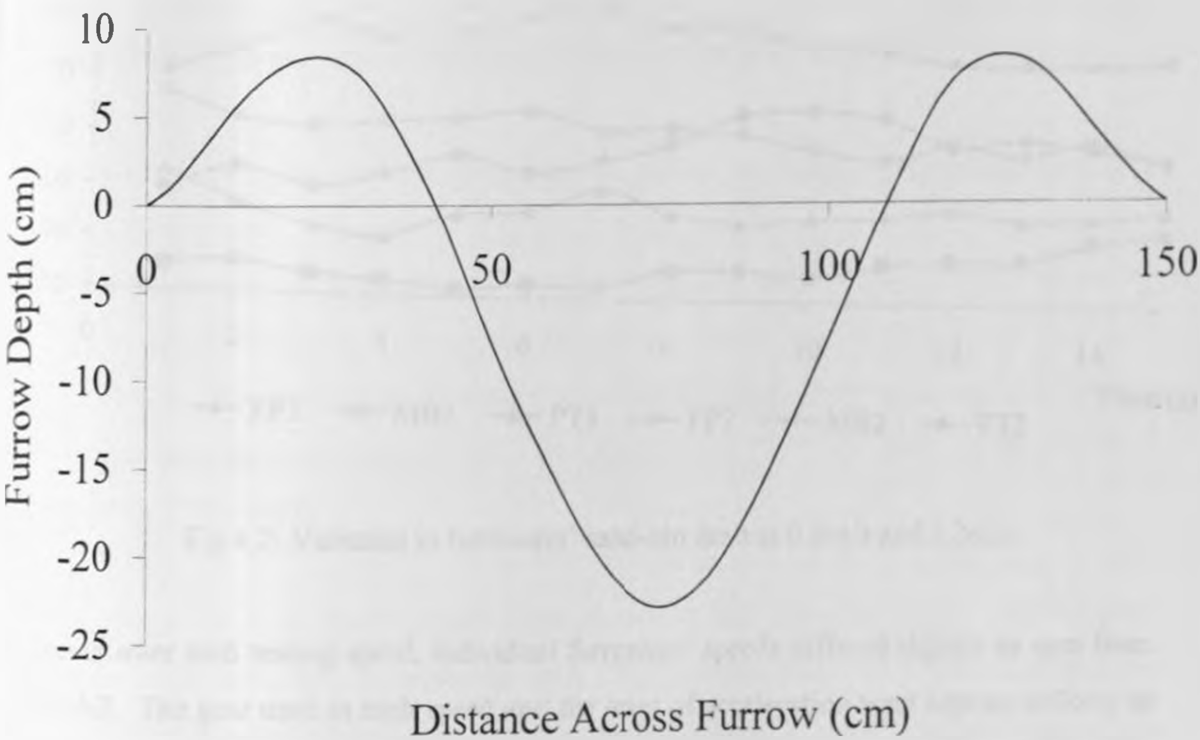

Fig 4.1 Furrow cross-section

The rated width for a two-bottomed prototype furrower was 1.5 m while typical furrowing speed was 8 km/hr (2.22 ms^{-1}). Most tillage operations would have field efficiencies between 75% and 90% (Kepner et al., 1976). Taking a field efficiency of 75% (the worst field efficiency), and substituting for S and W in Equation 14, the field capacity was evaluated as 0.9ha/hr. The value did agree closely with the field capacity for listers (furrower) as given by Kepner et al., (1976).

4.1.2 Draft, vertical force, moment variation with speed and final soil condition

4.1.2.1 Draft Variations With Speed

The furrowers draft curves over the two testing speeds (0.6m/s and 1.34 m/s) were presented in Fig 4.2. The tests were carried out over two testing speeds, 0.6m/s and 1.2m/s.

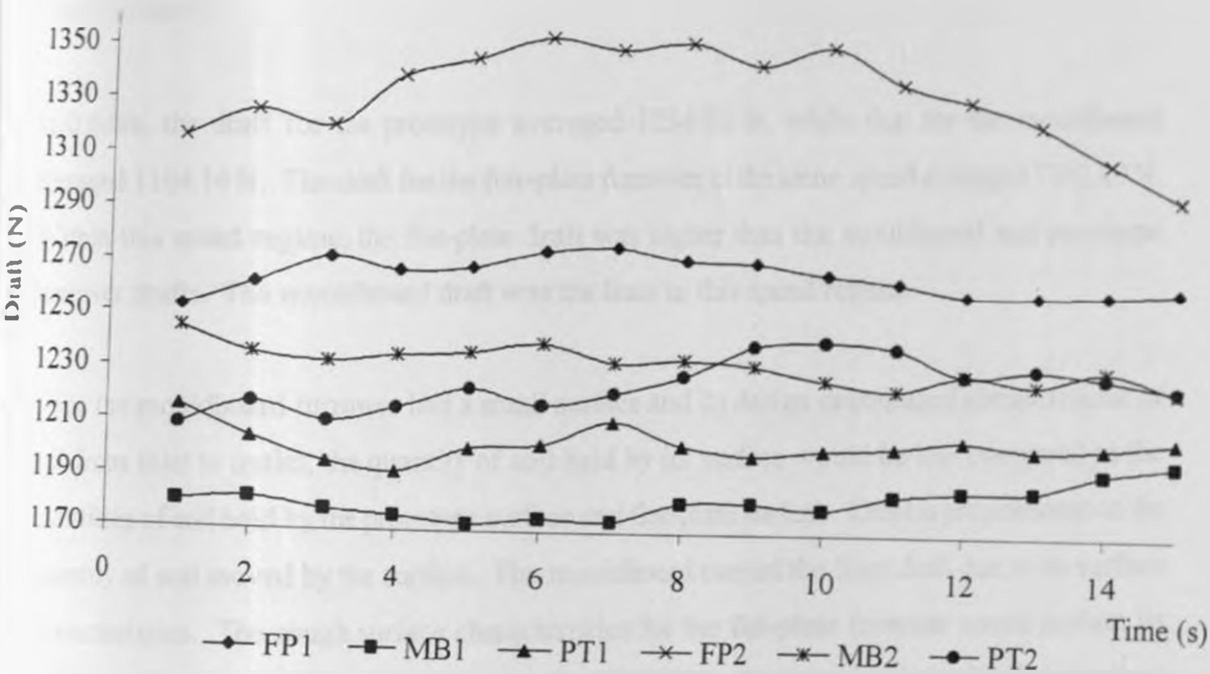

Fig 4.2: Variation in furrowers' sand-bin draft at 0.6m/s and 1.2m/s

However over each testing speed, individual furrowers' speeds differed slightly as seen from Table 4.2. The gear used in each speed and the level of acceleration were kept as uniform as possible, such that variations in the results could not be attributed to change of speed. Thus the variation in the draft could be attributed to weight, suction and draft among other factors. There was no significant statistical difference between the furrowers' drafts at 5% level of significance, over the two operating speeds. From Fig 4.2 and Table 4.1, the prototype furrower draft ranged from 1054.24 N to 1234.93 N with a mean of 1135.6 N. The mouldboard draft ranged from 1135.95 N to 1247.93 N with a mean of 1202.13 N. The flat-plate draft ranged from 1229.39N to 1335.18N.

The flat-plate furrower draft was highest over both testing speeds than the draft for mouldboard and the prototype furrowers. Its draft curve at 0.6m/s oscillated about 1260N, while at 1.35m/s it oscillated about 1240N. The high flat-plate draft could be related to various factors including the furrower surface characteristics, the depth of operation and the speed of operation. The flat-plate surface was rough, a factor that made scouring poor. The flat plate had a bulldozing effect, a tendency that increased the weight of the soil on the surface. Soil flow over the surface was poorly defined.

At 0.6m/s, the draft for the prototype averaged 1234.93 N, while that for the mouldboard averaged 1164.14 N. The draft for the flat-plate furrower at the same speed averaged 1292.49 N. Within this speed regime, the flat-plate draft was higher than the mouldboard and prototype furrower drafts. The mouldboard draft was the least in this speed regime.

Since the mouldboard furrower had a small surface and its design encouraged abrupt release of soil from inlet to outlet, the quantity of soil held by its surface would be low compared to the quantities of soil held by the prototype surface and flat-plate surface. Draft is proportional to the quantity of soil moved by the surface. The mouldboard carried the least draft due to its surface characteristics. The rough surface characteristics for the flat-plate furrower could explain its draft which averaged 1292.49N relative to the 1234.93N and 1164.14N drafts for the prototype and mouldboard respectively.

The prototype furrower broad surface held more soil than the mouldboard and flat-plate furrowers, which must have increased the draft. The prototype furrower was noted to have the tendency of bulldozing soil, which increased its draft requirements. Its ability to accelerate soil over the surface was likely to increase the draft. However the ability of the surface to accelerate soil and move it further could have a positive effect than the negative effect of increased draft. Probably once the furrower is highly polished, it would experience better scouring and hence reduced draft. The furrower was tested against furrowers that were in use while it was new. This could have reduced the relative scouring of soil against the prototype furrower surface with respect to the other furrowers. It may be necessary that the furrower is put under use and tested against the same furrowers once the surface is polished by soil.

At 1.36m/s, Table 4.1 gave mean draft for the prototype as 1136.38N. For the mouldboard the mean draft was 1164.38N while the mean draft for the flat-plate was 1282.28N. From Fig 4.1.2, the draft curves at 1.36m/s averaged about 1340N for the flat-plate, 1240N for the mouldboard and 1240N for the prototype furrower. The low draft for the prototype relative to the drafts for the mouldboard and the flat-plate could be related to the even and gradual development of the prototype soil-engaging surface. The furrowers' mean drafts were summarised in Table 4.4.

Table 4.4: Mean Furrowers Drafts (N) At 0.6m/s and 1.36m/s

Speed (m/s)	Mouldboard	Flat-Plate	Prototype
0.6	1164.14	1292.49	1234.93
1.34	1164.4	1282.28	1136.38

As the speed of operation increased, there was an increase and in some instances a decrease in the drafts for the three furrowers. The mean draft for the mouldboard furrower increased from 1164.14N to 1164.4N, which was an insignificant increase of 0.26N. For the flat plate, the mean draft reduced by 10.21N, while the prototype furrower mean draft increased by 98.55 N as the speed of operation rose from 0.6m/s to 1.36m/s.

From Table 4.1, drafts increased by 25N, 40N and 80N respectively for the prototype, mouldboard and flat-plate furrowers. The prototype furrower had least increase in furrower draft, which could be attributed to scouring resulting from the even and gradual development of the mouldboard from inlet to outlet.

The flat-plate furrower draft increased by 80N, as the speed rose from 0.6m/s to 1.36m/s, which was the highest increase among the three furrowers. The flat-plate design offered a rough surface design that favoured soil resistance to movement over the surface. This could be the reason for the increased flat-plate draft compared to the prototype and the mouldboard furrower drafts. Although the prototype furrower held more soil due to its broad surface relative to the mouldboard and the flat-plate, there could have been improved scouring as the speed of operation increased which resulted in an increase of draft by 25N. The draft for the mouldboard rose by

40N and the draft for the flat-plate rose by 80N for the same increase in speed. The improved scouring could be related to surface design that encouraged acceleration of soil from inlet to outlet and self-polishing of the surface under use.

4.1.2.2 Sand Bin Draft Variations With Final Soil Condition

The final soil conditions included the depth and width of operation. An increased depth of operation would be coupled with an increased width of operation for the three furrowers. Thus the depth of operation was used as a measure of the final soil condition. Also the soil micro-profile was used as a measure of the final soil condition. At a mean operating speed of 0.6m/s, the average depth of operation increased in the order of prototype with 25.8cm, mouldboard with 27.2cm and the flat-plate furrower with 32.8cm (Table 4.2). At 1.36m/s, the mean operating depths were 25.4cm for the prototype, 33cm for the mouldboard and 31.5cm for the flat-plate. The increase in depth as the speed of operation rose from 0.6m/s to 1.36m/s was -0.35cm for the prototype, 5.8cm for the mouldboard and -1.25cm for the flat-plate furrower. The corresponding drafts were 1200N for the prototype, 1190N for the mouldboard and 1260N for the flat-plate.

Although the mouldboard had the least draft, its depth lied between the flat-plate and the prototype operating depths. As the operating speed rose from 0.6m/s to 1.36m/s, the operating depths rose by -0.35cm (a reduction) for the prototype, 5.8cm for the mouldboard and -1.25cm (a reduction) for the flat-plate. The corresponding increase in draft was noted as 25N for the prototype, 40N for the mouldboard and 80 N for the flat-plate.

The changes in depths were minimal for the prototype and flat-plate furrows to warrant any significant analysis. These being sandy soil tests, the flat-plate managed to sink deep into the highly pulverised soils. The mouldboard depths were moderately deep, with the prototype having the least depths. The flat-plate long wedge had the tendency to penetrate the soils under the loose conditions.

The lift angle of the mouldboard was reportedly high. This must have increased penetration ability (suction) by the implement into the soil. To reduce this effect, the initial lift angle of the prototype was taken as low as 12.7^0. The effect of this was noted in form of highly controlled depths of furrowing. This was most probably the reason for the reasonably low prototype furrowing depths relative to the mouldboard and flat-plate furrowers' depths. Due to the low depths, the prototype draft was bound to be low.

4.1.2.3 Unit Draft and Power Consumption

The unit draft ranged between 0.97 N/cm^2 to 1.21 N/cm^2, with a mean of 1.07N/cm^2 for the flat-plate. For the mouldboard, it ranged from 1.03 N/cm^2 to 1.71N/cm^2 with a mean of 1.27N/cm^2, and for the prototype from 1.18 N/cm^2 to 1.64 N/cm^2 with a mean of 1.44N/cm^2. There was no significant statistical difference between the furrowers' unit draft at 5% level of significance. The tractor had an advantage handling the flat-plate as the mean unit draft was much lower than the mean draft for the other furrowers. Although the flat-plate furrower had the tendency of bulldozing soil, this was not reflected in the unit draft. The prototype had the highest unit draft range. Its mean unit draft was the highest compared to the flat-plate and the mouldboard furrowers. It weighed 43.42kg and 42.42 kg more than the flat-plate and mouldboard furrowers respectively. Its high weight must have increased the inertial forces in operation. Although its draft was lower than the draft for the flat plate and the mouldboard, it had lower surface area, and therefore the low furrow widths and depths of operation. These implied that within the same operating depths, the prototype would experience a high unit draft in comparison with the unit draft for the mouldboard and the flat-plate furrowers.

The unit power consumption by the prototype, mouldboard and flat plate furrowers ranged from 0.92 W/cm^2 to 1.78 W/cm^2, 0.77 W/cm^2 to 1.41 W/cm^2 and 0.68 W/cm^2 to 1.72 W/cm^2 respectively. There was significant increase in the furrowers power consumption at 5% level of significance as the speed of operation was increased from 0.6m/s to 1.34 m/s. The high power consumption implied high energy consumption and hence high fuel consumption. It would be cheaper to operate the flat-plate than the prototype plate, while the mouldboard would be the cheapest to operate as its energy consumption was least.

4.1.2.4 Vertical forces variation with depth and speed

At 0.6m/s, the vertical force curves magnitudes increased in the order of mouldboard, flat plate and the prototype furrower (Fig 4.3).

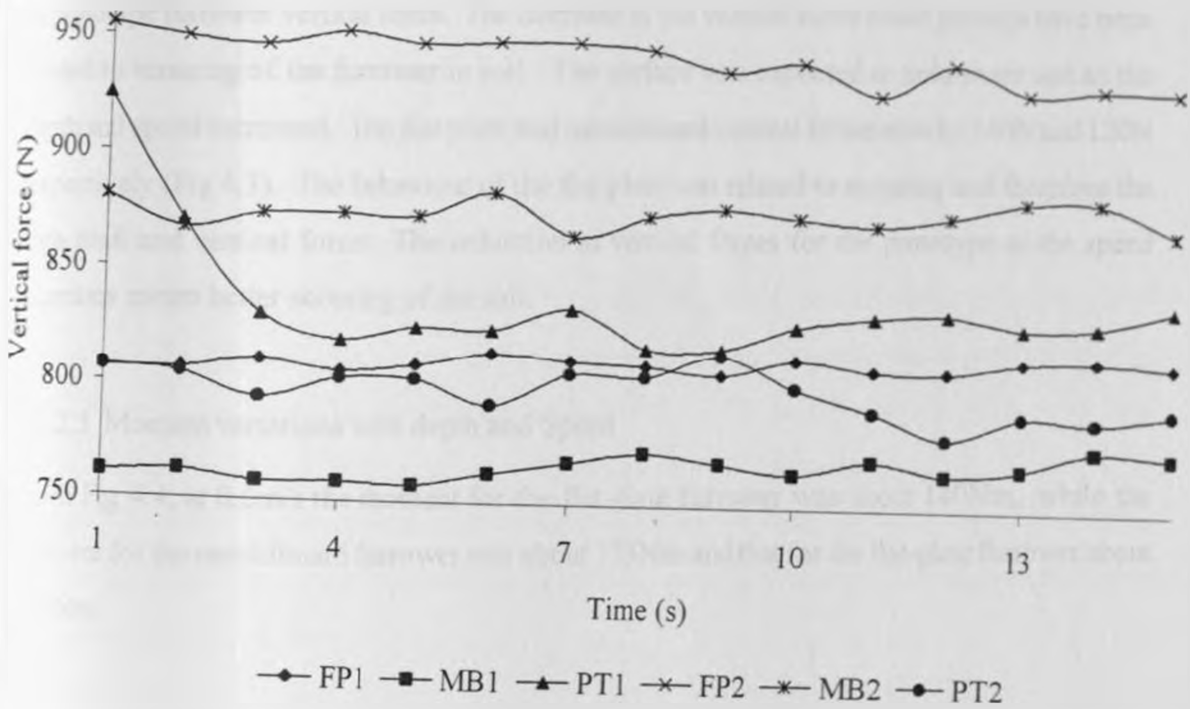

Fig 4.3 Sand bin vertical forces at 0.6 m/s and 1.36 m/s

The mean logged vertical forces for mouldboard, flat plate and prototype furrowers were 809.06 N, 811.34 N and 836.37 N respectively (Table 4.1). There was no significant statistical difference in furrowers vertical forces at the testing speeds used at 5% level of significance. The high vertical forces acting on the prototype could be associated with its heavy weight, and the amount of soil held on its broad surface. The prototype had a mean depth of 25.8cm. compared to the mean depths of 27.2 cm and 32.8 cm respectively for the mouldboard and flat-plate (Table 4.2). The high vertical forces could only be linked to the surface and design characteristics and not the final soil condition. The flat plate, due to its flat and rough surface design which must have led to poor scouring while in operation had 810N mean vertical force while the mouldboard had 750N mean vertical force. The mouldboard surface design encouraged scouring, which must have led to the low vertical forces. The weights must have increased the vertical forces on the furrowers.

At 1.36 m/s mean operating speed, the prototype had a vertical force of about 790N, the mouldboard had about 870N and the flat-plate about 950N. The furrow depth for the prototype decreased from 25.8cm to 25.35 cm (Table 4.2) which could be treated as an insignificant reduction in depth. An increase of 0.76m/s operating speed was accompanied by a 40N reduction in prototype furrower vertical force. The decrease in the vertical force could perhaps have been related to scouring of the furrower in soil. The surface was expected to hold more soil as the depth and speed increased. The flat plate and mouldboard vertical forces rose by 140N and 120N respectively (Fig 4.3). The behaviour of the flat plate was related to scouring and therefore the high draft and vertical forces. The reduction in vertical forces for the prototype as the speed increases meant better scouring of the soil.

4.1.2.5 Moment variations with depth and Speed

From Fig 4.4, at 0.6m/s the moment for the flat-plate furrower was about 140Nm, while the moment for the mouldboard furrower was about 125Nm and that for the flat-plate furrower about 125Nm.

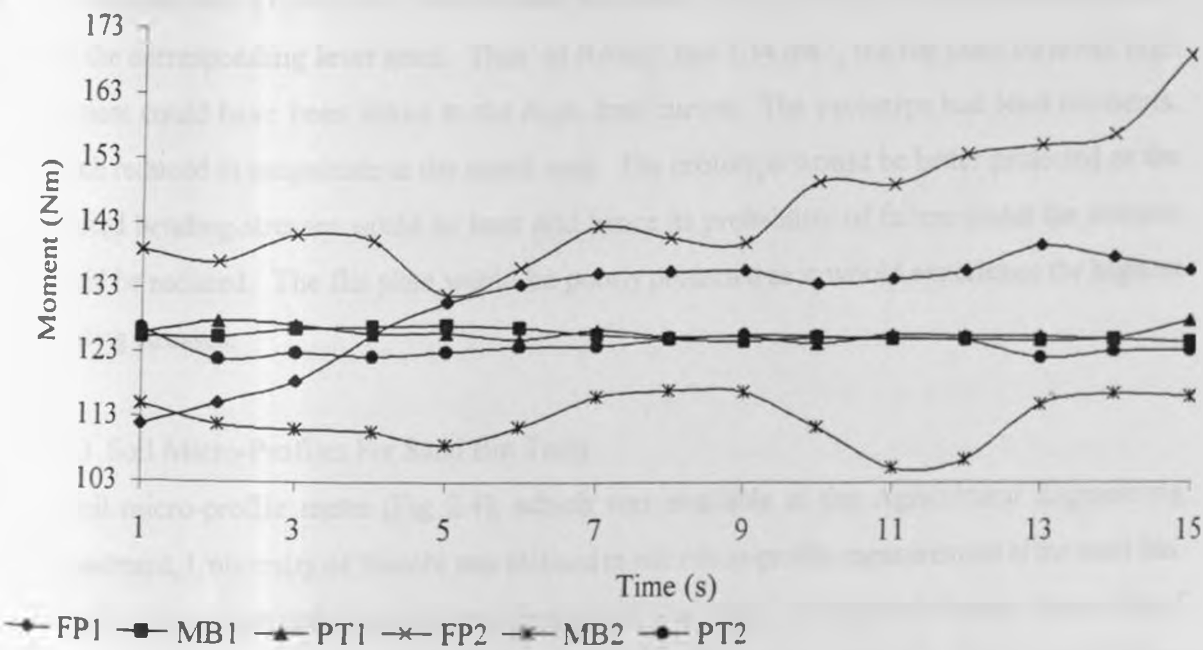

Fig 4.4 Furrowers sand-bin moments at 0.6m/s and 1.36m/s

At this speed of operation, the mouldboard and the prototype demonstrated the same magnitude of moment, as the flat-plate demonstrated a higher mean moment. At 1.36m/s, the flat-plate moment could be approximated to 135Nm, the mouldboard moment to 125Nm and the prototype moment to 121Nm.

The increase in depth of operation as the speed of operation increased from 0.6m/s to 1.36m/s was -0.35 cm for the prototype, 5.8cm for the mouldboard and -1.25cm for the flat-plate. The corresponding increase in moment was -4Nm for the prototype and -5Nm for the flat-plate. There was no increase in mouldboard moment for the increase in speed of operation. The moment for the prototype and the flat-plate furrowers decreased, despite an increase in speed of operation. The operating depths could have had an effect on the moment, as the reduction in depth was accompanied by a reduction in moment. This trend was not observed in the mouldboard, which had an increase in operating depth of 5.8cm and had no change in the resulting moment. The above argument was derived from graphical approximations. Table 4.1 gave a rise in the mouldboard moment from a minimum of 106Nmm to 129Nmm as the speed rose from 0.6m/s to 1.2m/s.

The moment was a function of the draft and the vertical forces acting on the structural member and the corresponding lever arms. Thus at $0.6ms^{-1}$ and $1.34\ ms^{-1}$, the flat plate furrower high moment could have been linked to the high draft curves. The prototype had least moments, which reduced in magnitude as the speed rose. The prototype would be better protected as the induced bending stresses would be least and hence its probability of failure under the stresses would be reduced. The flat plate would be poorly protected as it would experience the highest bending stresses.

4.1.3 Soil Micro-Profiles For Sand Bin Tests

A soil micro-profile metre (Fig 2.4), which was available at the Agricultural Engineering Department, University of Nairobi was utilised in soil micro-profile measurement at the sand bin. It had twenty depth rods spread over a distance of one metre. Along each furrow, three sets of readings were taken and tabulated in Table A3 and Table A4 in Appendix 1. The means for the readings of each point were evaluated to give the data in Table 4.5, which was used to plot soil profiles as in Fig 4.5 and 4.6. Table 4.5 gave the deepest points as 24.3cm for the prototype, 20.4cm for the flat-plate and 19 cm for the mouldboard furrower at the first set of readings.

Table 4.5: Means of sand-bin relief metre readings

Distance Across Furrow (cm)	Furrow Depth (cm) at 0.6m/s			Furrow Depth (cm) at 1.4m/s		
	Prototype	Flat Plate	Mouldboard	Prototype	Flat Plate	Mouldboard
5	-1.8	-1	-0.2	-1.3	-1.9	-2.7
10	-1.6	-0.6	-0.1	-1	-1.5	-0.1
15	0	-0.6	-2.4	-0.1	-1.4	-0.7
20	-2.3	-2.4	-4.5	-0.8	-0.7	-2
25	-6.6	-2.4	-4.5	-2.0	-3.2	-3.9
30	-7.2	-3	-6.1	-2.4	-6.6	-4.8
35	-8.7	-3.2	-8.5	-5	-9.4	-5.3
40	-13.1	-4.5	-13.5	-10.1	-12.9	-18.2
45	-17.2	-12	-17	-20.6	-17.2	-18.6
50	-23.8	-14.9	-19.2	-21	-18.2	-19.2
55	-24.3	-20.4	-19.5	-23.1	-17	-20.1
60	-17.3	-17.1	-12.9	-18.9	-16.2	-19.5
65	-13.4	-16.5	-9.4	-9.9	-13.7	-17.9
70	-8.8	-11.8	-5.3	-4.8	-9.7	-13.1
75	-7.7	-5.9	-0.8	-2.3	-5.3	-10.3
80	-3.5	-5.5	-0.5	-2	-4. 6	-9.5
85	-2.0	-5	-0.1	-1.1	-4.2	-8.9
90	-0.1	-2	-1.6	0	-2.8	-5.7
95	-1.4	-0.9	-1.4	-0.9	-2	-4.2
100	-1.6	-6.5	-2.6	-1.3	-0.4	-2.5

Fig 4.5 depicted the post design furrow relief at 0.6m/s. From the graph, the prototype curve was symmetrical along the 50cm mark of the distance across the furrow, indicating equidistant throw of soil away from the centre of symmetry. The prototype curve projected high above the mouldboard and flat plate curves. Its tails were about the same height on both sides of the abscissa of symmetry. The flat-plate line was skewed on the left of 50cm mark of the distance across the furrow, while the mouldboard was skewed to the right of the same mark. The implication was that the mouldboard and the flat-plate throw of soil was not equidistant on both sides of the furrow, implying lack of symmetry of the furrowers soil engaging surfaces for the mouldboard or for the flat-plate about the centre-line of the shank, while the prototype demonstrated the symmetry quality.

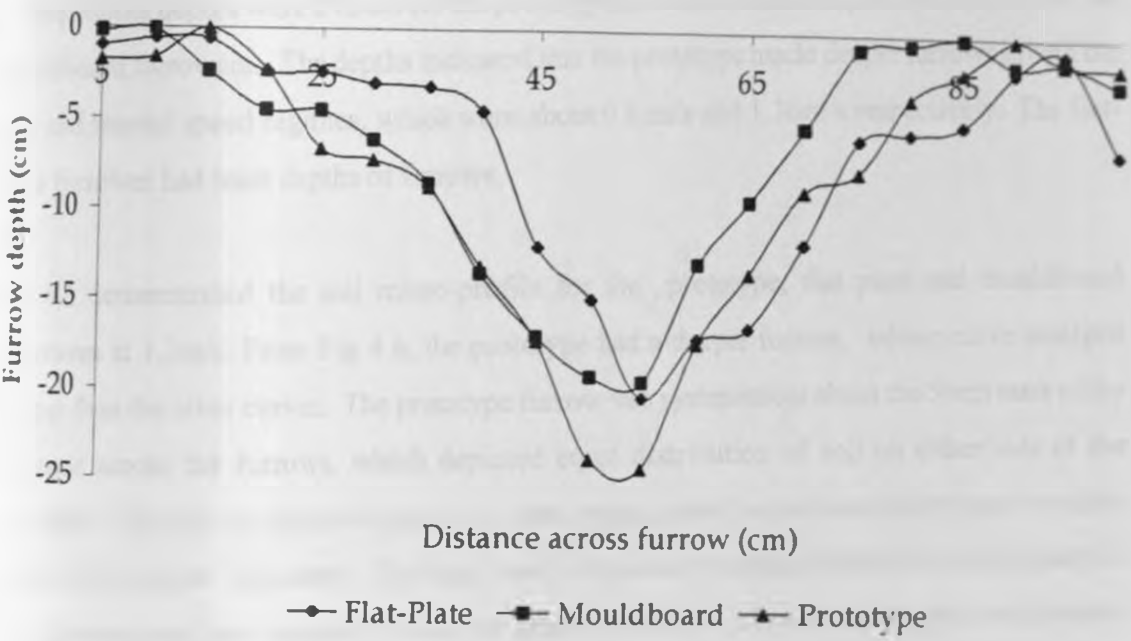

Fig 4.5 Sand-bin test result micro-profile curves at 0.6m/s

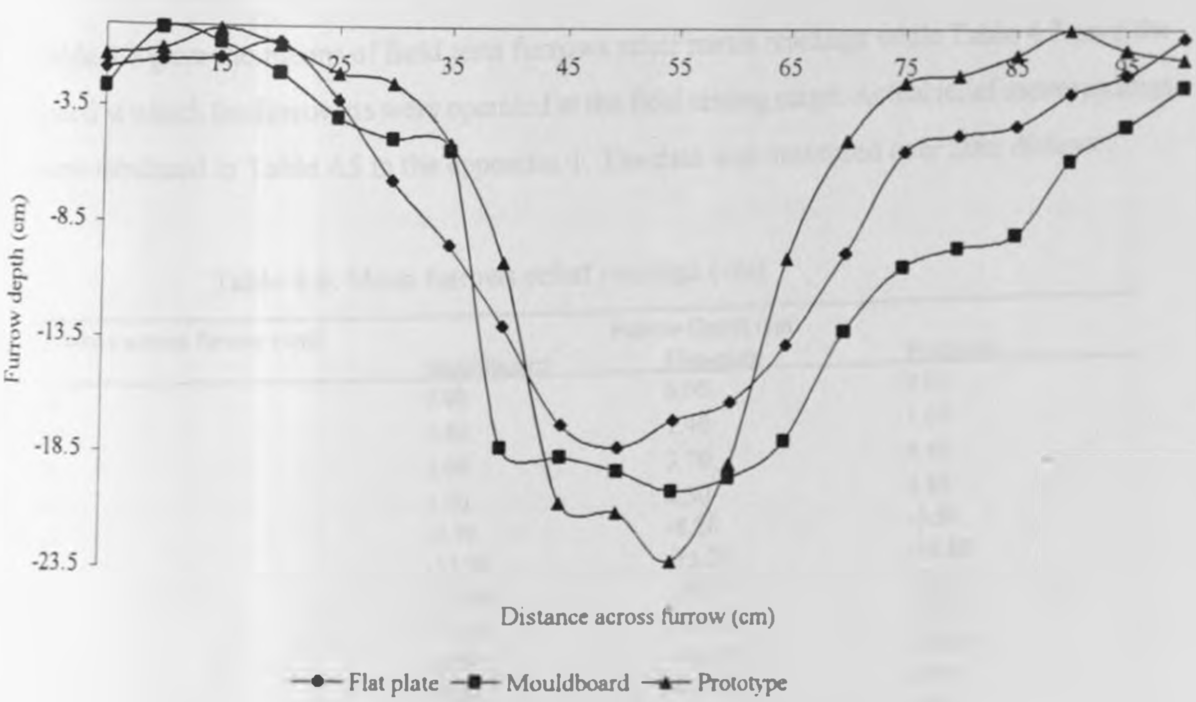

Fig 4.6: Soil Micro-profiles taken at the sand-bin At 1.4 m/s

At 50cm across the furrow, which was the centre point of the micro-profile metre, the corresponding depths were 24.3cm for the prototype, 22.4cm for the flat-plate and 19.5cm for the mouldboard furrowers. The depths indicated that the prototype made deeper furrows in both the first and second speed regimes, which were about 0.6 m/s and 1.36m/s respectively. The flat-plate furrower had least depths of furrows.

Fig 4.6 demonstrated the soil micro-profile for the prototype, flat plate and mouldboard furrowers at 1.2m/s. From Fig 4.6, the prototype had a deeper furrow, whose curve emerged deeper than the other curves. The prototype furrow was symmetrical about the 50cm mark of the distance across the furrows, which depicted equal distribution of soil on either side of the furrower. The tails of the prototype curve were approximately equidistant above zero on either side of the point of symmetry. The high level of symmetry implied high level of uniformity of mouldboards and their symmetry about the shank centre line. Lateral loads on the mouldboards and subsequently the shank should add-up to zero.

4.2 Furrowing Field Test Results and Discussion

Table 4.6 gave the means of field tests furrows relief metre readings while Table 4.7 gave the speed at which the furrowers were operated at the field testing stage. Actual relief metre readings were tabulated in Table A5 in the appendix 1. The data was measured over 20m distance.

Table 4.6: Mean furrows relief readings (cm)

Distance across furrow (cm)	Furrow Depth (cm)		
	Mouldboard	Flat-plate	Prototype
10	0.00	0.00	0.00
20	0.80	1.40	1.60
30	2.00	3.70	4.40
40	1.70	2.50	3.80
50	-2.70	-8.20	-5.50
60	-13.90	-15.20	-16.80
70	-19.90	-14.70	-23.40
80	-14.10	-16.80	-22.10
90	-8.30	-13.10	-15.10
100	-6.00	-4.70	-6.90
110	0.50	-0.60	2.30
120	-1.10	3.10	4.20
130	-2.40	-1.70	-2.50
140	1.30	-8.00	0.10

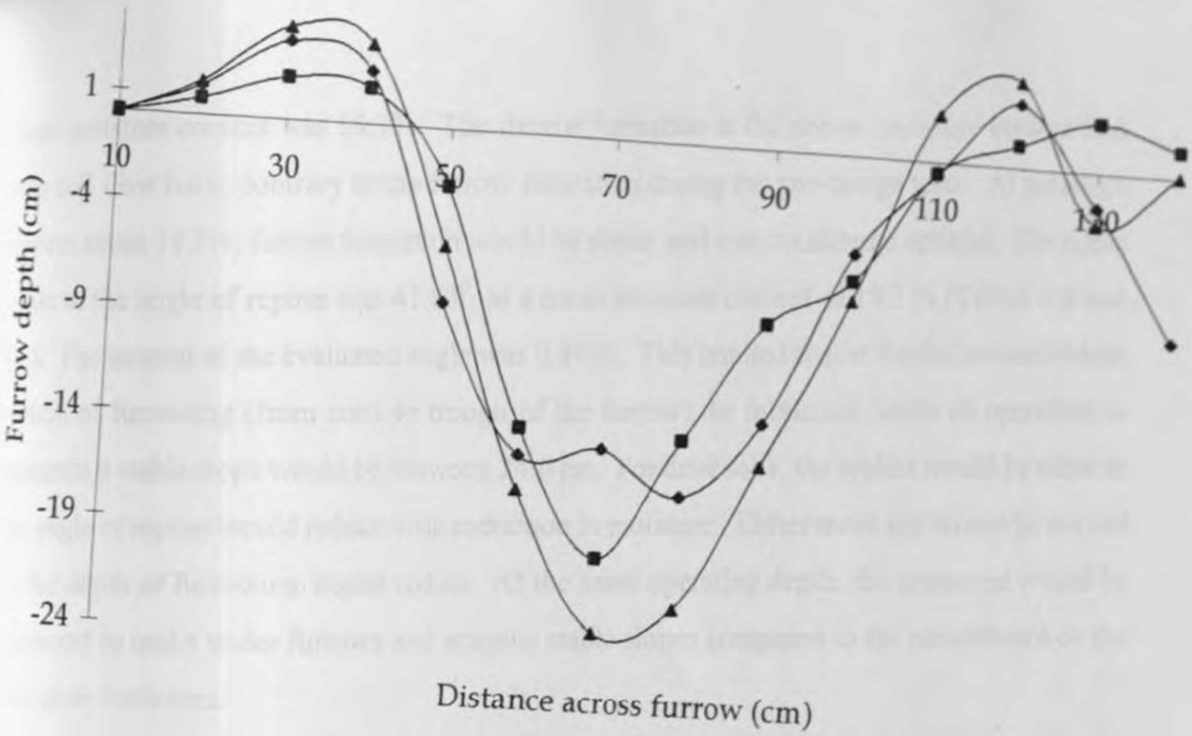

Fig 4.7: Field tests furrow relief

Table 4.7: Field Testing Speed.

Furrower	Distance Measured =20m)					
	First Trial		Second Trial		Third Trial	
	Time (s)	Speed (m/s)	Time (s)	Speed (m/s)	Time (s)	Speed (m/s)
Mouldboard	10	2	8.5	2.15	9	2.22
Flat-Plate	9.5	2.1	9	2.22	9.5	2.1
Prototype	9	2.22	9	2.22	10	2

Table 4.8 gave the soil moisture content at the testing period, while Table 4.9 gave the angle of repose (ϕ) of the soil as measured during in the field.

Table 4.8: Soil moisture content

Sample	First	Second	Third	Fourth
W_{ws}	100	100.5	100	100.2
W_{ds}	80.2	80.6	80.7	81.4
%M (wb)	19.8	19.8	19.3	18.3

Mean moisture content was 19.3%. The furrow formation at the above moisture content had little soil flow back, contrary to the furrow formation during the pre-design tests. At moisture content about 19.3%, furrow formation would be stable and was considered optimal. The mean value of the angle of repose was 41.83^0, at a mean moisture content of 19.3 % (Tables 4.8 and 4.9). The tangent of the evaluated angle was 0.8950. This implied that at depths between 44cm typical of furrowing (from crest to trough of the furrow) the minimum width of operation to maintain a stable slope would be between 24.6 cm. For drier soils, the widths would be more as the angle of repose would reduce with reduction in moisture. Either more soil would be moved or the depth of furrowing would reduce. At the same operating depth, the prototype would be expected to make wider furrows and achieve stable slopes compared to the mouldboard or the flat-plate furrowers.

Table 4.9: Angle of repose.

Sample	First	Second	Third	Fourth
Diameter (d) cm	20	20	20	20
Height (h) cm	8.9	9	9	8.9
Angle of Repose ϕ	41.67	41.99	41.99	41.67

From Table 4.6, the deepest point for the prototype had a mean depth of 23.4cm, while the deepest points for the mouldboard and flat-plate were 19cm and 17.7cm respectively. The depths for the mouldboard and flat-plate furrowers were lower than required depth, while 23.4cm was within 22 to 24cm, which are acceptable depths in furrowing. The reduced flat-plate and mouldboard furrow depths could have resulted from the soil flow-back due to the unstable slope, resulting in the reduced furrow width. The prototype demonstrated better performance in terms of stable and deep furrow formation. The flat-plate furrower performance was close to that of mouldboard furrower, because the soils were close to sandy conditions and were in the friable phase of its moisture content (19.3%).

The moisture content was adequate for soil workability, trafficability and soil pulverisation with minimum soil-soil and soil-metal movement resistance. Soil build up infront of the furrowers was minimal. This was confirmed by the performance evaluation on site. The flat-plate furrower had shallow furrows (Table 4.6) compared to the mouldboard and the prototype furrowers, as in the three cases it had depths lower than those of the mouldboard and the prototype furrowers. Its furrows were narrower. Under these soil conditions, with the flat-plate furrower having made poorer furrows than the other furrows, it became obvious that under worse soil conditions the flat-plate performance would be un-acceptably poor. The mouldboard furrows were narrow with poor formation (Fig 4.7), while the furrower demonstrated poor symmetry.

Although soil would move over the surface, the distance of throw of soil was minimal for the flat-plate (Fig 4.7). For soil to settle over the furrow slopes, the slope angle would be less than the soil angle of repose. If a furrower made narrow furrows, the slope of the furrows would be more than the angle of repose, common with the mouldboard and the flat-plate furrowers, thus the high level of soil flow back and shallow furrows. The mouldboard furrows were therefore shallow. The prototype furrower made wide furrows compared to the flat-plate and the mouldboard furrowers (Fig 4.7). The manner of soil movement was more of bulldozing than soil flow. However the furrower swept more soil on the ridge than the mouldboard furrower and flat-plate. Despite the depths of the furrows made by the prototype, its soil was stable on the ridge, indicating that the slope angle was lower than the angle of repose of the soil.

From Fig 4.7 the following could be observed.

(a) The prototype made furrows that were deeper than the furrows for both the mouldboard and the flat-plate, which could be associated to suction. Due to its surface characteristics as discussed earlier, the prototype furrower developed more suction than the flat-plate and the mouldboard furrowers.

(b) The flat-plate furrows were shallowest compared to both the mouldboard and the prototype furrows. The shallow depth of the flat-plate furrows could be attributed to the suction of the furrower and stability of the furrow slope. The furrow stability depended on the height of the furrow and the soil angle of repose. The flat-plate had been noted to demonstrate poor penetration and hence the suction was low. However its soil flow-back was less than that for the mouldboard furrower and hence the dominant problem noted was poor penetration and not soil flow back as the flat-plate furrow slope was relatively stable.

(c) The mouldboard furrow depths were between the flat-plate and the prototype furrow depths. The furrows were however scattered with clods of soil emanating from soil flow back (Fig 4.7). The oscillatory nature of the mouldboard furrower curves in Fig 4.7 resulted from soil clods, which flew back into the furrow during furrowing. The implication was a slope angle higher than the soil angle of repose (41.86^{o}). While previously the furrower was making shallow furrows, the main problem could have been a high magnitude of soil flow back.

The prototype furrower threw soil further than the mouldboard and flat-plate furrowers. The distance of throw was coupled with a greater depth of furrowing. The result was a slope (ratio of vertical height to horizontal distance) angle that was less than the angle of repose. Thus the prototype furrower made deeper and more stable furrows than those mad by the mouldboard and flat-plate furrowers. This observation could be attributed to the stable slope formation due to the distance of throw, hence the reduced soil flow back. The reduction in surface radius from inlet to outlet could have increased the acceleration of soil over the surface. At the outlet, the soil would experience higher angular speeds and hence would be thrown out at higher speeds. These would imply greater distances of throw, resulting in less soil flow back and therefore more stable furrow formation.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

From pre-design furrowers assessment tests, the furrowing forces were established from which a design force of 8341.37N was identified. The design focused on curved surface with respect to the flat-plate, as the curved (mouldboard) surface attained the required depths between 22cm-24cm while the flat-plate could not attain the required depths in the field. The furrower height was established as 46cm which was slightly less than twice the furrow depth (24cm)

From the design carried out, the shank dimensions of 900mm by 200mm by 25mm of 070m20 British standards (BS) steel was found adequate to support the furrower in operation. A shear bolt of 16mm diameter was considered adequate for the operation. The pivot bolt design gave its diameter as 25mm. Angle sections of 127mm by 127mm by 15.9mm were considered as adequate to support the furrower bottom to the tool-bar. A tool-bar of 170mm by 170mm by 6 mm of length 1.6m was chosen. The flanges that fitted the upper arm were designed from c25 mn 75 isi steel of height 607mm and 12.5mm thickness.

A mouldboard (soil engaging surface) of 12.5mm thickness was designed. A frog (to support the mouldboard to the shank) of the same thickness was designed. A prototype of 148.38kg per furrower bottom was fabricated. For a two bottomed furrower the mass estimated at 438.52kg. The furrower could be supported by a 80hp furrowing tractors both in transport and operation.

From sand-bin tests, the prototype had a mean draft of 1135.60N, the mouldboard had a mean draft of 1202.13N and the flat-plate had a mean draft of 1287.38N. The specific power consumption for the prototype ranged from 0.92Wcm^{-2} to 1.78Wcm^{-2}, for the mouldboard from 0.77Wcm^{-2} to 1.41 W/cm^{-2} and for the flat-plate furrower from 0.68Wcm^{-2} to 1.72 Wcm^{-2}. The mean lateral moment for the prototype furrower was 126.69Nm, for the mouldboard it was 122.40Nm and for the flat plate it was 136.12Nm. The flat-plate moment put the furrower at a higher risk in operation as the induced stresses would be high compared to the mouldboard and the prototype furrower.

The prototype mean maximum depth of operation at the sand bin was 25.8cm at 0.6m/s and 25.4cm at 1.36m/s. In field tests, the mean of the depths was 28.5cm. In both the field and the sandbin tests, the prototype furrowing depths were more than the expected 22-24cm furrowing depths. The mouldboard furrower had a mean maximum depth of 27.2cm at 0.6m/s and 33cm at 1.36m/s operating speeds in the sandbin. In the field, the mean maximum depth was 18.3cm. The average maximum operating depths for the flat-plate in the sand-bin tests were 32.8cm at 0.6m/s and 31.5cm at 1.36m/s, with a mean depth of 17.7cm. While in the sandbin all the furrowers demonstrated acceptable depths of operation, in the field both the mouldboard and the flat-plate demonstrated depths of operation which were below 22cm.

The cost of fabricating a prototype furrower was Kshs 93 000/=, while the cost of fabrication of the mouldboard furrower was Kshs 97 500/=. The cost of fabrication of the flat-plate could not be established. Quotation prices for a mouldboard furrower ranged from Kshs 108 850 to 1 915 690/=. The cost of the prototype was thus lower than the cost of the other mouldboard furrowers either by fabrication at Mumias sugar company or by local or import purchasing. The cost of the prototype was Kshs 183.04 per operating hour, while that for the mouldboard was Kshs 180.71 per operating hour. Surface polish and further modifications could reduce the prototype costs.

Despite the flat-plate low furrowing depths, its power consumption was higher than the power consumption for the mouldboard. Its use should be discouraged. The prototype furrower demonstrated increased power consumption coupled with better furrow formation, low operating moments and drafts. It was therefore superior to the previously existing designs.

5.2 Recommendations

a) The angle sections of 75mm by 75mm by 10mm previously in use in the mouldboard furrower could not support the furrower to the tool-bar in operation. The correct size of angle sections was 127mm by 127mm by 15.9mm. The tool-bar of 132mm by 132mm by 6mm (box section) of length 1.6m should replace the box section that was previously in use. The shear bolt should be reduced from the previous 25mm diameter to 16mm diameter bolt.

b) The evaluation tests were carried out using a newly made non-polished surface. Scouring of soil over such surface would be poor. Further testing of the furrower after some use would probably give lower levels of draft, vertical force and moments as the furrower would be polished by the soil. Incorporation of Teflon would also improve the surface scouring, although this would increase the costs.

c) The prototype furrower would consume more power (0.92 W/cm^2 to 1.78 W/cm^2) than the mouldboard (0.77W/cm^2 to 1.41 W/cm^2) and the flat-plate (0.68 Wcm^{-2} to 1.72W/cm^2). Its performance was superior to the performance of the mouldboard and the flat-plate furrowers. The use of the flat-plate should be totally discouraged as it was found to demonstrate poor performance coupled with high draft requirements.

d) The prototype furrower design curvature was picked arbitrarily. Its performance with respect to the power consumption was not desirable. The high power consumption increased its costs above those of the mouldboard. The prototype dimensions and curvature should be altered and the effects assessed with the view to reducing the energy consumption.

e) The thickness of the prototype mouldboard and frog were 12.5mm each, while the thickness of the existing furrower mouldboard, which was experiencing failure was 8mm. A combined thickness of 8mm for mouldboard and 8mm for frog would resist failure better than a single 8mm thick furrower mouldboard. The reduction would result in the prototype furrower weight reduction by 44.96 kgf or 441.06N. This would probably result in reduction of the furrower draft, vertical forces and power consumption.

This being the first prototype, further prototype modifications and testing would be necessary, aimed at achieving a lower power consuming furrower.

5.3 Future Work

The following will need to be done to improve the performance of the prototype

a) Longevity of the soil-engaging surface of the unit while in operation should be enhanced. Soils at Mumias Sugarcane farms are abrasive and would wear the soil engaging surface fast, hence reducing its useful life and increasing down time. Carbonising the soil-engaging surface, which could be within Mumias technical and financial capabilities, would increase its resistance to abrasion. Other means of increasing the useful life of the surface would be to use the off-centre- soft-centre three-ply material used in mouldboard plough design, and the use of Teflon on the surface, which would improve scouring. The last two means may not be available in the company at the time of need, though they could be within the technical and financial capabilities of Mumias Sugar company

b) Down time could be reduced by use of an automatic reset spring as a protective mechanism instead of using a shear bolt. The possibility of automating the protection should be investigated and if viable and possible incorporated

c) The prototype should be polished to the same level as the mouldboard for improved scouring. This could be done by using the prototype in the field for some time, as soil would polish the surface. The furrowers could then be re-tested to establish the level of energy consumption and furrow formation

d) Change of the curvature and dimensions in the design to establish a rational curvature that would reduce power consumption without compromising on the field furrowing performance. The depth of furrowing was 23cm. The height of the furrower was made as 46cm. The maximum height of furrows under field condition was 25cm. Thus, the 46cm height was too high above the height of the furrows. Furrower dimensions could be reduced to probably as low as 35cm for the front radius and probably 25 to 30 cm for the rear radius. The furrow weight would be reduced, the quantity of soil held by the surface would also be reduced while the accelerability of soil over the surface would not be lost in the design.

e) The thickness of the furrower mouldboard and frog should be reduced to 8mm each from the current 12.5mm. This would result in reduced furrower weight. The effect of the reduction of the weight on the vertical force, draft, moment and power consumption in addition to field performance should be investigated.

f) The prototype should be subjected to further tests after the modifications. These tests should include furrower power consumption, tillage performance, as well as the performance of the two bottoms combined.

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APPENDICES

Appendix 1: Furrow Relief Readings For Various Furrows

Table A1: First set of pre-design furrows relief readings

	Flat- plate					Mouldboard				
X	1st	2nd	3rd	4th	v̄	1st	2nd	3rd	4th	v̄
10	-2.1	-2.3	-1.8	-2.2	-2.1	-2	-1.8	-2.1	-2	-2
20	-5.7	-6	-5.4	-5.8	-5.7	-4	-4.5	-3.8	-4.2	-4.1
30	-1.1	-1	-0.8	0	-0.3	-6.9	-5.5	-5.9	-6.8	-6.3
40	-0.2	-0.1	0	-0.5	-0.2	-11	-11	-12	-11	-11
50	-6.6	-6.4	-5	-6.9	-6.2	-14	-15	-15	-14	-15
60	-13.1	-13	-12	-13	-13	-19	-19	-19	-19	-19
70	-19.2	16.8	-15	-16	-17	-25	-24	-25	-25	-25
80	-20.5	-21	-20	-21	-21	-20	-20	-19	-19	-19
90	-17.5	-17	-18	-18	-18	-14	-14	-14	13.6	-14
100	-13.6	-14	-13	-14	-14	-9.9	-9.2	-10	-9.5	-9.6
110	-7.7	-7.5	-7.8	-8	-7.8	-1.8	-2	-1.6	-1.9	-1.8
120	-1.1	-1.2	-1	-0.8	-0.6	0	-0.2	-0.1	0	-0.1
130	0	-0.5	-0.4	-0.5	-0.4	-1.1	-1	-1.2	-0.8	-1
140	-1.1	-1.2	-0.8	-1	-1	-2.2	-1.9	-2.1	-1.8	-2

Table A2: The second set of pre -design furrow relief readings (cm)

	Flat-plate					Mouldboard				
X	1st	2nd	3rd	4th	v̄	1st	2nd	3rd	4th	v̄
10	-2.5	-2.4	-1.9	-2.9	-2.4	-0.9	-1	-1.2	-0.8	-1
20	0	-0.5	-0.8	0	-0.3	-1.9	-1.8	-1.7	-1.9	-1.8
30	-8.1	-1	-0.8	-2.3	-1.1	-2.4	-2.7	-2.1	-2.5	-2.4
40	-5.6	-5.4	-5.3	-6.1	-5.6	-2.6	-2.5	-2.7	-2.5	-2.6
50	-15.8	-6.3	-6	-5.4	-5.9	-11	-11	-11	-11	-11
60	-13.7	-14	-14	-13	-13	-19	-19	-19	-19	-19
70	-18.3	-19	-18	-18	-19	-23	-23	-23	-24	-23
80	-19.9	-18	-19	-19	-19	-17	-17	-17	-18	-17
90	-18.8	-19	-19	-19	-19	-8.6	-8.4	-8	-7.8	-8.2
100	-12.7	-13	-14	-13	-13	-5.7	-5.9	-5.5	-5.3	-5.6
110	-5	-5.6	-4.8	-4.9	-5.1	-2.7	-2.9	-2.5	-3.1	-2.8
120	-1.1	-0.8	-1.2	-4	-1.8	-2.3	-2.7	-2.1	-2.2	-2.3
130	-1.1	-0.7	-1.2	-7	-2.5	-0.9	-1.1	-0.8	-0.9	-0.9
140	-4.6	-1.4	-3	-5	3.5	0	-1.1	0	-0.8	-0.5

Table A3: Sand-bin furrows relief readings at V_1

	Flat-plate				Mouldboard				Prototype			
X	1st	2nd	3rd	$\bar{y}$	1st	2nd	3rd	$\bar{y}$	1st	2nd	3rd	$\bar{y}$
5	-0.9	-1	-1.2	-1	0	-0.3	-0.1	-0.2	-1.8	-1.6	-2.1	-1.8
10	0	-0.5	-1.4	-0.6	0	-0.1	-0.1	-0.1	-1.6	-1.7	-1.4	1.6
15	-0.3	-0.6	-0.8	-0.6	-3	-2.6	-2.1	-2.4	0	0	-0.2	-0.1
20	-2.2	-2.4	-2.5	-2.4	-4	-5	-4.3	-4.5	-2.3	-2.1	-2.5	-2.3
25	-2.5	-2.6	-2.1	-2.4	-4	-4.6	-4.6	-4.5	-6.7	-6.8	-6.3	-6.6
30	-2.9	-2.5	-3.6	-3	-6	-6.2	-5.8	-6.1	-7.3	-7.2	-7	-7.2
35	-3.2	-3	-3.3	-3.2	-9	-8.2	-8.8	-8.5	-8.6	-8.6	-8.8	-8.7
40	-4	-4.6	-4.9	-4.5	-14	-13.7	-13	-14	-13	-13	-13	-13
45	-12.	-12.	-10.	-12	-18	-16	-18	-17	-17	-17	-18	-17
50	-16	-15.	-12.	-14.	-19	-19.5	-19	-19	-24	-24	-24	-24
55	-21.	-19.	-26.	-22.	-18	-18.2	-22	-20	-25	-24	-24	-24
60	-19.	-18.	-12.	-17.	-12	-12.3	-14	-13	-17	-17	-18	-17
65	-17.	-17.	-14.	-16.	-9	-10.2	-8.9	-9.4	-13	-14	-13	-13
70	-12.	-12	-10.	-11.	-5	-6.1	-4.8	-5.3	-8.8	-9	-8.5	-8.8
75	-6.3	-6.1	-5.2	-5.9	-1	-0.8	-0.8	-0.8	-7.6	-8	-7.4	-7.7
80	-6	-5.8	-4.8	-5.5	-1	-0.8	-0.3	-0.5	-3.2	-3.3	-4	-3.5
85	-5.2	-4.9	-4.9	-5	0	-0.2	-0.1	-0.1	-2	-1.8	-2.3	-2
90	0	-4	-2	-2	-2	-1.7	-1.4	-1.6	0	-0.2	0	-0.1
95	-0.5	-1.4	-0.8	-0.9	-2	-0.8	-1.8	-1.4	-1.4	-1.1	-1.6	-1.4
10	-6.3	-7.2	-6.2	-6.5	-3	-2.3	-2.8	-2.6	-1.7	-1.5	-1.6	-1.6

Table A4: Sand-bin test results for the furrows at V_2

	Flat-plate				Mouldboard				Prototype			
X	1st	2nd	3rd	$\bar{y}$	1st	2nd	3rd	$\bar{y}$	1st	2nd	3rd	$\bar{y}$
5	-2	-1.7	-2.1	-1.9	-2.6	-2.9	-2.7	-2.7	-1.2	-1.4	-1.3	-1.3
10	-1.5	-1.2	-1.8	-1.5	0	-0.1	-0.3	-0.1	-1	-1.2	-0.8	-1
15	-1.2	-1.3	-1.6	-1.4	-0.8	-0.6	-0.7	-0.7	0	-0.3	0	-0.1
20	0	-1.2	-0.8	-0.7	-2.1	-2.2	-1.8	-2	-0.8	-0.9	-0.8	-0.8
25	-3.2	-3.7	-2.8	-3.2	-3.7	-4.2	-3.9	-3.9	-2	-1.8	-2.3	-2
30	-7.4	-5.6	-6.8	-6.6	-4.8	-4.6	-4.9	-4.8	-2.5	-2.2	-2.5	-2.4
35	-9.9	-8.7	-9.6	-9.4	-5.4	-5.3	-5.2	-5.3	-5	-5.2	-4.7	-5
40	-13	-12.6	-13.2	-12.9	-17.8	-18.2	-19	-18	-10	-9.7	-10.5	-10.1
45	-17.4	-16.4	-17.8	-17.2	-18.4	-18.4	-19	-19	-20	-21.5	-20.1	-20.6
50	-17.9	-18.5	-18.2	-18.2	-18.4	-19.2	-20	-19	-21	-20.9	-21.2	-21
55	-17.3	-16.7	-17.1	-17	-19.5	-19.5	-21	-20	-22	-23.6	-23.4	-23.1
60	-16.2	-16.3	-16	-16.2	-19	-19.3	-20	-20	-20	-18	-19.2	-18.9
65	-13.3	-14.7	-13.2	-13.7	-17.8	-18.2	-18	-18	-9.8	-10.2	-9.7	-9.9
70	-8.1	-12	-8.9	-9.7	-13	-12.7	-14	-13	-4.8	-5.1	-4.6	-4.8
75	-4.5	-5.8	-5.5	-5.3	-10.1	-10.2	-11	-10	-2.4	-2.3	-2.1	-2.3
80	-4.3	-4.9	-4.5	-4.6	-9.2	-9.8	-9.6	-9.5	-2.1	-2.2	-1.8	-2
85	-4.1	-4.3	-4.2	-4.2	-8.9	-9.1	-8.6	-8.9	-1.1	-1.3	-1	-1.1
90	-2	-4.2	-2.2	-2.8	-5.6	-6.2	-5.4	-5.7	0	0	0	0
95	-1.9	-1.9	-2.1	-2	-4.4	-4.2	-4.1	-4.2	-0.9	-0.8	-1.1	-0.9
100	0	-0.5	-0.8	-0.4	-2.5	-2.3	-2.6	-2.5	-1.2	-1.3	-1.4	-1.3

Table A5: Post-design filed testing furrow relief readings (cm)

	Flat-plate				Mouldboard				Prototype			
x	1st	2nd	3rd	$\bar{y}$	1st	2nd	3rd	$\bar{y}$	1st	2nd	3rd	$\bar{y}$
10	0	0	0	0	0	0	0	0	0	0	0	0
20	0.2	4	0	1.4	2	-0.5	1	0.8	0.6	3.9	0.4	1.6
30	4	4	3	3.7	3.1	0	3	2	4.2	5	4.1	4.4
40	4	0.5	3	2.5	1	3.2	1	1.7	4.6	5.2	1.6	3.8
50	-11.2	-7	-6.3	-8.2	-2.8	12.3	-3	2.2	-10.3	3.9	-10.1	-5.5
60	-15.6	-16	-14	-15.2	-10.7	-20	-10.9	-13.9	-15.4	-19	-15.9	-16.8
70	-15	-19	-10	-14.7	-18	-14.4	-14	-15.5	-22.9	-23.9	-23.4	-23.4
80	-16.1	-16.2	-18	-16.8	-13.2	-12	-17	-14.1	-22.2	-22	-22.1	-22.1
90	-15.5	-7.7	-16	-13.1	-8	-3	-14	-8.3	-15.9	-19	-10.5	-15.1
100	-7	1	-8	-4.7	-8	0	-10	-5.3	-13	2	-9.8	-6.9
110	-7	4	1.2	-0.6	-0.9	1.5	0.8	0.5	4.2	4.9	-2.1	2.3
120	2.2	4	3	3.1	1	-5	0.9	-1	4.2	5	3.4	4.2
130	1.1	-6	-0.1	-1.7	0.8	-7	-1	-2.4	-12	3.7	0.9	-2.5
140	-5.7	-11.5	-6.9	-8	0	4.8	-1	1.3	0	0.1	0.1	0.1

x is distance across the furrow (cm)

$\bar{y}$ is the mean depth (cm)

Appendix 2: Structural Design For The Furrower

Fig A.01 in the Appendix 3 indicated the parts of the implements that required designing These included the shank, bolts, tool carrier, mast and the angle irons. A factor of safety (N_y) of 4 was chosen as given by Mahadevan and Reddy (1987) in Table 3.9. Distortion (shear) energy theory or Henckey-Von Mises theory was considered adequate for design of various material, as given by Mahadevan and Reddy (1987) and in Table 3.10.

Stresses considered in design included bending stress, axial stress, torsional shear stress and transverse shear stress. For a cantilever of depth d (mm) with a rectangular cross-sectional area A (mm), carrying a concentrated transverse load F (N) at a distance x from the free end (Fig 3.6), the shear stress τ (Nmm^{-2}) at a depth y_1 is

$$\tau = \frac{F}{2I_x}\left(\frac{d^2}{4} - y_1^2\right) \qquad \text{i}$$

The maximum shear stress τ_{max} would occur when y_1 is zero becomes

$$\tau_{max} = \frac{3F}{2A} \qquad \text{ii}$$

Since F was obtained from field measurements and τ_{max} was available from design data handbooks, it was possible to evaluate A.

Equations 26 to 40 were used to evaluate the size of the shank and its deflection. Taking a shank of 070M20 British Standards (BS) steel, a yield stress S_y of 200 N/mm^2 (Shigley, 1986) was established. Increasing N_y to 6 to take care of yielding by bearing, the working stress σ_w became

$$\sigma_w = \frac{My}{I} \qquad \text{iii}$$

The working shear stress τ_w was $0.577\sigma_w$(by Henckey-Von Mises Theory) Thus

$$\tau_w = 0.577\sigma_w = (0.577)*33.33 = 19.25 N/mm^2 \qquad \text{iv}$$

Applying the force F as evaluated from field tests as 8341.37 N and τ_{max}, the area of the shank became 433.32mm^2.

The point of action of draft on the furrower was concentrated at one-third of the height of the furrower bottom. from an analogy to point of action of force on retaining walls in weirs design. The moment arm was thus evaluated as 547mm, and taking moment as 4562729.99Nmm, the value of Z was evaluated as 136895 596mm^3. Considering combined stresses due to both bending and tensile stresses, the shank dimensions were as 900mm by 200mm by 25mm, which were the actual design dimensions for the shank in use.

Mahadevan and Reddy (1987) gave the values of E_r and G_r for carbon steel as $202X10^3$ N/mm^2 and 78.5 X 10^3 N/mm^2. The deflection, from equation 40 became $1.52X10^{-1}$mm. The allowable elongation, according to Shigley (1986) was 20% for a length L_o given by

$$L_o = 5.65A^{-\frac{1}{2}} \qquad \text{v}$$

The cross-section for this deformation was evaluated as $1.81x10^{-2}$ mm^2, while a shank of 25 by 200 mm^2 would have an allowable deformation of 79.9mm. Thus, the shank deflection could not exceed the design requirements.

The diameter (d) for a bolt of shear strength τ experiencing a shear force F is given by

$$d = \sqrt{4\frac{F}{\pi\tau}} \qquad \text{vi}$$

The following equations were obtained as the sums of the forces and moments acting on Fig 3.7.

$$\Sigma F_v = 0 \Rightarrow V_k + V_j = W_f + V_f \qquad \text{vii}$$

$$\Sigma F_h = 0 \Rightarrow F_k + F_j + D = 0 \qquad \text{viii}$$

and taking moments about point K,

$$\sum M = 0 \Rightarrow V_j(x_3 - x_4) - F_jL_k - D(L_k + L_j) - V_f(x_1 + x_3) - W_f(x_3 + x_2) \qquad \text{ix}$$

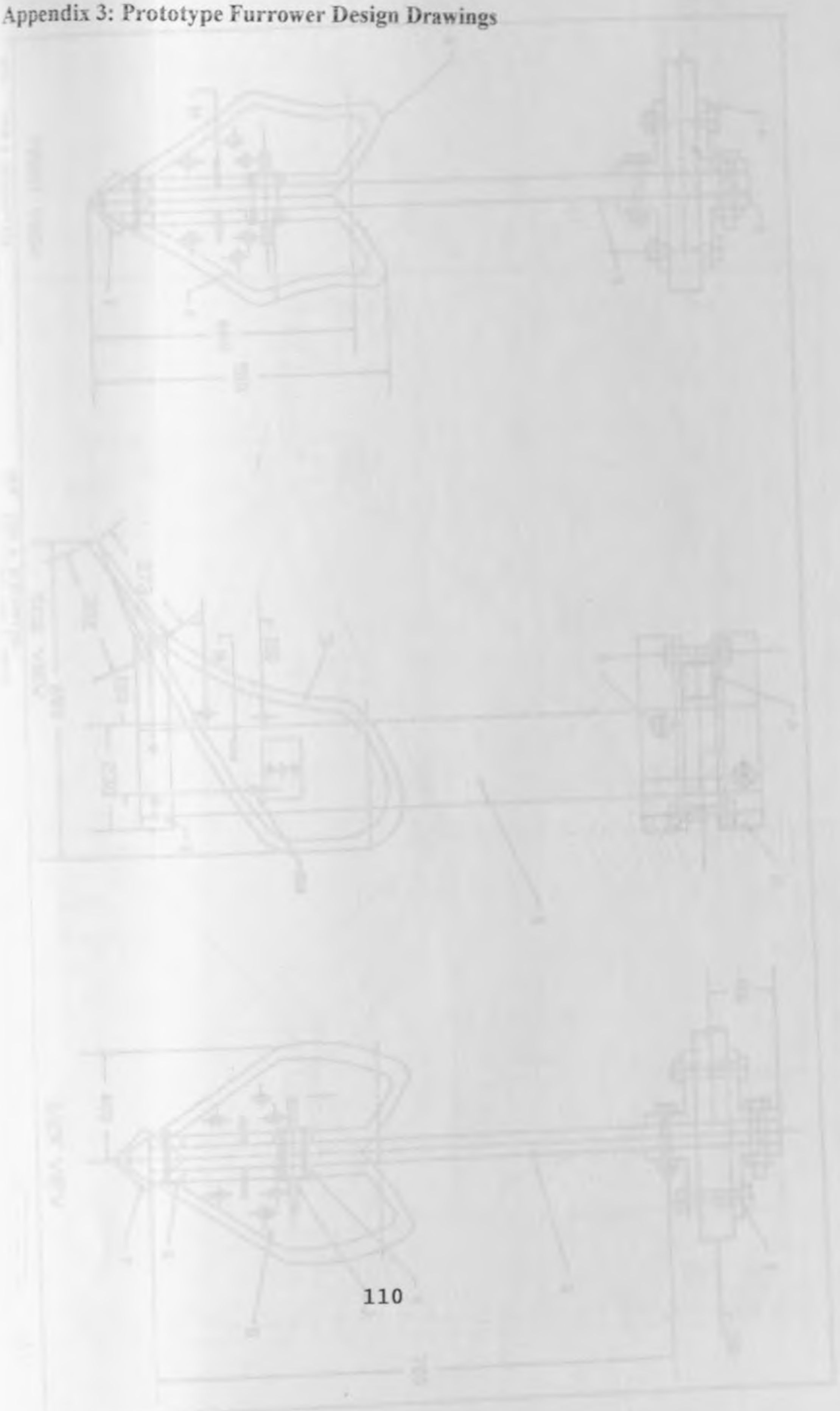
Applying the forces as expressed in Fig 3.7 and taking vertical forces as 30% of draft (Kepner, 1976), the shear bolt diameter was evaluated as 16mm, and the pivot bolt diameter as 25mm.

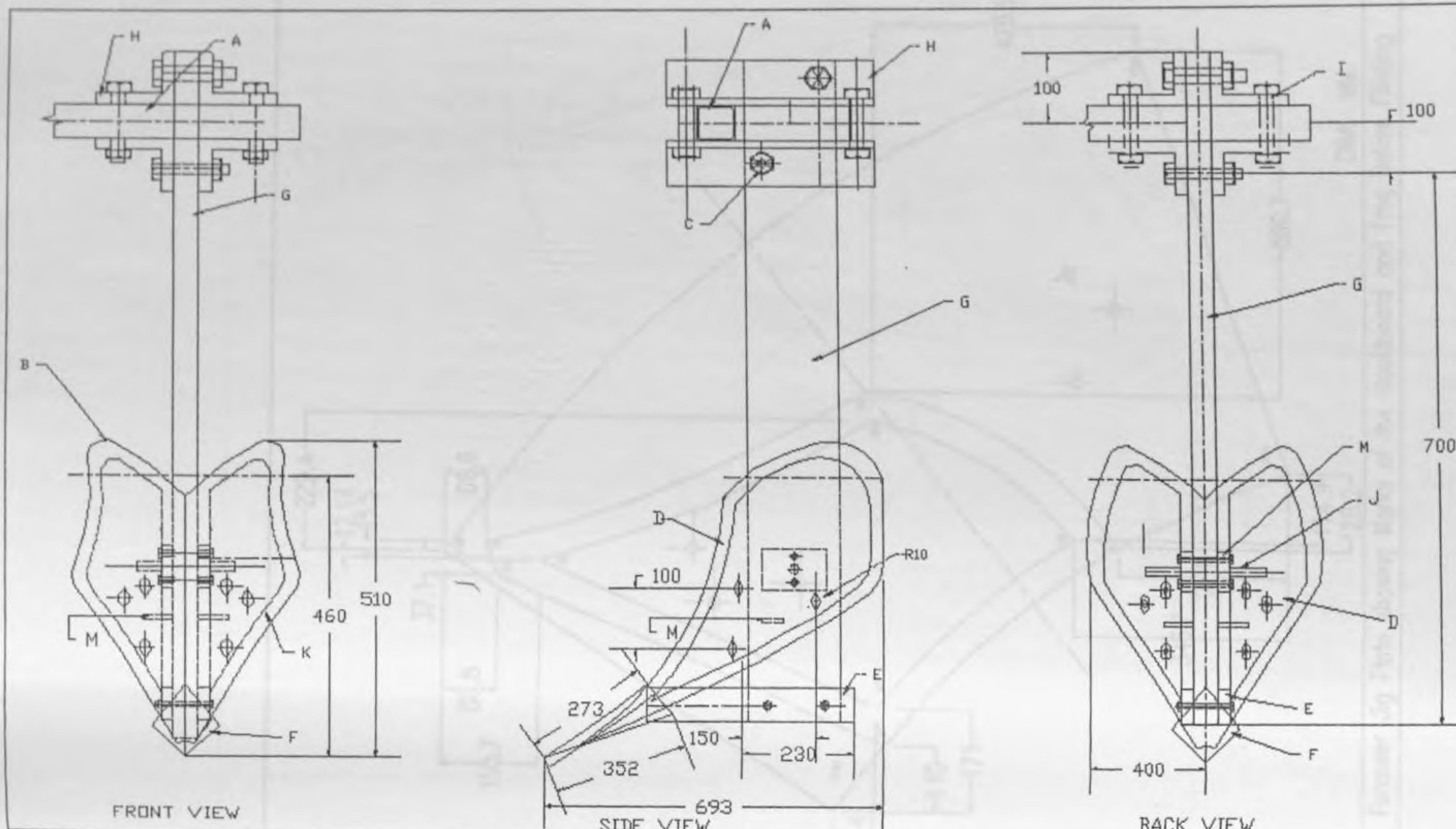
The formulae for calculating the centre of mass y, section modulus z and moment of inertia I for various sections was given by Mahadevan and Reddy (1987) and Shigley (1986) A 070M20 BS steel with a yield strength of 200 N/mm^2 (Shigley, 1986), would give a working stress of 5000 N/cm^2 , considering 4 for N_y, in steady loading . From equation 59, the section modulus of the section was evaluated as 60.57cm^3.

From Kraut (1984) and Shigley (1987), the size of the angle section was evaluated as 127mm by 127mm by 15.9mm (Table 3.12). It was thus evident that the angle sections of sizes 75 by 75 by 10 mm that were in use were under-designed

Equation 60 to 62 and Fig 3.9 were utilised to evaluate the size of box section. By iteration, the size of the box section was evaluated as 170 mm x 170 mm x 6 mm of 1.6m length Equation 62, Fig 3.10 and Fig 3.11 were utilised to design the mast. The mast material of C25 Man 75 ISI carbon steel was considered adequate for the design.

Appendix 3: Prototype Furrower Design Drawings





REF	ITEM & DESCRIPTION
A	100X100X6 MM MS BOX SECTION
B	12.5 MM MS MOULDBOARD
C	M16 SHEAR BOLT
D	12.5 MM FROG
E	LANDSIDE
F	SHARE
G	900X300X30MM MS SHANK

REF	ITEM & DESCRIPTION
H	75X75X10MM ANGLE IRONS
I	M25 BOLT
J	FROG-SHANK SUPPORT ROD
K	FROG-SHANK SUPPORT PLATE
L	M25 PIVOT BOLT
M	WEB (WELDED TO SHANK AND FROG)

SCALE: NOT DRAWN TO SCALE.

DIMENSIONS: MM, UNLESS OTHERWISE STATED

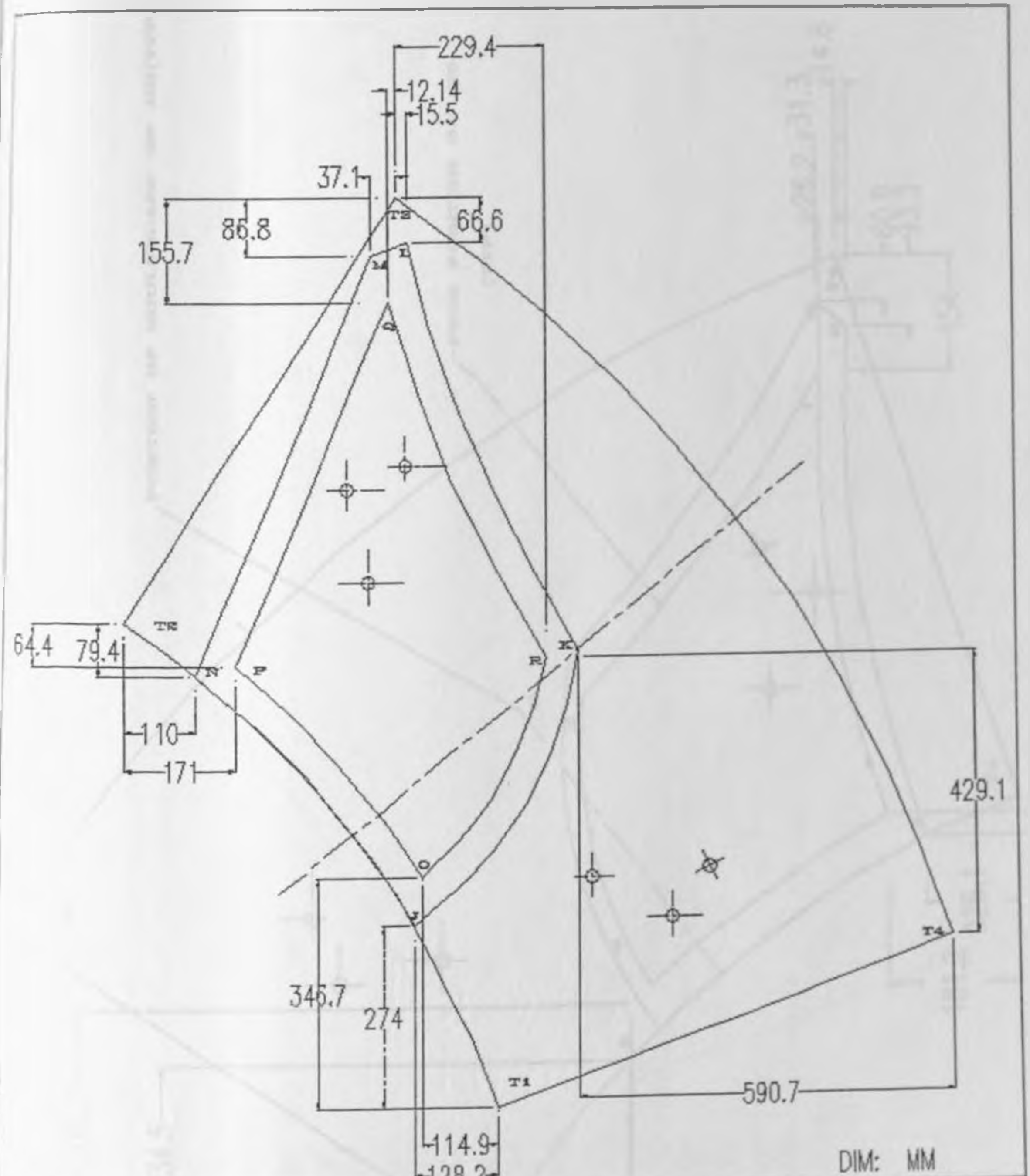


Fig A.02A: Furrower Jig Plate showing Marks of the Mouldboard and Frog Before Filleting

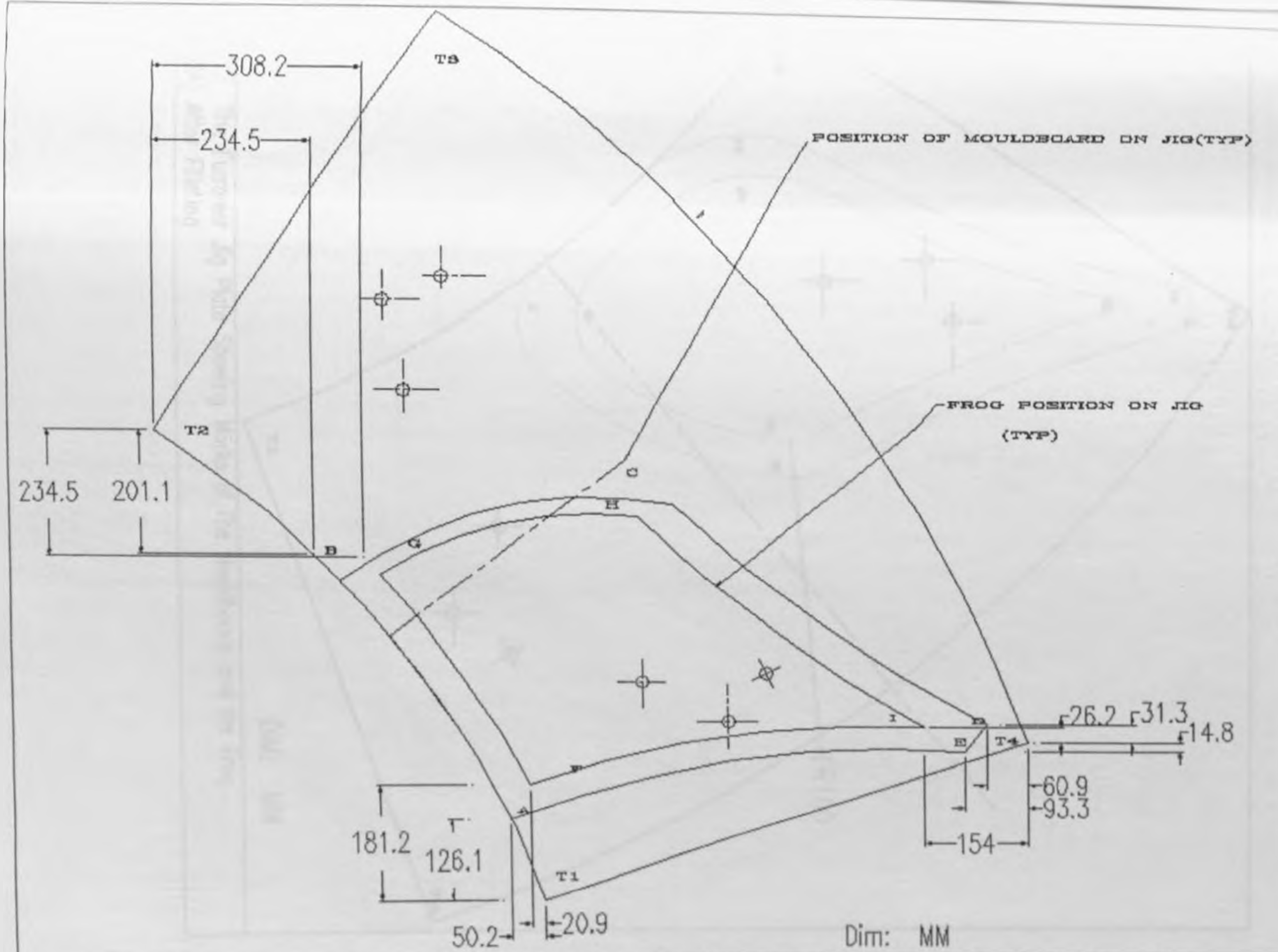


Fig A.02B: Furrower Jig Plate Showing a Reflection of the Mouldboard and Frog Outlines in Fig A.02A

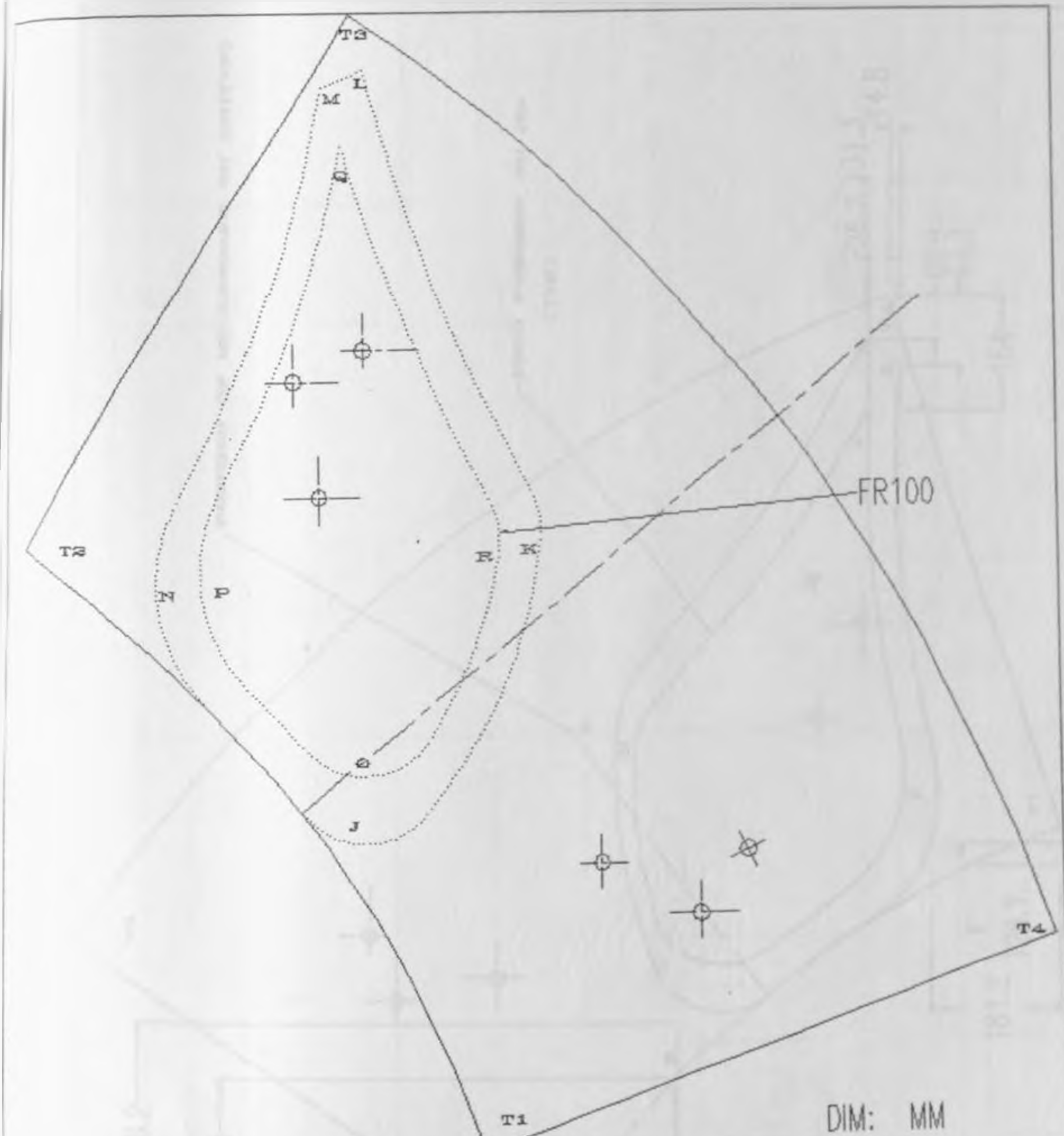
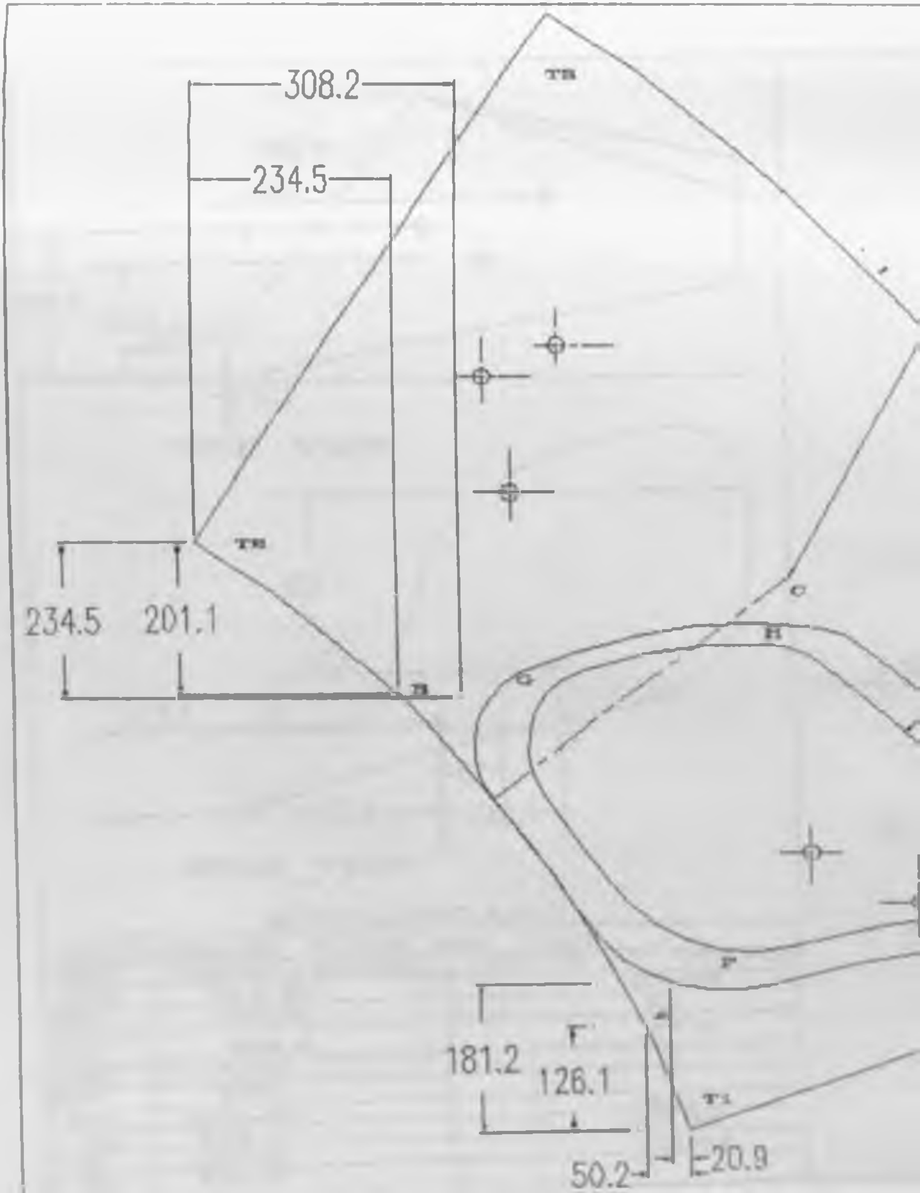
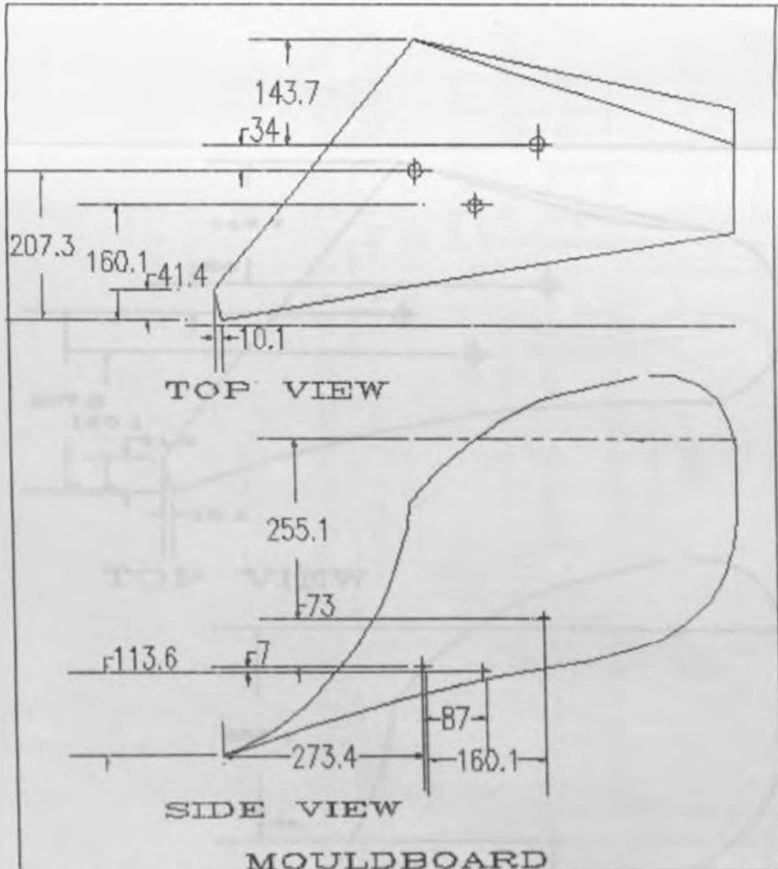


Fig A.02C: The Furrower Jig Plate Showing Marks of The Mouldboard and the Frog (Fig A.02A) After Filleting


308.2
234.5
234.5
201.1
181.2
126.1
50.2
20.9


POSITION OF MOULDBOARD ON JIG(TYP)
FROG POSITION ON JIG
(TYP)
I
D
E
T4
26.2
31.3
14.8
60.9
93.3
154

Dim: MM



MOULDBOARD PLATE ARC DIMS

ARC	CHORD LENGTH	DEPTH AT CENTRE
AB	501.25	22.22
BC	484.6	51
CD	668.6	27.5
DE	58.4	0
EA	683	0
FG	428.43	16.51
GH	379.1	33.63
HI	587.2	20.64
FI	591.9	0

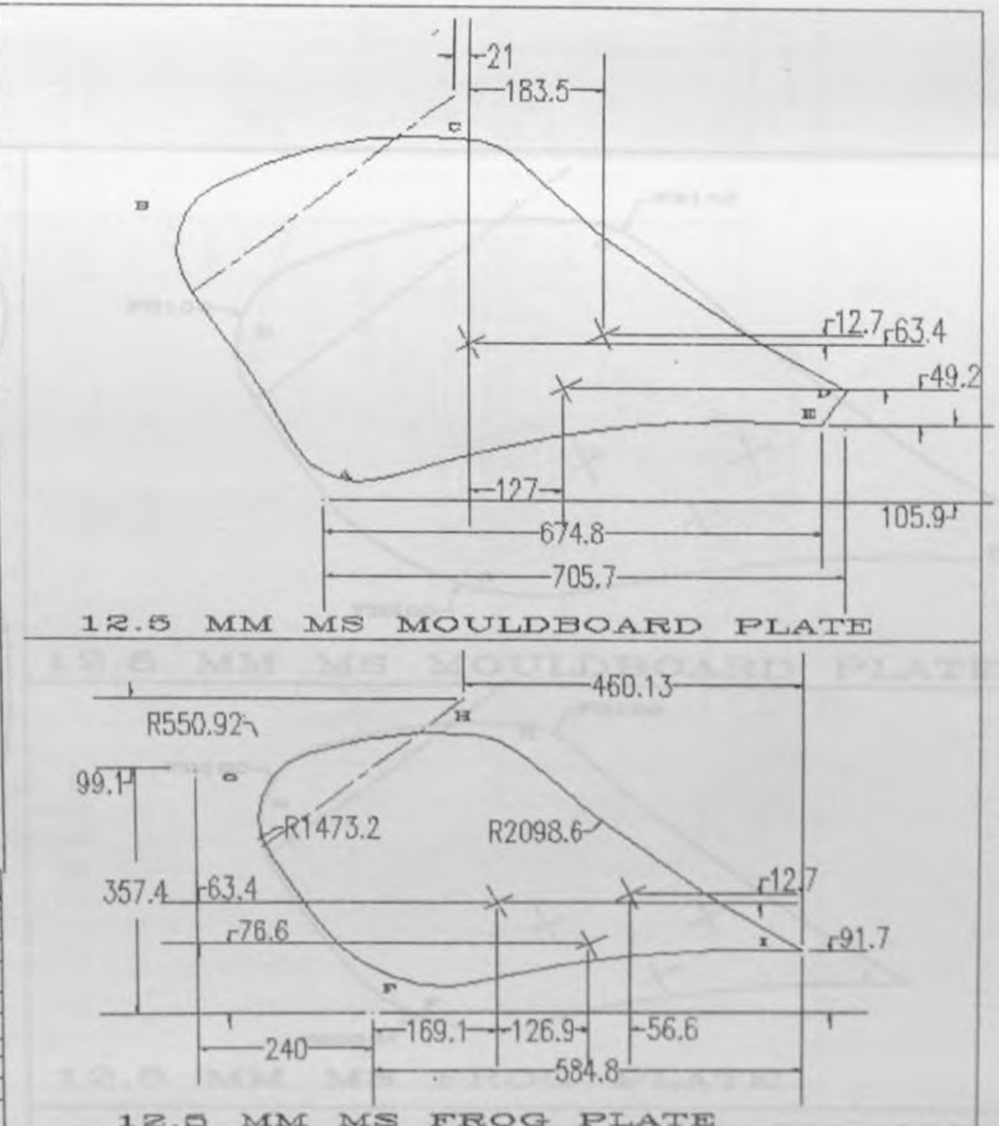


Fig A.03: Right; The Mouldboard and Frog Plates, and Left; Top and Side Views of The Mouldboard
DIMS: MM

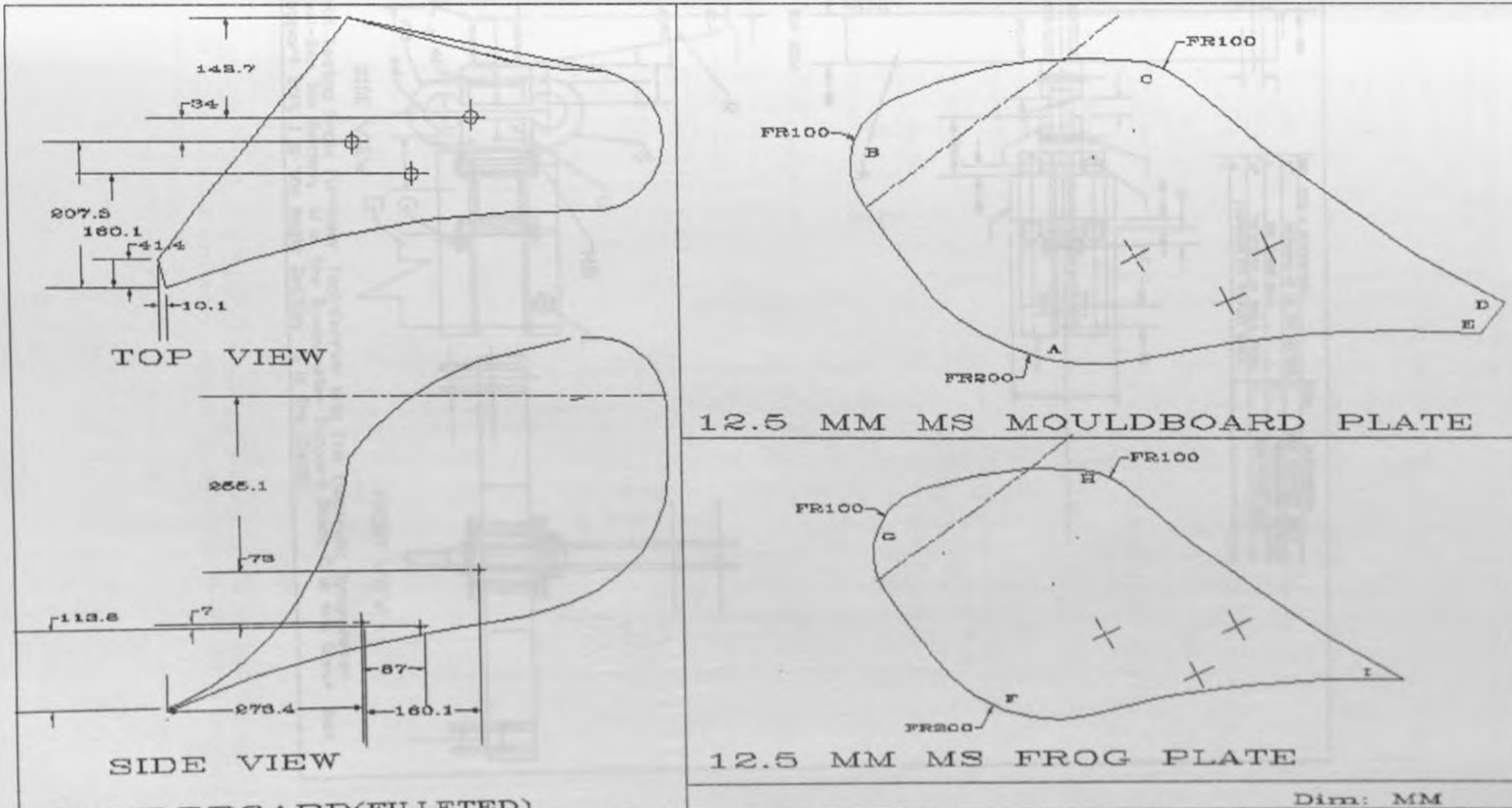
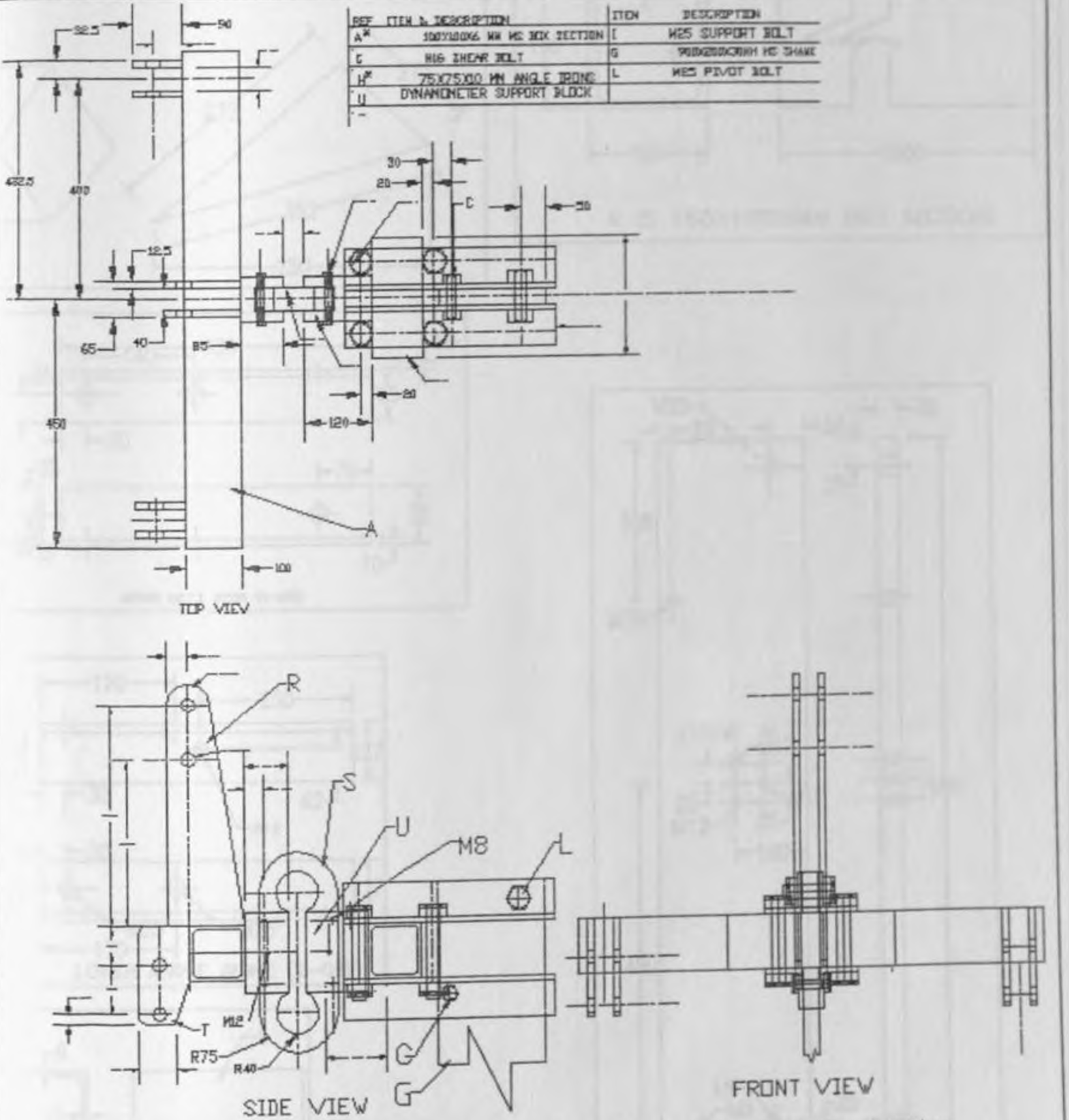


Fig A.03B: Right; Mouldboard anf Frog Plates in Fig A.03 Showing the Filleting Radii of the Various Filletted Corners
Left; Side and Top Views of the mouldboard plates after filletting



REF	ITEM & DESCRIPTION	ITEM	DESCRIPTION
A*	100X100X6 MM MS BOX SECTION	I	M25 SUPPORT BOLT
C	M16 SHEAR BOLT	G	900X200X30MM MS SHANK
H*	75X75X10 MM ANGLE IRONS	L	M25 PIVOT BOLT
U	DYNAMOMETER SUPPORT BLOCK		

Fig A.04: Field Testing Single Furrower Tool-Carrier With The Electronic Dynamometer
A is the Tool-Bar Box Section, U is the Dynamometer Support Block, C is the Shear Bolt
T is the Support Bolt, I is the Angle Section, G is the Shank

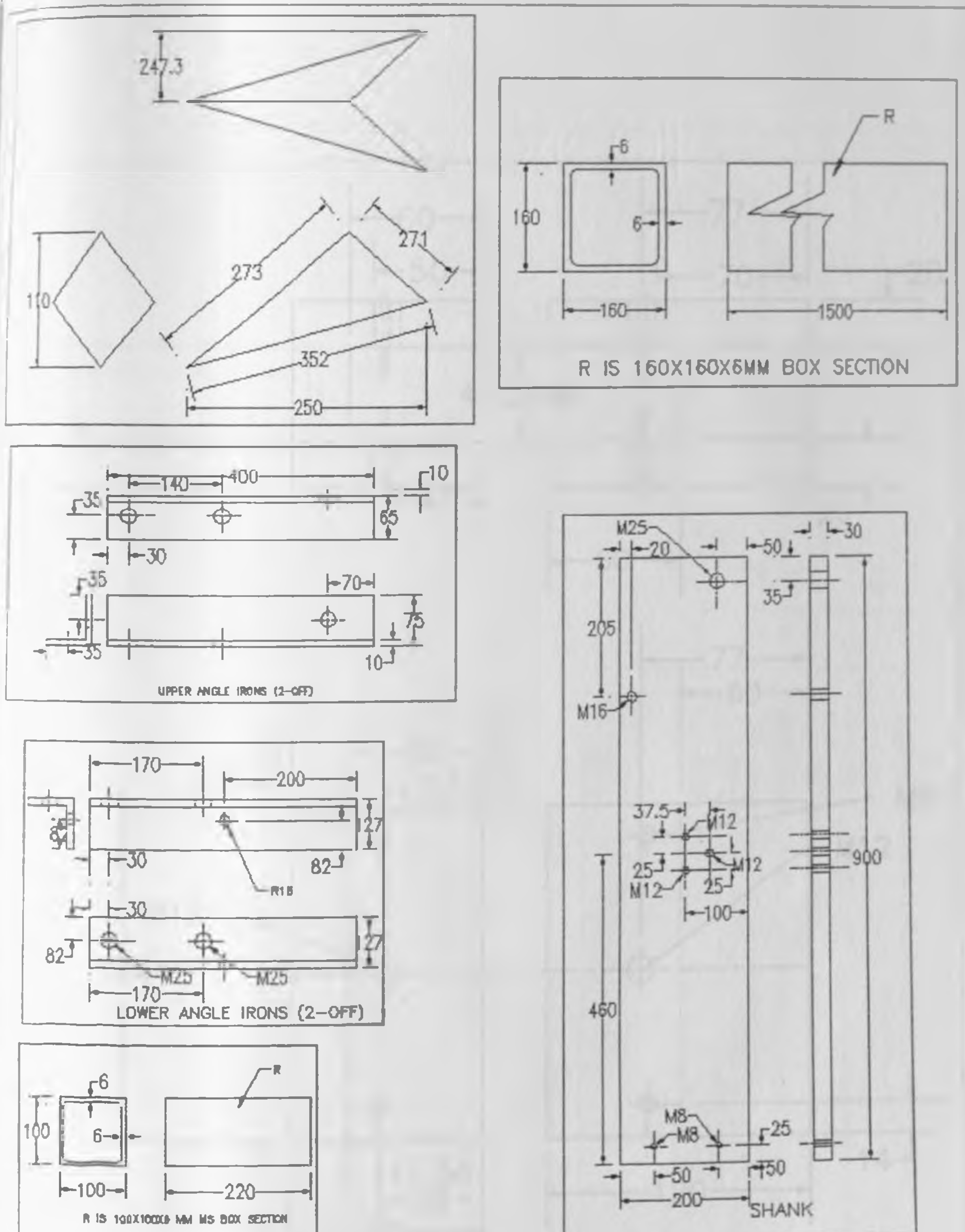


Fig A.05: Some Assorted Furrower Parts, Top Left is the share, Second and third Top Left are the Angle Sections (designed for testing only), Left bottom is the tool box section (designed for testing only), bottom right is the shank and top right is the actual design tool—bar DIM: MM

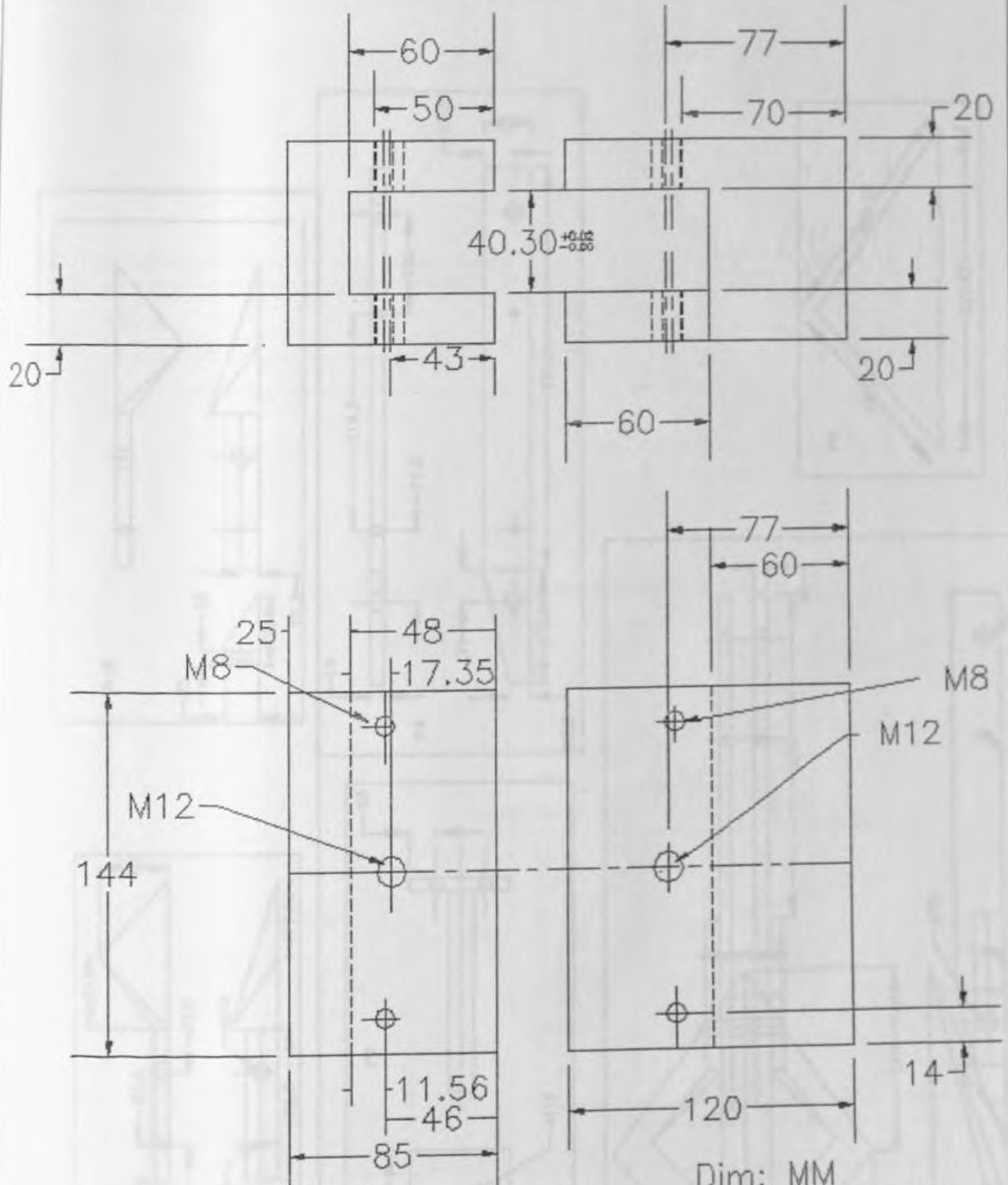


Fig A.05B: Furrower Dynamometer Connecting Block

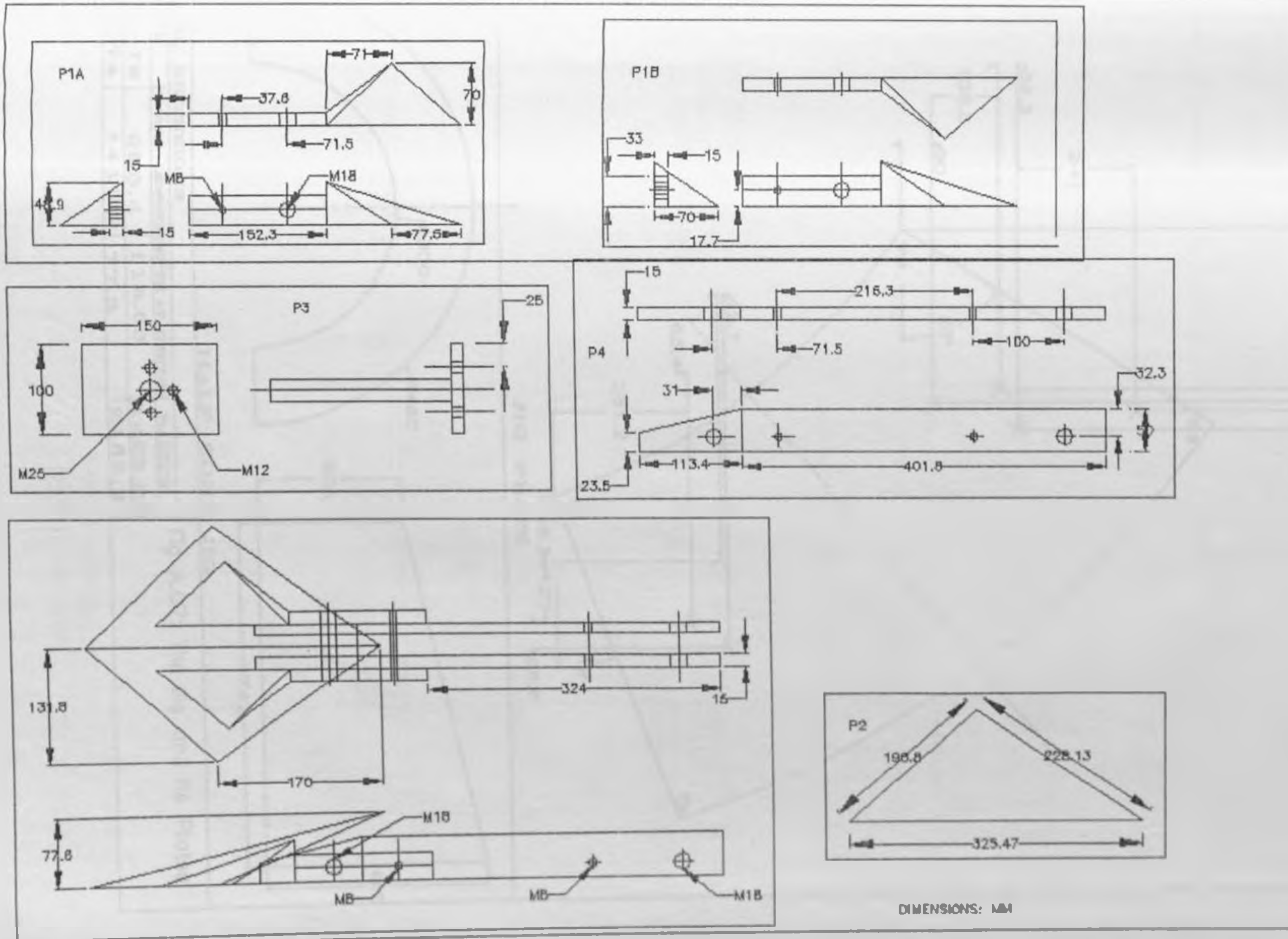
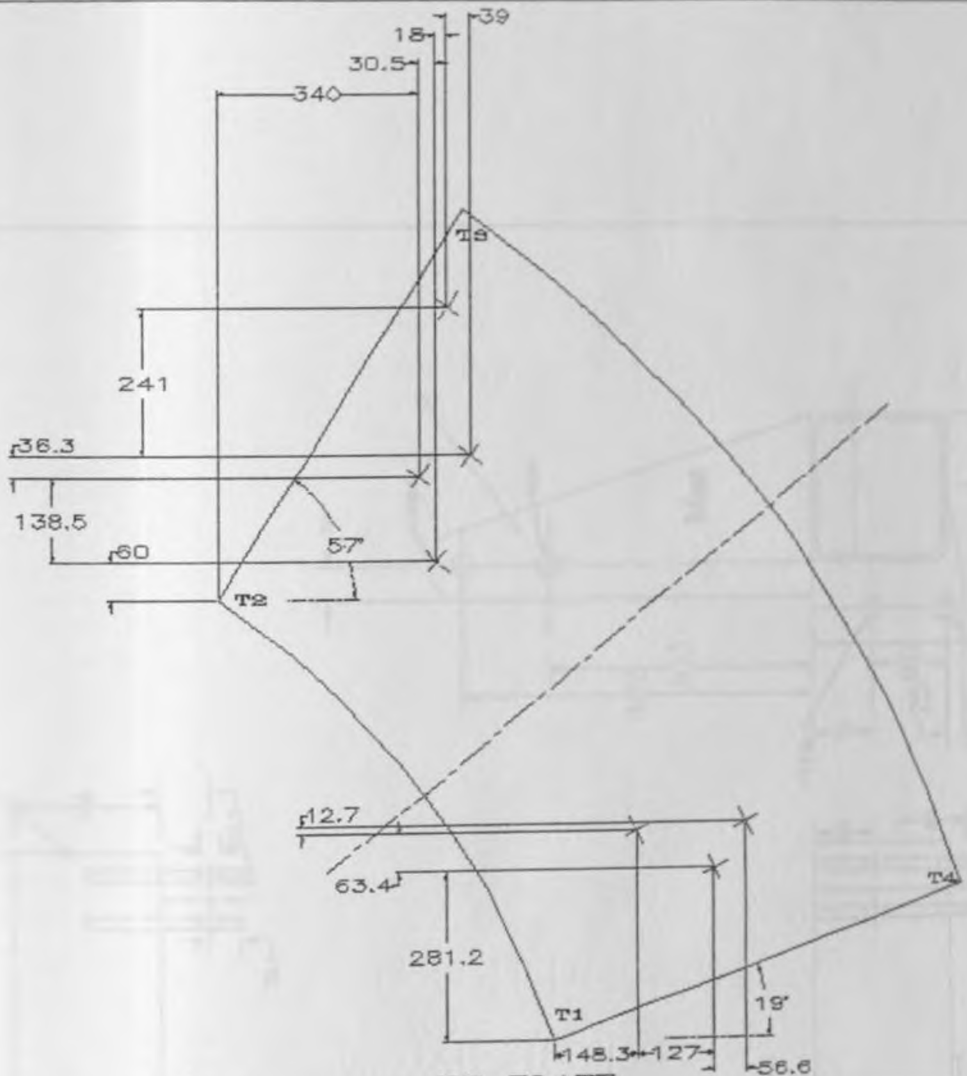
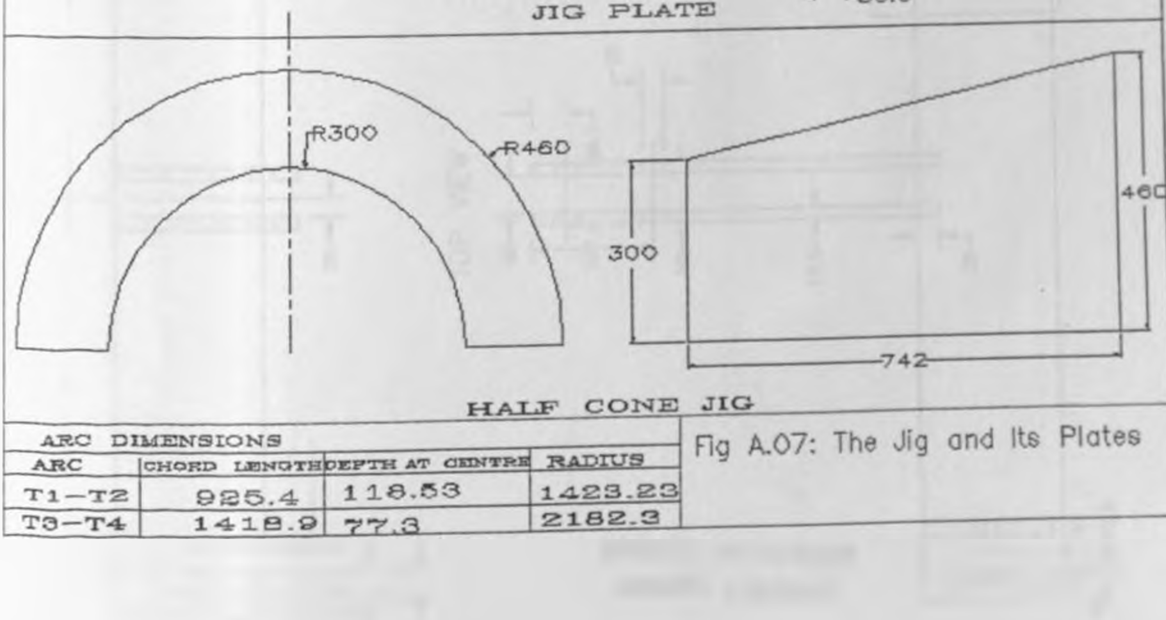


Fig A.06: Working Drawings of a Group of Related Components in the Furrower Design. Centre Right is the Landside (P4), Top is the Block Connecting Share to the Landside (P1A and P1B). Centre Left is a Plate and a Rod Connecting the Frog to The Shank (P3). Bottom Right is the Share Plate (P2), and Bottom Left is the Assembly of P1A, P1B P2, P3 and P4



JIG PLATE



HALF CONE JIG

ARC DIMENSIONS			
ARC	CHORD LENGTH	DEPTH AT CENTRE	RADIUS
T1–T2	925.4	118.53	1423.23
T3–T4	1418.9	77.3	2182.3

Fig A.07: The Jig and Its Plates

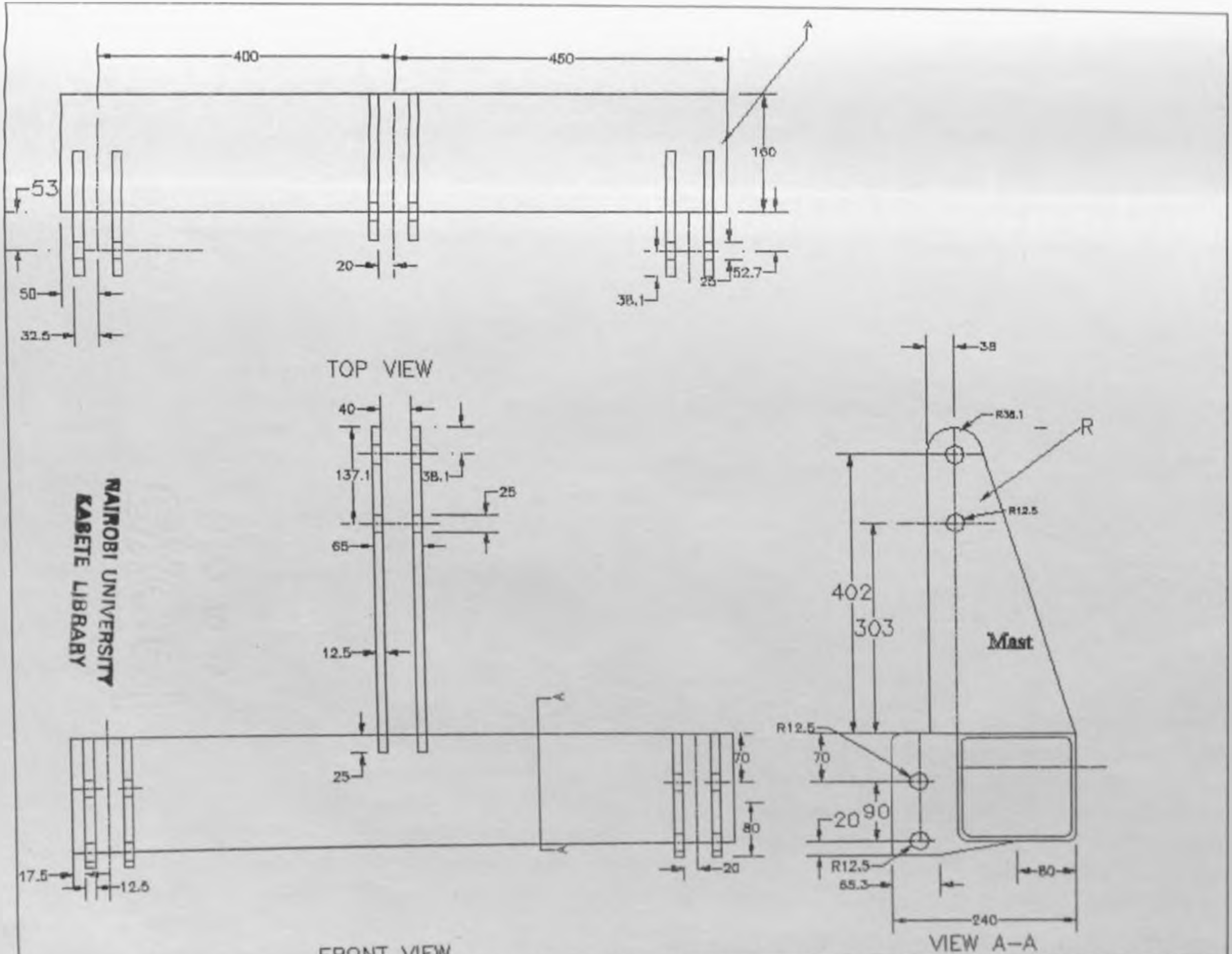


Fig A.08: The Tool-bar (dimensions are for testing only), Two Bottomed Tool Carrier Is Discussed Under Section 3.2.2 in Main Text

Dimensions : MM