THEORETICAL ANALYSIS OF HARVEST COLLECTION OF MEDIC PODS BY PNEUMATIC MEANS

by

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DECLARATION

This is to certify that the work presented in this dissertation was carried out by the author and it contains no material previously published or written by another person except where due acknowledgment has been made in the text. I certify that the substance of this thesis has not already been submitted in full or part to any other university for any degree or award.

I consent to the thesis being made available for photocopying and loan if accepted for the award of the degree.

Signed Date 3/7/004

Alaeddin Rahmani-Didar

LIST OF SYMBOLS AND DEFINITIONS

Notations:

α	angle of air jet spread
γ	air specific weight, N m^{-3}
ρ_a	air density, kg m^{-3}
ρ_w	water density, kg m^{-3}
A	cross sectional area of the pods, m^2
ANOVA	analysis of variance
a	air jet coefficient factor
b	radius in circular and breadth in rectangular and square shaped air delivery head, mm
c	drag coefficient, dimensionless
d	depth of air delivery head of rectangular shape, mm
d	diameter of particle, mm
D	distance, mm
DM	dry matter
FC_e	effective field capacity, ha h^{-1}
FC_t	theoretical field capacity, km h^{-1}
F_d	drag force, N
FE	field efficiency, %
g	acceleration due to gravity, 9.81 m s^{-2}
h	vertical height of water column, m
L	pick-up duct pod losses, kg ha^{-1}
LSD	least significant difference
MC_e	effective material capacity, kg h^{-1}
PC	pod collection efficiency, %
R^2	statistical correlation coefficient, dimensionless
S	forward speed, km h^{-1}

T_p	pick-up times, min
T_t	total times, min
V	relative velocity between airstream and particle, m s^{-1}
v	air velocity, m s^{-1}
v_0	air velocity at air delivery head face, m s^{-1}
v_m	maximum air velocity at centreline, m s^{-1}
v_t	terminal velocity, m s^{-1}
W	weight of pods, N
w	width of harvester pick-up duct, m
x	axial distance from head, mm
Y	field pod yield, kg ha^{-1}
y	transverse distance of air jet, measured from centreline of the jet, mm
y_c	distance from centreline where velocity is equal to half of centreline velocity, mm
Re	Reynolds number

Definitions:

head	airstream passage device, being used to deliver or intake air in positive or negative pressure
face velocity	average airstream velocity at the exit of delivery head
effective velocity	airstream velocity at pod location
effective distance	horizontal distance from head that pods are affected by airstream

ABSTRACT

Medicago spp. or annual medics are important components of the ley farming systems used in dryland areas of Australia and other countries with similar Mediterranean environmental conditions. In Australia, medic pods are harvested by pneumatic suction collection, mostly by the Horwood Bagshaw Vacuum Seed Harvester, a machine designed in the late 1950's. This harvester is slow in operation with consequential demands on energy consumption and time, and has the potential to cause damage by the removal of the fertile top soil.

Current harvesting machines were evaluated with a view to increasing pod collection efficiency and simultaneously reducing the intake of loose surface soil. The effects of harvester ground velocity and height of suction head above field surface were investigated. Both variables affect performance significantly, although it appears that the harvesters were normally operated at optimum levels. Measurements indicate that harvesters operating under optimum performance conditions have pod collection efficiencies of around 80%. The mass of soil particles picked up by the harvester may be 4 to 5 times that of pods.

Subsequent research was based on the hypothesis that the best approach would be to separate pods from soil particles before being taken into the harvester. Specifically this could be achieved by windrowing pods and a minimum of soil particles under the action of a blowing airflow for later collection by a suction head.

Physical and aerodynamic properties of medic pods (*Medicago truncatula* cv Paraggio) and typical pasture surface material were measured. Measurements indicated that pod diameter was typically in the range of 6 to 8 mm, while soil particles existed up to 8 mm with 82% by mass being 2 mm diameter and less. Bulk densities of pods and soils were 338 kg m^{-3} and greater than 820 kg m^{-3} respectively. Terminal velocity of pods was 5.2 to 6.4 m s^{-1}, while soil particles had a terminal velocity of 4.0 to 8.9 m s^{-1}.

The characteristics of airstreams producing by blowing and suction heads were studied

experimentally, as free jets and when in contact with surfaces. Blowing heads and suction heads produce very different airstream characteristics. Finite element analysis of the wall jets resulting from impingement of free jets on a surface at different inclinations led to a comprehensive understanding of velocity magnitudes and directions throughout the airstream profile. The wall jet is like a carpet of airflow, confirming its suitability for the proposed application.

The result of subjecting masses of pods and soil particles separately to airstreams both blowing and suction established the different nature of movement along a surface. Under low velocity blowing flow pods, and to some degree soil particles, roll and/or slide until the velocity decreases or movement is impeded by material in front. In suction flow there is no impediment to movement. Velocities for initiation of movement under blowing action were 3 to 8 m s^{-1} for soil particles up to 2 mm (82% of total soil mass), 8 to 13 m s^{-1} for pods and soil particles 2 to 4 mm (8% of total) and 13 to 18 m s^{-1} for soil particles 4 to 8 mm (10% of total). In suction flow, velocities appeared to be slightly less with pods requiring minimum magnitudes. These figures establish the potential for separation of pods from the majority of the soil mass. Subjecting a combined mass of pods and soil to a blowing airflow suggests that large accumulations of material will reduce the possibility for successful separation of the smaller soil fraction.

Finite element analysis of configurations of three blowing heads shows that it is possible to generate airstreams with different characteristics. An arrangement of three heads on an arm capable of some backward rotation will be effective over a harvester width of 2 m in generating a flow of reasonably constant velocity magnitude and in directions that will minimise any chance of accumulation of surface material in advance of harvester travel. This arrangement will leave surface material in 3 bands parallel to the harvester travel path. The most distant band will contain soil particles <2 mm, then there will be the windrow of pods and some small quantity of soil for collection by the suction head. This leaves the larger soil material, some remaining unmoved. The concept of closely controlling velocity is fundamental to the success of separation.

Chapter 1

INTRODUCTION

1.1 Importance of Medic Species

In agricultural areas of southern Australia which receive 250-500 mm of annual rainfall, as well as in areas of North Africa and West Asia with a Mediterranean climate, annual *Medicago* species are important pasture cultivars, especially when grown in rotation with cereals on alkaline soils (see Figure 1.1). They produce self-regenerating pastures that provide large quantities of high quality feed, promote soil fertility and benefit subsequent cereal crops by adding nitrogen to the soil, improving soil structure and allowing a break from cereal fungal diseases (Cocks *et al.* 1980; McDonald 1989; Crawford *et al* 1989). Experience has shown that land degradation is alleviated by establishing annual Medicago species as pasture and when they are used in rotation with cereals in the cereal zones (McDonald 1989; Crawford *et al.* 1989).

In view of the significant benefits obtained from medics, high seed production is critically important to maintain those benefits and extend ley farming systems in Australia and other Mediterranean type climatic areas of the world. According to the Australian Department of Agriculture (cited by Cribb 1991), specialist seed growers annually sow and harvest around 10,000 hectares with more than 2000 tonnes of the 6 main commercial cultivars in Australia (Crawford 1983). Australia is the main producer and exporter of medic seeds in the world.

1.2 Medic Seed Harvesting

Medicago spp. produce seeds within a wooden capsule called a pod. The pods separate easily from plants and fall to the surface when mature (Crawford *et al.* 1989). At harvesting time the crop consists of pods on the field surface and dried plants. The medic seed harvesting process consists of removing dried plants by raking (see Figure 1.2), loosening pods (Figure 1.3), lifting pods from the field surface, threshing pods and separating seeds from undesirable material.

Most current medic seed harvesting is carried out using the Horwood Bagshaw Vacuum Seed Harvester. This machine is used throughout Australia and other parts of the world (see Figure 1.4). This harvester uses a vacuum system with a large fan to create suction to lift pods through a duct.

Ground preparation is critical to the effectiveness of pod harvesting, as it improves pick-up and sample quality with less wear and tear on the harvester. Figure 1.3 shows a Paraggio medic field after ground preparation by a specialist seed grower.

1.3 Problems Associated with Medic Seed Harvesting

Many difficulties are associated with the medic seed harvesting process.

- It is a very slow operation. Ragless (1977) stated that the time required for harvesting one hectare is around two hours. Observations have shown that the time is more likely to be three hours.

- Energy consumption is high, as a result of harvester power requirements and the slow speed of operation.

- It is an expensive operation. Mulligan and Coleman (1974) reported a cost of $196 per hectare for harvesting a yield of 900 kg $ha.^{-1}$ (including cleaning and certification of seeds), with a further $144 per hectare for other operations in the establishing year. Boyle (1995) reported hourly charges for harvesting from $80 for a single machine to $140 for a double where two harvesters are pulled by a single tractor.

- The process adds to soil degradation. In the long term, this may be a more serious aspect than energy consumption and direct financial cost.

Although the demand for export medic seed is increasing, the high cost of production inputs and a growing awareness of the soil damage taking place during harvesting are causing medic seed producers to question current methods of seed harvesting.

1.4 Objectives

Australian agriculture requires a cheap and plentiful supply of high quality medic seed for internal needs and to maintain international markets, and there are obvious difficulties with the present harvest procedure for medic seeds. This study examines pneumatic means of harvesting and the ways in which pod collection could be optimised and soil damage minimised. Experiments were conducted with the following objectives:

a) To quantify the existing harvesters in terms of efficiency, capacity and soil displacement.

b) To evaluate the effect of parameters which influence the pick-up performance of existing harvesters.

c) To establish mechanical and physical properties of medic pods and associated soils, such as shape, size, density and aerodynamic properties.

d) To investigate the characteristics of blowing and suction heads and the airflow produced, particularly when the air stream is impinging on a ground surface.

e) To investigate the possibilities of blowing and suction flow acting together.

f) To investigate the aerodynamic behaviour of medic pods and associated soil particles subjected to ground airflow with a view to improving the present method of collection.

g) To investigate the potential of combining several blowing heads to create particular airstreams designed to optimise pod collection whilst reducing soil intake

1.5 Outline of Approach

To fulfil the above objectives the work was conducted in the following stages:

a) *Investigation of harvester performance (Chapter 3).*

b) *Characterisation of medic pods and soil particles (Chapter 4).*

c) *Evaluation of airflow characteristics* (Chapter 5).

d) *Investigation of aerodynamic behaviour of pods and soil particles* (Chapter 6).

e) *Finite element simulation of blowing flow using the sofware package Fluent (Chapter 7).*

Figure 1.1 View of medic pasture during vegetative growth

Figure 1.2 Pre-harvest preparation of medic field, raking to remove dried plants

Figure 1.3 View of medic pods on the field after pre-harvest ground preparation

Figure 1.4 View of medic seed harvesting with a Horwood Bagshaw Seed Harvester

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The literature reviewed in this Chapter initially focuses on the nature of *Medicago spp.* plants and their importance to agriculture in Australia and other countries with Mediterranean environmental conditions. This is followed by a survey of seed harvesting techniques that have been employed for the collection of medic seed pods and the extraction of seeds. Emphasis is placed on the only commercially available medic harvester in Australia (the Horwood Bagshaw Seed Harvester) and its problems. Pneumatic conveying and harvesting of other crops is also described.

The potential for improvements in pneumatic harvesting depends on a thorough understanding of the behaviour of medic pods in air streams, and the characteristics of the equipment used to produce airflows. The theory and practice of seed harvesting using pneumatic means is reviewed in the second segment of the literature review.

2.2 Annual Medics

The annual species of the genus *Medicago*, commonly known as annual medics, are very important pasture plants in Australian agriculture. Carter (1981) estimated the overall value of annual pasture legumes to Australia's crop and livestock industries to be at least 2.5 billion US dollars per annum.

Annual medics have a dual role in agricultural production in Australia. In the dryland cereal zones they are an essential component of ley farming systems. They are also used extensively as grazed pasture, particularly in the drier regions beyond the cereal zone.

The genus *Medicago* is native to western Asia and the Mediterranean region, although many species have become naturalised over wide areas in many parts of the world, particularly those with a Mediterranean climate (Heyn 1963).

Medic plants are sown from seed in the first year (Amor and Mann 1966), but regenerate from their own seed in subsequent seasons (Quinlivan 1965; Mathison 1973b; Crawford *et al.* 1989), even after several years on the same land on which other crops have been grown. The annual medics produce seeds within a woody capsule or pod. The pods separate readily from the rest of the plant and fall on the soil surface when they mature (Crawford *et al.* 1989; Chatterton and Chatterton 1991). However, the time required for maturation of seeds from a single plant, in order to become germinative, may vary over an extended period from one week to several months (Lesins and Lesins 1976). Futhermore, seeds can remain viable for many years in a dominant state due to a hard seed coat which restricts water entry.

At harvesting time, the crop consists of pods already separated from the dried plant and pods which will separate if disturbed in some way.

The *Medicago* genus has a wide genetic diversity. Heyn (1963) outlined the characteristics of 28 annual medic species. According to Crawford (1983), 32 species of medics and more than 17,000 naturally occuring accessions have been collected, reflecting the high degree of genetic diversity. Puckridge and French (1983) stated that since 1950 there has been an extensive programme of planned introductions of annual legumes in South and Western Australia carried out under a national genetic improvement programme. Cultivars from Greece, Italy, Turkey and the Middle East are being tested to meet the needs of a wide range of environmental conditions.

Bellotti (1995), referring to the Genetic Resources Information Network of the United States Department of Agriculture, stated that there are 251 known species of *Medicago*, of which only eight are commercially available in Australia, namely:

M. truncatula, M. littoralis, M. scutellata, M. polymorpha, M. rugosa, M. tornata, M. murex, and M. sativus.

Of these species, three (*M. truncatula, M. polymorpha* and *M. littoralis*) form the basis of pastures through the vast low rainfall wheat belt areas. The important annual *Medicago* species which are currently commercialised in Australia are given in Table 2.1.

Table 2-1 Important commercialised species of annual medics in Australia

Species	Common name	Cultivars
M truncatula	Barrel medic	Jemalong, Parabinga, Paraggio, Sephi, Mogul, Caliph
M. polymorpha	Burr medic	Serena, Santigo, Circle Valley
M. littoralis	Strand medic	Harbinger AR, Harbinger, Herald
M. rugosa	Gamma medic	Paraponto
M. scutellata	Snail medic	Sava

The importance of annual medics mainly relates to:

a) their considerable capacity for biological nitrogen fixation (BNF) (Dahmane 1978; Crawford *et al.* 1989; Hossain *et al.* 1995);

b) providing large quantities of high quality feed for livestock (Carter 1978; Crawford 1983);

c) increasing soil structure and preventing soil erosion (Greenland 1971); and

d) controlling root diseases (Rovira 1980).

(a) ***Nitrogen fixation:*** Annual medics are legumes obtaining nitrogen from the air through nodules on their roots which contain bacteria (*Rhizobia spp.*) (Day and Michelmore 1952; Mcdonald 1989; Peoples *et al.* 1991). Consequently, medics are rich in nitrogenous compounds (Wood and Myers 1987). As these compounds are returned to the soil, either through decaying plant residues (Ladd *et al.* 1981) or grazing animals, the amount of soil nitrogen increases. The amount of biological nitrogen fixation (BNF) by a medic pasture varies with many physical, environmental, nutritional and biological factors (Peoples *et al.* 1991). Several research projects have measured the rate of increase of total soil nitrogen by pastures. Webber *et al.* (1976) reported that in the Australian wheat belt an average medic stand increases soil nitrogen by at least 60 to 70 kg ha^{-1} in one season. An increase averaging 100 kg ha^{-1} of nitrogen per year has been recorded by Clarke and Russell (1977).

The net increment of soil nitrogen resulting from symbiotic nitrogen fixation varied with the productivity of the medic sward from 30 to 99 kg N ha^{-1} annum^{-1} (Bergersen and Turner 1983; Butler 1988). Ladd *et al.* (1981) reported that 40% of medic derived N was in an available form in the first year, and some of the remaining 60% was available in subsequent years.

Improvements in cereal production after 1950 in Australia are largely attributed to nitrogen from the annual legumes and to improvement in soil structure. Amor (1965) estimated that the adoption of medic pastures by farmers in crop rotation on 200,000 ha in Victorian Mallee gave an additional 27,000 tonnes of wheat annually.

(b) ***Feed production:*** Annual medic forage provides valuable feed production for animals, particularly during the late autumn / early winter period (Crawford 1983). The potential yield varies due to rainfall, length of growing season, weed control and some other factors. Crawford (1977b) showed that pasture growth rates up to 28 kg DM ha^{-1} day^{-1} were possible in some species.

In addition, annual medic pods and seeds provide highly nutritious feed for over-summer grazing by livestock, particularly sheep (Crawford *et al.* 1989).

(c) ***Soil structure:*** Medics, like other legume pastures, add organic matter to the soil and increase the size and stability of soil aggregates (Greenland 1971), and consequently reduce soil erosion (Chatterton & Chatterton 1984).

(d) ***Controlling root diseases:*** The value of annual legume pastures in controlling root diseases and nematodes of cereal crops has been investigated by Rovira (1980). He attributed a two-fold increase in grain yields to the control of disease by grass-free pastures grown in the year before the crop.

Although the potential of annual medics had already been recognised early this century, they were not commercialised until the 1930's, when it was recognised that subterranean clovers were not adapted to drier regions (250-450 mm rainfall) and the more alkaline soils of the cereal belt (Robson 1969; Carter 1975). Great progress was made with annual medic pasture production (Crawford *et al.* 1989) when farmers began to use phosphatic fertilisers.

2.2.1 History of Seed Production

Seed production of annual medics (*M. truncatula* and *M. scutellata*) in South Australia commenced with the gathering of Hannaford barrel medic at Noarlunga in the mid-1930's (Trumble and Donald 1938; Trumble 1939). Since then, production has increased rapidly and South Australia was the main producer and exporter of medic seeds in Australia (Cribb 1991). According to the Australian Department of Agriculture (cited by Cribb 1991) Western Australia is now the greatest producer of seed (see Table 2.3).

Table 2-2 Average medic seed production in Australia for 1989-90 (Cribb 1991)

Crop	unit	NSW	VIC	SA	WA	TAS	QLD	tot. Aust.
barrel medics	'000ha	0.1	0.4	3.2	7.7	-	-	11.4
	'000ton.	-	0.1	0.7	1.3	-	-	2.1

Seed production is carried out by a number of farmers who grow seed crops in conjunction with other farming activities. Tuncks (1981) pointed out that most of these farmers purchase and operate their own harvesting machinery, but pay for a specialist to clean, grade and bag the seed, which is then available at market for local usage or to export to other countries.

The production of medic seed is a specialised enterprise. Specialist seed growers have achieved seed yields exceeding 1200 kg ha^{-1}, although according to the National Farmers Federation (Cribb 1991) the average yield for seed of rainfed medic in South Australia during 1979-89 was 300 kg ha^{-1}, in the range of 50-600 kg ha^{-1} depending on location, climatic conditions, cultivars and agronomic management.

2.2.2 Description of Medic Plant, Pods and Seeds

Morphological details of annual medics vary only slightly between species, as indicated by Whyte *et al.* (1953) and Oram (1990). In general, the vegetative plant is herbaceous, consisting of weak stems, trifoliate leaves and conspicuous yellow flowers (see Figure 1.1).

Medic pods (which may also be called burrs) are formed by a number of woody coils, usually two to five depending on species. The seeds are contained within the pods. Variation in shape, weight, number of coils, number of seeds and spininess are the significant characteristics of medic pods. Pods vary in shape and size depending on species. Paraggio has barrel shaped pods; others may be spherical or even disc-like.

The variability of seed and pod characteristics of eight commercial species of annual Medicago and two lines of the most commercially promising species can be seen in Table 2.3.

Table 2-3 Ranges of mean variation in six major characteristics of 10 important annual medicago species (Australian Medicago Genetic Resource Centre,. SARDI Plant Research Centre)

Species	Spines	No. of Seeds/Pod	Mass of 1000 pods (g)	Mass of 1000 seeds (g)	Mass of Seed/pod (%)	No. of Seeds per gram
M. truncatula	12	4	139.90	8.46	25	118
M. sphaerocarpos	8	6	96.30	4.32	27	231
M. murex	14	8	146.30	5.35	30	187
M. littoralis	10	4	30.20	2.78	35	360
M. scutellata	spineless	5	259.60	18.94	40	53
M. orbicularis	spineless	21	228.80	5.23	47	191
M.rugosa	spineless	2	41.40	9.24	39	108
M. rigidula	9	6	67.40	3.18	30	315
M. polymorpha	16	3	38.00	4.62	39	216
M. tornata	2	2	28.80	7.48	52	134

Today, medic improvement programs take account of the degree of spininess in the selection of new cultivars for the various farming systems. Short and straight spined species such as *M. littoralis* and *M. truncatula* (Crawford *et al.* 1989) give less adherence to a sheep's fleece and are preferred to others with long and hooked spines. The angle of insertion of the spine into the pod face and the number of spines per row in the spiny pods are other important characteristics (Lesins and Lesins 1979). Spininess has been a characteristic employed to harvest pods in the past, but it is not a desirable aspect for wool production (Lunney 1983).

2.3 Medic Seed Harvesting

The separation of pods from the mature plant necessitates a ground harvesting technique. A full description of the pre-harvest preparation designed to remove dried plant material and, where necessary, separate pods from that material is given in Section 2.6. Sweeping, blowing, vacuuming and combinations of these techniques have been practised for ground harvesting agricultural products for over fifty years.

The sweeping technique has been employed to push a crop into piles to make windrows, for collection by another pick-up device, or to sweep a crop through a ramp into a bin. Sometimes, those operations can be done with blowing airflow. Pneumatic techniques have been employed to harvest a variety of agricultural products since 1945, when Price and Lunde constructed a mechanical filbert nut picker. This technique is attractive because of the major advantage of having few moving parts, which makes the equipment simple in components and small in size. Reduction of moving parts, besides reducing maintenance costs, gives the potential for the machine to be operated close to crops, which is important for ground harvesting purpose (Humphries *et al.* 1979).

In the suction approach, crops are vacuumed directly from the soil surface into the harvester. Examples of ground harvest techniques with pneumatic systems are briefly described in the following sections. Later, sweeping may be used to push the crop into piles to make windrows for collection by a pick up device, or for direct movement of the crop onto a ramp into a bin.

2.3.1 Brush Pick up Harvester

Hand raking and sweeping was the earliest method used to collect medic pods. This method was mechanised by using a rotary road broom and brush pick-up machine (Day and Michelmore 1952). A pick-up trailer and stationary threshers were used with this machine to separate seeds from pods. This technique was used up to 1948.

The rotating brush was used at an angle to the forward moving direction in order to accumulate the pods into a windrow, where some lifting arrangement was employed. Figure 2.1 illustrates the technique.

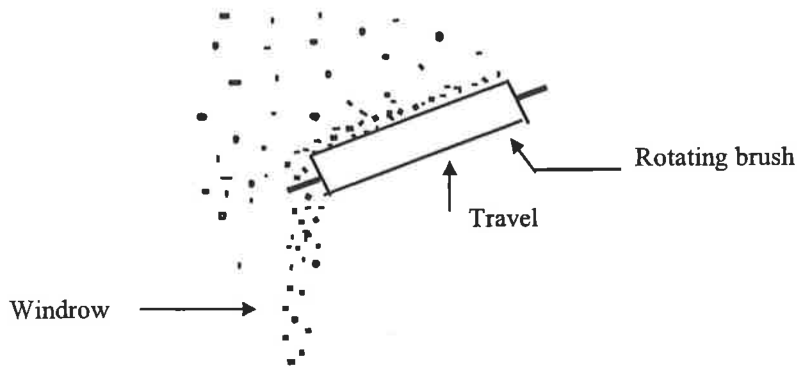


Figure 2.1 A plan view of a rotary brush used to form a windrow

Another sweeping technique employed a linear motion as the basis of a horse drawn harvester (see Figure 2.2). Brushes were rotated on a metal-linked endless belt to move the pods into a collecting box.

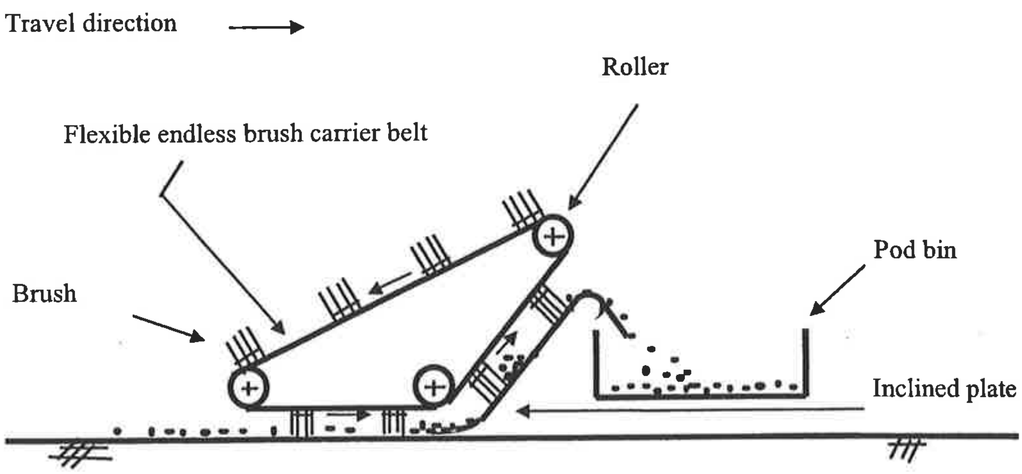


Figure 2.2 Medic pod sweeping harvester using a linear brush mechanism

Tuncks (1981) concluded after running tests with brushes that using a linear brush system is effective and economical in picking up loose pods and materials from a suitable surface.

In addition he suggested that using a series of air jets is effective in agitating pods in locations where brushes would fail. He stated that this technique requires less power than a suction pick up of the same width (see Fig. 2.3). In further refinements he suggested using several brush segments, each of which is attached to a transverse brush carrying beam with two springs (see Figure 2.4).

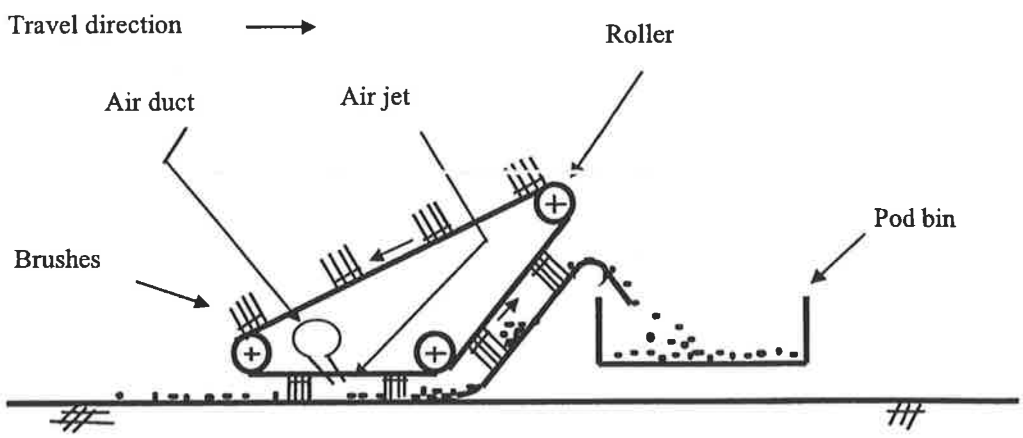


Figure 2.3 The linear brush mechanism with airflow incorporation

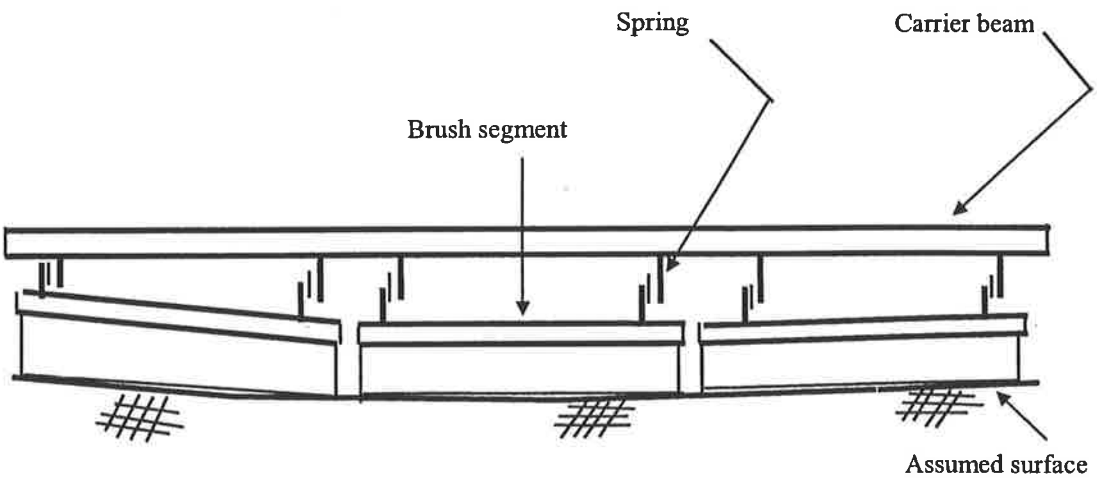


Figure 2.4 Linear brush set with three sets of brush segments

2.3.2 Sheepskin Roller Harvester

This technique relies on the natural spininess of pods and their ability to cling to wool. It was developed in 1948 and used to harvest subterranean clover as well as medic pods in Western Australia (Hely 1950; Day and Michelmore 1952).

The equipment consisted of one or several hollow wooden rollers covered by sheepskin with the wool on the outside. A brush was driven by a belt or chain from the end of the roller at a speed approximately four times that of the roller, to separate pods from the fleece and dislodge them into a container. Various modifications were made to this machine to suit the local conditions. Although it proved quite satisfactory for gathering varieties of barrel medic pods which had spines of moderate length, pick-up was low and several passes were required. The life of the sheep-skin was short; in general it was an expensive technique. and was discontinued when more efficient machines became available.

2.3.3 Blower Harvesters

Tuncks (1981), citing Carlin (1973), stated that a few sets of unpopular blower machines were developed by Western Australian farmers to harvest medic and clover seeds.

The Dickerson Super Harvesting Machine was one example of this early blower harvester. This machine consisted of a large fan, driven by a separate engine or by a tractor through the power take-off (PTO) shaft. Clover and medic pods, as well as any other loose material existing on the surface, were blown onto an inclined chute by the fan. From this chute, the materials were lifted mechanically or by a suction fan to the next stage of processing. These machines encountered fan problems and a great deal of maintenance was required for the many bearings, pulleys and belts.

The Barrow Linton BL 63 was another type of blower machine driven by a PTO and comprised two blast fans which blew the pods from the ground in 0.9 metre strips with 0.16 metres in between. The pods passed through a compression chamber into the pod catcher, where some separation occurred. An expansion chamber fitted with deflectors collected the pods in an auger trough, and allowed the trash to continue with the exhaust onto the ground. A threshing drum and concave winnower, riddles and a final cleaner auger were used to separate seed from trash.

2.3.4 Blower-Suction Harvester - Dutchke's Harvester

A description of this harvester, which was developed by a local farmer in South Australia, is given in Figure 2.5. The pick-up head comprises an area with side wall confinement, a steel roller in front and another one at the rear. A brush which rotates at almost three times machine ground speed is located between the two rollers. The airstream is directed by an inclined duct with the full width of head length towards the ground surface and pulled up by another opposite inclined duct into the harvester. The machine has a pick-up width of 1.86 m. Pods are lifted by the combination of brushing action and air agitation. The collected material is transported in a high velocity airstream into the separation chamber. As the airstream enters the separation chamber, the air velocity is reduced by an increase in cross-sectional area. This allows pods and other dense material to drop from the airstream onto a cross conveyor auger which rotates in a perforated cylinder screen to separate pods from soils and move them into a separate trailer by a throwing action.

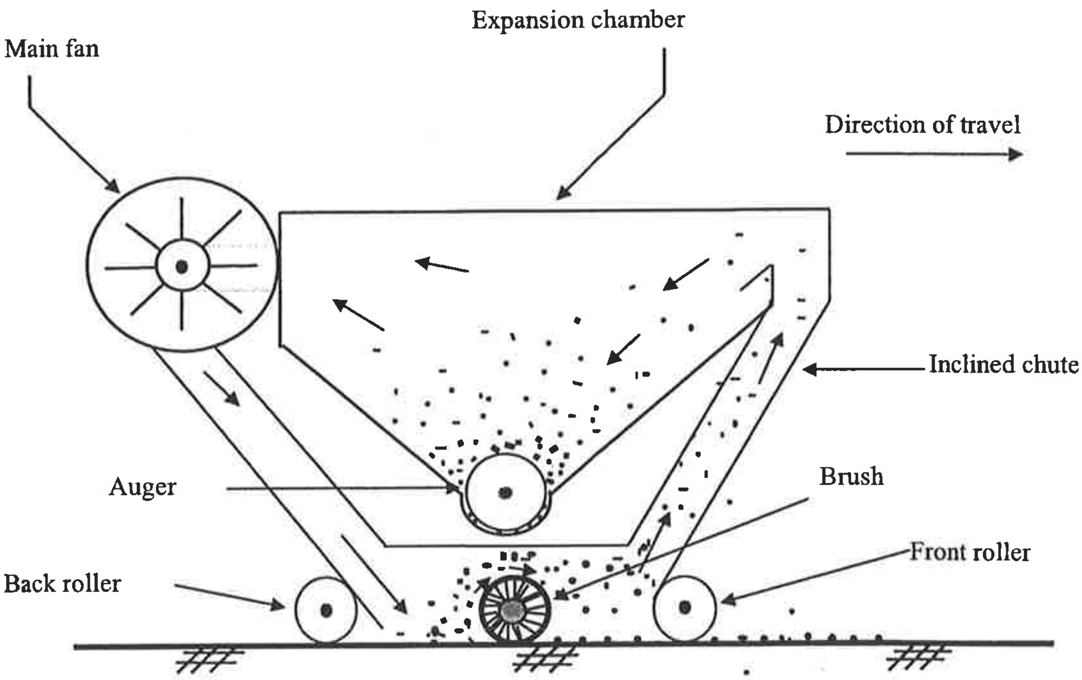


Figure 2.5 A schematic side view of Dutchke's medic pod collector

The applied air is generated and circulated in the harvester by a large paddle fan which is driven by a PTO shaft of a tractor.

2.3.5 Suction Harvesters

Tuncks (1981) reported that this medic seed harvester was another Western Australian invention; it employed a suction pick-up in association with a rotating screen, as shown in Figure 2.6.

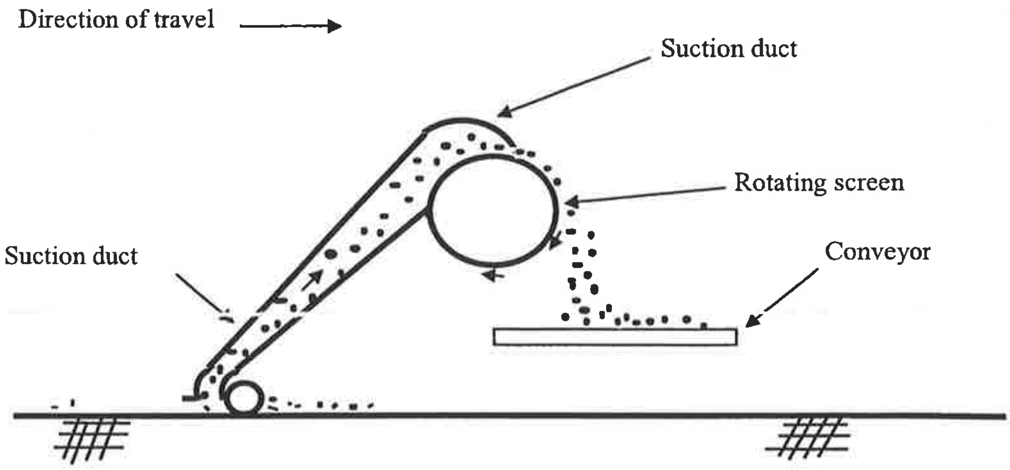


Figure 2.6 An illustration of an early suction machine for medic seed harvesting

Employing a revolving screen as a pre-cleaner was a significant advantage of this machine, ensuring that material from the pick-up duct did not directly enter the thresher. Material was deposited onto a conveyor to enter the thresher and other stages of harvesting.

2.3.6 Horwood Bagshaw Vacuum Seed Harvester

Today almost all medic seeds are harvested by using a suction type machine manufactured by Horwood Bagshaw Ltd (Ragless 1977; Tuncks 1981; Boyle 1995). This machine, which is operated by one man, is a significant improvement over older methods in terms of convenience and output in relation to the manpower requirement, but it is still slow. This harvester was designed in the late 1950's (Tuncks 1981; Boyle 1995) and it is the only seed harvester currently being manufactured commercially for medic seed harvesting throughout Australia and other parts of the world such as South America, Africa and countries around the Mediterranean.

Although it has not undergone any significant design alteration since 1961 (Tuncks 1981), seven series models have been made (Boyle 1995) incorporating changes to rotary screens, fan and cyclones to overcome difficulties, and improve maintenance and service life.

The standard Horwood Baghaw harvester is operated with a 540 rpm PTO drive requiring a minimum power input of 45 kW. An option of 1000 rpm was available during the G series production of this harvester.

A flow diagram of this machine is illustrated in Figure 2.7. The main functional units and their operation are as follows.

Pick-up duct: This unit is available in two standard sizes of 1.22 and 2.14 m width. The small size of duct is better suited to high operating speed and seed density. The 2.14 m duct is usually used in dry regions with low pod density (Boyle 1995). The pick-up duct is guided over the ground by a 200 mm diameter steel roller which controls the height of the duct and affects the airflow in the vacuuming of the material. The 2.14 m wide duct operates at a maximum speed of about 2.8 km h^{-1} with an air gap setting of 44 - 51 mm depending on speed. The 1.22 m wide duct, which is more popular, is capable of operating at a maximum speed of 5.6 km h^{-1} with an air gap setting of between 45 and 75 mm (Horwood Bagshaw Ltd. 1989; Boyle 1995).

Tuncks (1981) measured an airflow velocity of 23 m s^{-1} at the thresher entrance where the cross section area of the duct was 0.24 m^2. This gives a flow rate of 5.52 m^3 s^{-1}.

The roller can be replaced by small single or dual wheels mounted on the end of the duct. The air gap should be reduced to increase the vacuum performance without the steel roller. Boyle (1995) stated that a common modification to these harvesters is a round street sweeper brush mounted to the front of the harvester to further agitate seed pods, improving the efficiency of the pick-up. The brush rotates at 3 - 4 times the forward speed of the harvester to provide adequate disturbance.

Fan: A large paddle fan with six blades of 737 mm diameter and 1790 rpm is used as a main fan to create the suction of material into the harvester. A small paddle fan with four blades of 787 mm diameter and 1010 rpm is employed to transport cleaned seeds to the seed bin.

Thresher: All material passes directly into the thresher, where particles are reduced in size by a combination of crushing and shearing forces. The thresher consists of two sets of a concave screen in 3 mm mesh as an upper and lower side, with each half consisting of 4 replaceable sections (Tuncks 1981). There are two rub bars on the sides at the joint between the top and bottom halves of the mesh screen. A rotor with two half length rasp bars and two longitudinal groove bars, which can be operated at 350, 500 or 690 rpm, is included in the thresher.

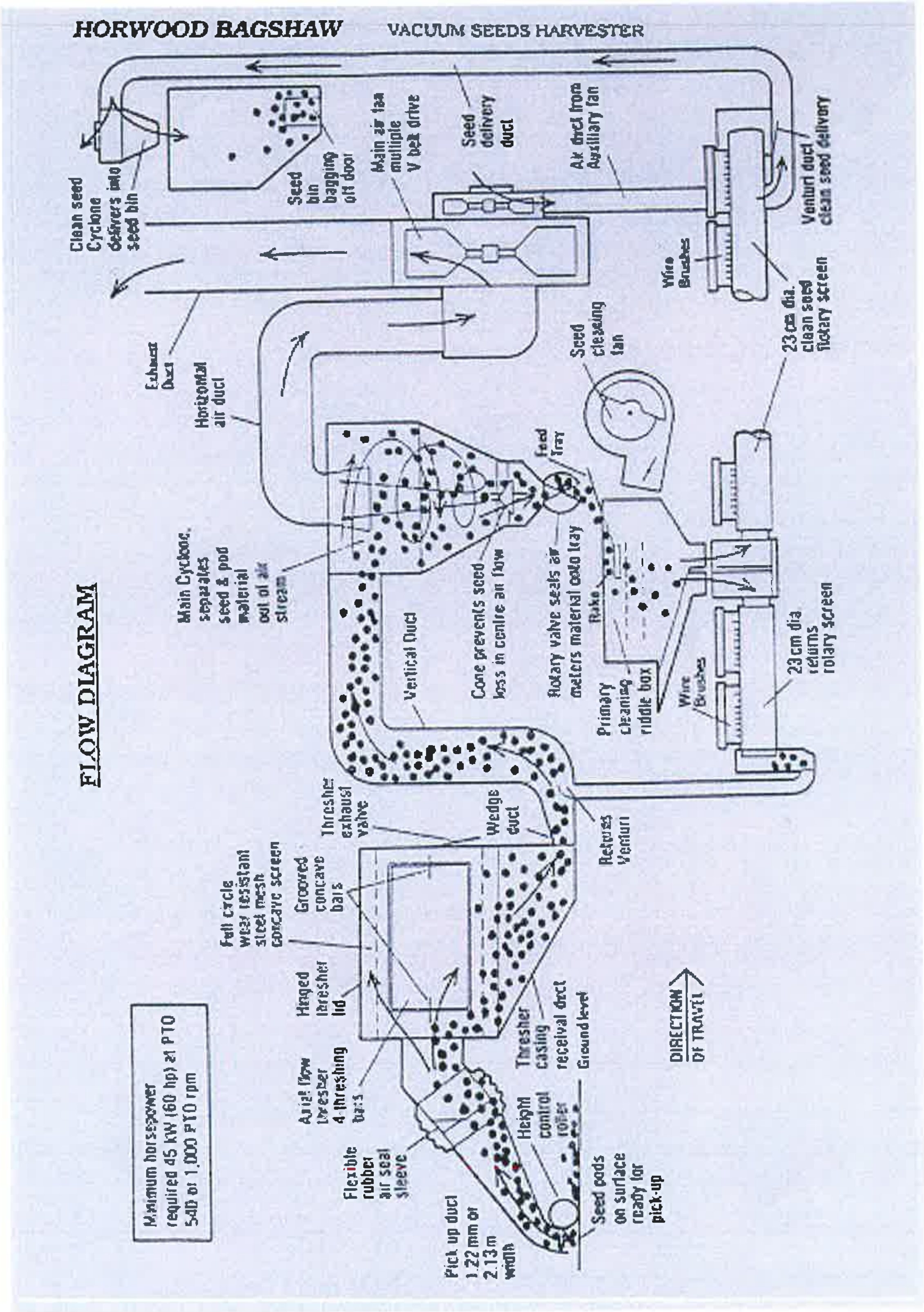


Figure 2.7 Flow diagram of Horwood Bagshaw Vacuum Seed Harvester (Horwood Bagshaw Ltd.

1989)

The thresher was updated from two sets of four bars to four sets of eight bars on the J model harvester. This change improved the threshing capacity of the harvester.

Seed cleaning units:

Cyclone: A large cyclone is used to expel excessive air, dust and light material from the main pick-up and threshed materials; while a small one is employed for the final seed transport to the seed bin. In the cyclone, centrifugal force, increasing as material moves downward and constrained to rotate about a smaller radius, separates constituents according to their properties of mass and terminal velocity.

There is a rotary valve at the bottom of the main cyclone to keep the system sealed, maintaining the vacuum. Keeping the rotary valve in good order is critical to the efficient operation of the harvester and minimises wear on the main fan blades from dust and other material.

Riddle box: The riddle box incorporates a feed tray that directs material from the rotary valve exit from the cyclone over a rake and into riddles. The riddles have a circular motion at the front and a linear motion at the end, due to being driven by a crank in the front and a hanging support at the end.

Winnowing is carried out using a commercial type of winnowing fan that consists of six paddles attached to a shaft. Seed husks and vine fragments are blown out from the riddles by winnowing. Seeds along with particles of sand and small aggregations of soil particles, pass through the sieves into the seed collector chute.

Rotary screens: Material that has passed the sieves and dropped into the collecting chute is augured through a rotary screen into a seed delivery venturi duct and thence by an airstream (generated by the seed delivery fan) into the seed bin. Rotary screens rotate against a fixed set of brushes with the purpose of preventing degradation of performance due to clogging holes. The rotary screens were enlarged to 225 mm in diameter and the speed of rotation lowered from 87 to 54 rpm since model G (Boyle 1995).

Tuncks (1981) stated that the Horwood Bagshaw harvester is considered to be unsatisfactory in at least three significant areas.

A) Performance is slow, thereby increasing the cost of seed harvesting and the eventual price of medic seeds (Mulligan and Coleman 1974; Lehmann 1994; Chapman 1995).

B) The soil surface structure is degraded in the harvest process, increasing the risk of soil erosion by wind.

C) Abrasive material enters the thresher, resulting in excessive wear on harvester components.

Tuncks (1981) and Boyle (1995) summarised some attempts to overcome these deficiencies as below.

a) The Horwood Bagshaw machine capacity can be increased by incorporating a 2.1 meter wide duct. However, it is rarely used in practice because of pod pick-up problems in difficult conditions (Boyle 1995).

b) Coupling machine pairs is the most successful alternative to increase the field capacity. The second machine can be driven by a separate engine or by the same tractor that drives the first machine through a transmission adjustment on the first one. This set-up maintains the same labour cost with twice the field capacity. The problem of abrasive material entering the thresher still remains.

c) Employing a rotating brush in conjunction with the duct could provide a solution to boost the lifting performance, consequently increasing operating speed. It appears with peripheral speed around 2 times the forward speed, materials would be ejected from the brush towards the pick-up duct. This effort causes the pick-up efficiency to be maintained whilst either the duct width or the machine forward speed, or both, are increased.

d) Employing a pre-cleaner between the pick-up duct and the thresher can significantly reduce the quantity of material smaller than pods entering into the thresher. A pre-cleaner consists of an oscillating screen which transports pods and materials larger than the openings into the thresher. Materials below the sieve openings fall through the screen and rotary valve towards the field surface. The pre-cleaner increases the total cost of the machine by approximately 25% and the power requirement by about 15% due to airflow losses in the expanded chamber.

2.4 Other Ground Pneumatic Harvesters

Literature discussing pneumatic harvesting of medic seeds is very limited. However equipment used for pneumatic harvesting of other crops can provide useful design information.

One method of collecting pecans is by vacuum from the ground surface. The main parts of a pecan harvester are described by Sarig *et al.* (1984) as: fan, vacuum head and duct, expansion chamber, container and other components like frame and PTO coupling. Soil degradation is not a problem with this machine as it is for medic pods because of field surface conditions. Pecan fields are generally covered with grasses and present less exposed soil to the harvester.

The mechanical filbert nut harvesters are another class of a pneumatic harvesting system. Suction heads are mounted on the front of the machine with a knee action linkage to follow the ground contours. Price and Lunde (1945) stated "nozzles work best when designed to have a constant cross sectional area, so that air velocities do not change" in conveying material. Operating parameters of this machine were airflow rate 3 m^{-3} s^{-1}, and air velocity at the head 30 m s^{-1} . In the experimental tests of this machine the best results were obtained in wet soils after rain, rather than in dry loose soils.

An almond harvester has also been developed by Parks and Fairbank (1948) with a similar design to the filbert nut harvester. Vacuum head height from soil surface was adjusted by trailing gauge wheels, while the best position was about 40 mm from ground. Applied air velocity was 23 m s^{-1} at the entrance of the head. The separation system was similar to the filbert nut harvester. Both machines used a rotary valve to seal vacuum in the nut chamber and to release the collected material (nuts) into further processing components. However, in the almond harvester, this valve clogged frequently. To reduce clogging, employing a flat conveyor with a rubber flap extension toward the nut chamber, or an auger type conveyor, were suggested, although these methods were not tried in the study (Parks and Fairbank 1948).

A macadamia nut harvester has been based on blowing used a closed system approach to recirculate the applied air. Excessive power consumption and clogging were major problems with this machine. Finally it was abandoned due to the clogging (Liang and Kirchbaum 1982).

Liang and Kirchbaum (1982) stated the main parts of the redesigned macadamia nut harvester, which did not used a closed system, as:

- a fan to generate air movement;
- an air sweeper (blowing head) mounted on a wheel;
- a nut collecting wheel made from a rotating coil spring ramp;
- a nut pan and pick-up elevator;
- a screw conveyor to carry the nut into a bin; and
- a bin to store nuts.

In a review of jojoba equipment, Coates (1987) noted that all ground harvesting devices under development used vacuum to collect seed from the soil surface. In one case, a sweeper was combined with a blower to gather the seed into windrows which are then vacuumed up by the harvester.

Coates and Lorenzen (1990) described a trial to compare two designs of jojoba harvesters with vacuum principles to develop a commercially acceptable machine. The first designated implement was a straddle harvester, in which the engine, cleaning components and operator's platform were positioned to pass over one row of plants, while the harvesting heads, conveying system and locomotion means passed between the straddled row and adjacent rows. This harvester, which was suitable for fields planted with 2.4 m row spacings, collected seeds from both sides of the straddled row plus the inside of each adjacent row for a total of two rows. The second harvester was suitable for fields planted with the more common 3.6 m spacing. The power unit and all of the associated harvesting components passed between two rows and collected seed from the inside half of each row for a total of one row at a time.

Similar design concepts were employed on both harvesters. Pick-up heads were used to collect seeds from the ground surface into the machine. Collected material was transported in a high velocity airstream into a separation chamber where the seed and other dense material fell from the airstream. The air was then exhausted through the fan to the atmosphere. The seed and other material passed from the bottom of the separation chamber through an airlock which removed them from the vacuum. The seed was then cleaned and conveyed into a seed hopper. Air velocity at the entrance to the head was approximately 78 $m\ s^{-1}$ for harvester one, which was provided by two fans; each required 35 kW power for four heads. There were two pairs of heads on the second harvester with air velocity at the opening of 56 $m\ s^{-1}$, which was generated by two fans requiring a total of 30 kW power. The comparison of the two designs showed that both machines successfully collected seed from the soil surface. However, harvesting efficiency varied with field conditions and head adjustments. Also, the amount of collected soil increased on both machines when heads were too low.

The principles of these harvesters are similar to those employed in the H.B. Harvester for medic seed harvesting, with a difference being that the thresher is not included on them. Threshing is required in medic seed harvesting, and takes place before separation of collected material from the airstream. Fortunately, high air velocity is not required to move the medic pods. However, applying an airstream even with low velocities is dangerous for soils, since the medic fields generally are not grass covered, and the surface soil becomes liable to wind erosion in harvesting situations.

2.5 Disadvantages of Ground Harvesting Techniques

The problems that have been identified in the ground harvesting techniques are:

a) A large amount of soil and other surface material is collected and consequently clogging is a common problem with pneumatic harvesters. Coates (1987) reported that in some cases of jojoba harvesting, 85% by weight of the harvested material was soil and rocks. Similar problems with soil pick-up have been identified in medic pod harvesting by Tuncks (1981). In a study of two different medic crops (*M. truncatula* and *M. scutellata*), he determined 75% by mass of the collected material was soil.

b) Beyond the very serious problem of damaging fertile soil and the wear costs of the harvester there are additional costs in hauling harvested material to a cleaning facility and in the necessity for an expensive cleaning operation prior to processing (Coates 1987; Tuncks 1981).

c) Pneumatic harvesters require a smooth field surface for efficient operation. The existence of plants, obstacles on the field and irregularities on the surface causes the loss of a high proportion of seed (Parks and Fairbank 1948; Liang and Kirschbaum 1982; Coates and Lorenzen 1990 and Tuncks 1981).

d) Low operating speed and excessive power requirements, as well as noise and dust, were reported as some major deficiencies of ground harvesting by Parks and Fairbank (1948).

2.6 Field Preparation for Medic Pod Harvesting

The successful harvesting of medic seed requires good field preparation both pre and post-seeding and pre-harvest (Ragless 1977; Tuncks 1981). Pre-seeding preparation usually consists of rolling crops with a heavy flat roller. This may also be carried out after sowing. On sandy soils, for example, rolling is best done immediately after sowing, and on heavy soils when crops are approximately 10 cm high and the soil is not too wet (Ragless 1977). Uneven surfaces and the presence of medium sized stones are particular problems.

The object of pre-harvest preparation is to remove overburden and have the medic pods resting lightly on the surface without any obstructions or entanglements. Different localities often require different preparation (Horwood Bagshaw Ltd 1989), but the following techniques have proved generally satisfactory (Ragless 1977).

1. *Cutting:* Plants are usually cut by a rotary mower. In some cases, raking is an alternative to cutting.

2. *Windrowing:* Most of the time a side delivery rake or finger wheel rake is used to move the overburden into circuitous round corner windrows. It is usually done by several passes raking in opposite directions.

3. *Baling:* Sometimes overburden and vines are baled before seed harvesting commences,

but care must be taken to prevent too many pods being lost in bales.

4. *Pod spreading:* this is an operation which involves dragging "cyclone" type wire mesh at a relatively high speed over the bare ground surface. The most important stage in the pre-harvesting process is brushing-up the field and loosening pods on the surface. The wire mesh dragging may be done in conjunction with light harrowing. The combination of tractor speed (24 to 32 km h^{-1}) and harrow points down and or up is designed to loosen but not bury pods. This process, however, may result in a large increase in the soil entering the harvester.

2.7 Evaluation of Harvesting Machines

The level of performance of harvesters is influenced by the interaction of many parameters of machine and crop (Cervinka 1974). Economy of harvesting operations generally requires high performance of the harvesting machine. Renoll (1981) stated that farm machinery has become larger, more complex and more expensive. If these machines are to make their maximum contribution to production, it is important that they be effectively used. Agricultural machine performance has been investigated as field capacity, material capacity, losses and time efficiency (Cervinka 1974; Bargen and Cunnery 1974; Renoll 1981). A few of these indicators are defined in Chapter 3.

Field efficiency is a measurement of time spent performing the operation relative to the total time in the field. Table 2.4 lists field efficiency for several harvesting machines.

Hunt (1983) stated that capacity, when expressed only as area per time, is usually not a sufficient indicator of a machine's true performance, particularly with harvesting machines, because differences in crop yields and crop conditions can affect machine field capacity. Therefore, a valid comparative capacity would be mass of crop which is harvested per hour. This property is called material capacity.

Cervinka (1974) noted for grain harvesters that losses and throughput rate are the decisive factors generally used in the evaluation of the work performance of these harvesters. Gathering losses which can be compared with pick-up head losses in medic seed harvesting was reviewed by Walsh (1991) in bean harvesting. He cited from Quick (1972) that gathering loss averaged 9% of yield and represented on average 85% of total losses. A careful search of the literature provided no information about the performance of the H.B.

Harvester for medic pod harvesting.

Table 2-4 Range in typical field efficiencies and operating speeds for some harvesting machines (Hunt 1983)

Harvesting machine	Field efficiency (%)	Operating speed (km h^{-1})
Mower - conditioner	80 - 95	5 - 9
Rake	62 - 89	6 - 9
Baler, rectangular	65 - 80	5 - 10
Baler, round	40 - 50	5 - 19
Forage harvester	50 - 76	6 - 10
Combine (standard)	63 - 90	3 - 8
Corn picker	55 - 70	3 - 6
Potato harvester	50 - 90	3 - 6
Cotton, spindle picker	65 - 90	3 - 5

2.8 Physical Characteristics

It is essential to have a knowledge of the crop characteristics for the design of agricultural mechanisation or automation equipment (Simmonton 1990). Stephens and Rabe (1977) suggested that more information on crop physical and mechanical properties would help define the best treatment to be applied to the crop during harvest to achieve the desired result. The importance of the physical properties of agricultural products for designing process equipment and harvesting machines has also been emphasised by several other workers, including Fridley and Adrian (1966), Shepherd and Bhardwaj (1986), Deshpande *et al.* (1993), Mesquita and Hanna (1995) and Singh and Goswami (1996). Information is available on the physical properties of fruit (Mohsenin 1986), nuts (Muller *et al.* 1967; Prussia *et al.* 1985) and grain crops (Bilanski *et. al.* 1962; Bilanski and Lal 1965; Garret and Brooker 1965; Hawk *et. al.* 1966; Oje and Ugbor 1991), but information on the physical properties of medic pods and seed is not available.

This review mostly attempts to deal with those characteristics of crops that are involved with the movement of material in an airstream, such as shape, size, volume, density (bulk and kernel density), projected area and other physical characteristics.

2.8.1 Size and Shape

Size and shape of agricultural products are important characteristics in many processes, such as harvesting, separating, washing, grading, handling, aeration, drying, milling, storing and packaging (Makanjuola 1972; Singh and Goswami 1996). Mohsenin (1986) noted that shape and size are inseparable in a physical object, and both are generally necessary if the object is to be satisfactorily described. Several researchers have described the size of grain by measuring length, width and thickness (Shepherd and Bhardwaj 1986). Makanjuola (1972) studied the shape and size of two varieties of melon seeds in terms of length, width and thickness as parameters which influence the design of a shelling machine. Table 2.5 presents the size of some seed grains that Bilanski *et. al.* (1962) investigated to determine their behaviour in an airstream.

Other criteria of size include "*projected area*" or "*frontal area*", which is a significant factor in applying aerodynamic principles to agricultural products. This criteria was initially proposed by Houston (1957) in developing a sizing machine for lemons.

In most cases, particles of small sized agricultural products are assumed to be spherical inshape with projected area equal to $(\pi/4)\,d_p^{\,2}$, where d_p is the diameter of the sphere of the same volume as the particle (Mohsenin 1986; Dutta *et al.* 1988).

Table 2-5 Size dimensions and weight for some seed grains that were investigated by Bilanski *et.al.* 1962

Crop	Length (mm)	Width (mm)	Depth (mm)	Weight (g)×100
Alfalfa	2.35	1.43	1.07	0.24
Barley	8.81	3.20	2.38	3.31
Corn	11.64	8.02	4.15	28.58
Flax	4.33	2.26	1.10	0.54
Large oats	12.22	2.80	2.16	3.36

Small oats	9.60	2.44	2.07	1.81
Soybeans	7.77	6.77	5.88	20.59
Wheat	6.95	3.35	2.96	4.54

2.8.2 Volume, Density and Specific Gravity

The volume and specific gravity of agricultural products such as seeds and grains are usually determined by water displacement, because of irregularity in shape and small size (Browne 1962; Mohsenin 1986).

Density and specific gravity of agricultural products play an important role in many applications. Drying and storing of hay (Day and Panda 1965), design of silos and storage bins (Otis and Pomroy 1957), separation and grading (Kunkel *et al.* 1952), separation from undesirable materials (Maak 1957) and determining the purity of seeds (Stermer 1965) are a few examples of applying volume, density and specific gravity in design.

Bern and Charity (1975) described the effect of density of agricultural products on the resistance to airflow of the stored mass. Bulk density of granular materials is required in the design of bulk handling systems (Henderson and Perry 1976). Bulk density is also a basic parameter in predicting the structural loads for storage structures (Jayas *et al.* 1989). In application of pneumatic techniques for handling material, a kernel (true) density is required.

The bulk density and kernel density of most agricultural products have been determined. Table 2.6 shows approximate bulk density and kernel specific gravity of some grains or seeds (ASAE Standards 1994).

Table 2-6 Approximate bulk density and kernel specific gravity of grains and seeds (ASAE Standard 1994)

Crop	Bulk density (kg m^{-3})	Kernel specific gravity
Barley	618	1.13 - 133
Canola	669	1.10 - 1.15
Corn	720 - 901	1.19 - 1.30
Flax	721	1.10

Oats	412	0.95 - 1.05
Rice	579	1.11 - 1.12
Soybeans	772	1.13 - 1.18
Wheat	772	1.29 - 1.30

2.8.3 Aerodynamic Characteristics

Aerodynamic properties of agricultural products play an important role in pneumatic conveying (Humphries *et al.* 1979), grain drying, pneumatic separation (Hawk *et al.* 1966; Mohsenin 1986) and pneumatic harvesting (Coates and Yazici 1990). Properties must be known for optimal design of harvesting equipment. The parameters which characterise the aerodynamic properties of particles are drag coefficient and terminal velocity (Klenin *et al.* 1985).

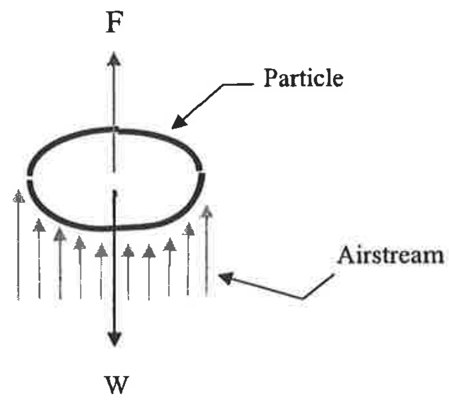


Figure 2.8 Schematic diagram of a particle subjected to a vertical airstream

A particle in a vertical airstream is acted on by two forces, the aerodynamic force, F and the weight of the particle, W (see Figure 2.8).

The force F may be obtained from Newton's equation [2.1] as below:

$$F = \frac{1}{2} c A_p \rho V^2 \qquad [2.1]$$

where: F = force due to airstream, N

c = overall drag coefficient (dimensionless)

A_p = projected area of particle perpendicular to the direction of airstream, m^2

ρ = density of air (1.18 kg m^{-3} at 20°C)

V = relative velocity between airstream and particle, m s^{-1}

W = gravitation force (or weight)of the particle, N.

Depending upon the relative magnitude of these forces, the particle may move downward when $W > F$, upward when $W < F$ or may remain suspended when $W = F$, that is the particle has no motion relative to the airstream. The velocity of the airstream at which the particle remains suspended is known as the critical velocity or terminal velocity (v_t). Therefore terminal velocity of the particle may be expressed as:

$$v_t = \sqrt{2mg / c\rho A_p} \qquad [2.2]$$

As shown in equation [2.2], the terminal velocity is dependent on the variables of mass, drag coefficient, density of air and projected area of particle. The terminal velocity of agricultural products should be determined experimentally for accuracy, because of irregularity in shape. The drag coefficient can be calculated from the experimentally determined terminal velocity. In addition, studies with regular shaped bodies (spheres, discs and cylinders) have shown a relationship between the drag coefficient (c) and Reynolds number, Re (Henderson and Perry 1976). This relationship, which is generally plotted on a system of logarithmic coordinates as (Figure 2.9), assists in determining the drag coefficient for a body.

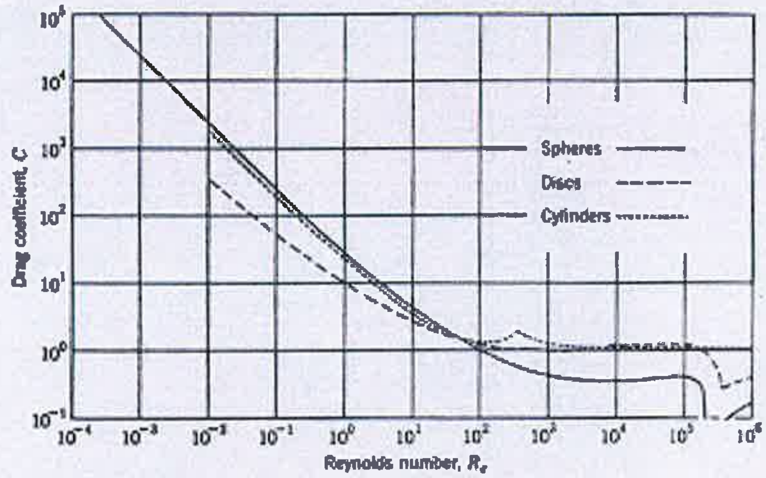


Figure 2.9 Relationship between drag coefficient and Reynolds number for various particles of regular shape (Henderson and Perry 1976)

The drag coefficient decreases with increasing Reynolds Number. The drag coefficient for agricultural products depends also on the shape and orientation of particles. Terminal velocities and drag coefficients for various crops, assuming uniform steady airflow, are summarised in Table 2.7.

However, a careful search of the literature provided no information about the physical properties and aerodynamical characteristics of medic seeds and pods nor any similar materials.

Table 2-7 Terminal velocities and drag coefficients for some agricultural products (Mohsenin 1986)

Crop		Terminal velocity (m s^{-1})	Drag coefficient
Alfalfa		5.5	0.50
Barley		7.6	0.50
Corn		10.7	0.56
Flax		4.7	0.52
Maize		11.4	0.56 - 0.70
Oats		6.6	0.47 - 0.51
Soybean		14.5	0.45
Wheat		9.6	0.50
Wheat straw:			
	0.6 cm	5.15	0.84
	2.5 cm	4.25	0.80
	7.5 cm	3.0	0.90
Apples		42.0	
Apricots		34.0	
Potatoes		32.0	0.64

2.9 Principles of Airflow in Harvesting Techniques

The two key components in the creation of an airflow of the type used in a pneumatic harvester are the fan and the head. Any extensive ducting between the fan and head is designed to minimise losses.

The fan providing the airstream for harvesting must be sized appropriately (Coates and Lorenzen 1990). It must be large enough to provide the required air volume and velocity, but too much air movement is unnecessary since it requires excessive power and increases the amount of debris picked up. Among several types of fan, the centrifugal radial-tip straight blade fan, which has a small number of blades (from 6 to 20), is suitable to handle dirty air and convey materials that go through the fan (Henderson and Perry 1976). Henderson and Perry (1976) noted that the blades of this type of fan are essentially in a plane radiating from the shaft and normally about 2 to 3 times as long as they are wide.

The characteristics of fans are well known and can be found in many texts e.g. (Osbone 1977). The head used with the fan, whether blowing or suction, determines the actual airflow velocity distribution and is therefore fundamental in the pneumatic system design.

An airstream required for harvesting can be generated by using either a positive or negative pressure approach (also referred to as blowing or suction and push or pull flow) (Coates and Lorenzen 1990). Push systems have been used to convey agricultural products (Humphries *et al.* 1979) and to move the crop into windrows for mechanical pick-up (O'Brien *et al.* 1983) or to assist with mechanical pick-up (Whitney *et al.* 1966); Pull systems have been used to pick-up crops directly.

2.9.1 Airflow Characteristics

Hayashi *et al.* (1985) noted that blowing and suction types of flow situations have fundamentally different characteristics. The simplest illustration of this was provided by Alden and Kane (1982), who indicated that the effective distances of the velocity distribution of positive and negative pressure heads vary significantly.

As illustrated in Figure. 2.10 with a tapered inlet head having a rectangular face area, the effective air distance, using 10% of the face velocity as the criterion, will be 30 times the width of the head when blowing, but equal only to the width when vacuuming. With increasing distance from the suction head, the velocity decreases faster than if air jets were delivered from the same head with the same flow rate (Baturin 1972).

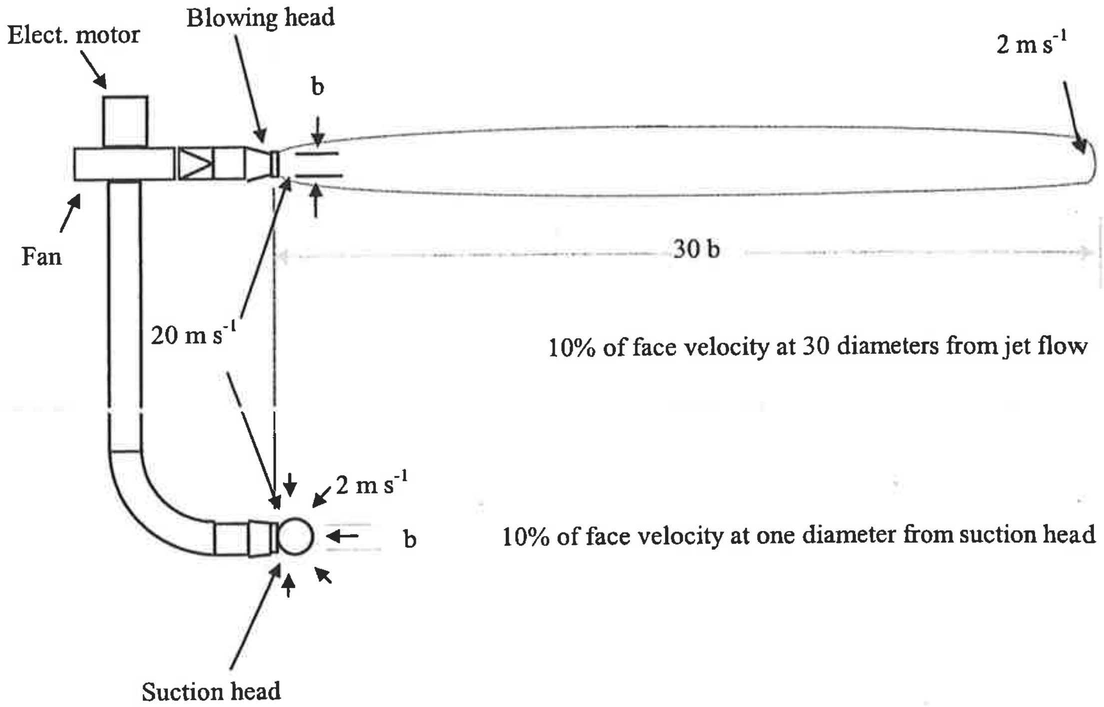


Figure 2.10 Velocity distribution for positive and negative pressure heads (SMACNA 1976)

2.9.2 Air Jet (Blowing Flow)

In the past, many theoretical and experimental studies have been performed on jet flows because of their wide applications in engineering. Recently air jets have become attractive systems in ventilating animal buildings in the agricultural sector. Some work has been conducted by Blackwell *et al.* (1989), Bottcher *et al.* (1995a), Bottcher, *et al.* (1995b) and Liu, *et al.* (1996) based on earlier work on the theory of turbulent jets by Abramovich (1963) relating to industrial ventilation.

Air jet theory is also relevant in the design of air sprayers (Brazee, *et al* 1981; and Fox, *et. al.* 1992) material handling systems (Elawady and Akesson 1969) etc.

A free circular jet is produced when a fluid flows into an infinite or, in practice, sufficiently large space fully occupied by this same fluid in relatively calm condition (Baturin 1972).

The flow structure in a turbulence free jet consists of two distinct regions - initial and main, as illustrated in Fig. 2.11.

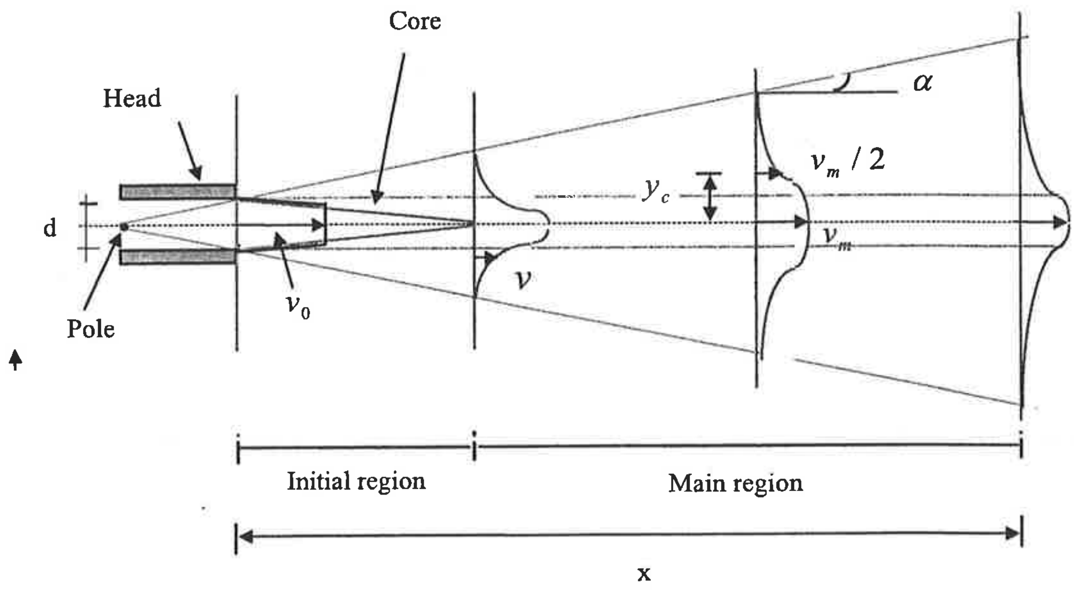


Figure 2.11 Diagram of the regions of an ideal jet (Baturin 1972)

The initial region of a jet contains a core of potential flow confined by the jet boundary layers that originate at the head walls. The axial velocity of the jet in this region remains unchanged and equal to the velocity at the exit head, until the core disappears (Baturin 1972). Beyond the initial region the jet energy is consumed by entrainment, expansion and turbulence, so that the centreline velocity decreases with increasing distance (Abramovich 1963). This region of the jet is known as the main region or established region.

Free air jets have been studied in terms of velocity profile, jet spread and turbulence properties (Schwarz and Cosart 1961; Abramovich 1963; Myers *et al.* 1963; Wilson *et al.* 1970; Randall 1971; Tanaka and Tanaka 1976; Walker 1977; Wygnanski *et al.* 1992). With reference to Figure 2.13, the velocity profile is the variation in axial velocity in the vertical or lateral plane at some horizontal or axial distance, x, from the face of the head. The maximum value for this plane is v_m. The spread of the jet is defined by the angle α.

A free plane jet typically issues from a slit at the end of a converging channel (Baturin 1972). Velocity profiles relate to a plane parallel to the short side of the slit. The axial velocities are given in Table 2.8.

Table 2-8 Summary of axial velocity for free circular and free plane jet (Baturin 1972)

type of jet	notation	initial region	main region
circular free jet	$\frac{v_x}{v_0}$	1	$\frac{0.45}{\frac{ax}{b}+0.145}$
plane free jet	$\frac{v_x}{v_0}$	1	$\frac{1.2}{\sqrt{\frac{ax}{b_0}+0.41}}$

where; v_x = centreline velocity at x distance from head.

v_0 = velocity at head

x = distance from head

b = head diameter

a = coefficient factor determined experimentally

The coefficient factor relates to the construction and shape of the head and defines the degree of turbulence. A large value of a indicates mixing of the jet with surrounding air and large angle of spread of the jet (Baturin 1972).

The velocity profiles of a free jet at various distances from the head are similar, and in the main section they can be represented in dimensionless coordinates by one generalised distribution (Abramovich 1963). To represent a dimensionless velocity profile, (Abramovich 1963) described that the ratio of velocity at a point to the velocity at the exit of head, $\frac{v}{v_0}$ is plotted against the ratio of the distance between the point and jet axis to the head diameter, $\frac{y}{b}$.

Ground harvesting methods do not use free jets, but wall jets to impart force to the crop on the surface. A wall jet is defined as a jet of air which flows along a boundary such as a floor (Tuve 1953; Tani and Komatsu 1964; Blackwell *et al.* 1989; Liu *et al.* 1996). Figure 2.12 illustrates a plane free jet and a plane wall jet.

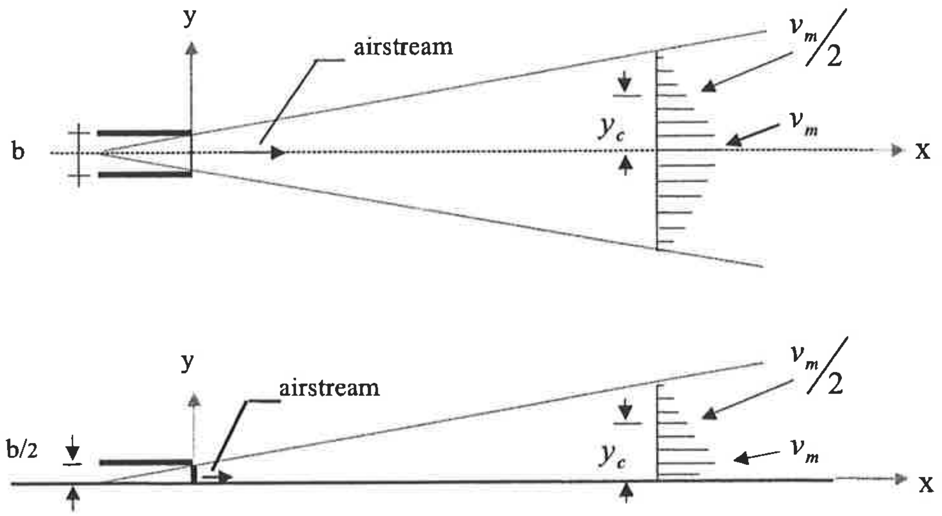


Figure 2.12 A plane free jet and a plane wall jet (Liu *et al.* 1996)

Jets directed at any angle to a surface (boundary) generate wall jets (Baturin 1972). Figure 2.13 shows the flow of airstream for an inclined and a vertical impacting jet on a surface.

Zhivov (1993) analysed such flows based on division into three regions: a free jet region, an impingement region and a wall jet region (Figure 2.13). Air in the free jet region flows downward due to the momentum imparted by the fan in the form of pressure difference across the head (Tani and Komatsu 1964). An impacting region is produced by the free jet on the surface. The impacting of the free jet on the surface causes a rise in static pressure, which forces the jet to move away from the impacting region and imparts forces to material.

Baturin (1972) described that, whereas the spread of the jet for a 90° impact takes place uniformly in all directions (Figure 2.13b), at an angle smaller than 22.5° the whole of the jet flows in the one direction, and at an angle greater than 22.5°, the majority of the air travels forwards (Figure 2.13a).

Wall jets are characterised in the same way as free jets, i.e. velocity profile, velocity decay and jet spread (Liu *et al.* 1996). The velocity decay of a wall jet was found to be equivalent to that of a free jet having twice the head width of the wall jet (Tuve 1953; Newman *et al.* 1971; Walker 1977). The same was true for the velocity profile of a wall jet except for the region close to the wall.

2.9.3 Pull Flow Suction Flow

In suction flow, the air is drawn into the head from all directions, whereas in blowing flow air is issued as a cone with an angle which depends on the turbulent structure of the jet (Baturin 1972). Since suction openings tend to draw air equally from all directions, the flow lines and the velocity contour surfaces are bulged transversely of the head axis (Alden and Kane 1982). Figure 2.14 shows the velocity contours and flow lines in a longitudinal centreline of a round pipe. With reference to Pt (a) it is clear that the velocity drops rapidly as the distance from the opening increases. This statement is graphically illustrated in Pt (b) in which distances are expressed as percentages of opening face diameter and velocities as percentages of opening face average velocity, v_0. The velocities at distances greater than 0.5 diameter are almost inversely proportional to the squares of the distances from the opening face.

Alden and Kane (1982) concluded that:

- the shape of the contour lines for a given shape of head is nearly identical for all sizes of that shape; and
- large heads are more effective over greater distances than small heads since contours representing the same percentage of the face velocity lie far from the head face.

Alden and Kane (1982), in refering to DallaValle's experiment, noted that in suction flow, centreline velocities are affected by the distance from the opening face and opening face area. This relation between velocity, distance and face area could be expressed as:

$$\frac{v_0}{(100 - v_0)} = 0.1\frac{A}{D^2} \qquad [2.7]$$

where v_0= velocity in % of face velocity,

A= opening face area,

D= distance from opening face.

This equation is often expressed as:

$$v_x = \frac{Q}{10D^2 + A} \qquad [2.8]$$

Where: v_x = velocity at distance x from opening face,

Q = flow rate, $m^3\ s^{-1}$.

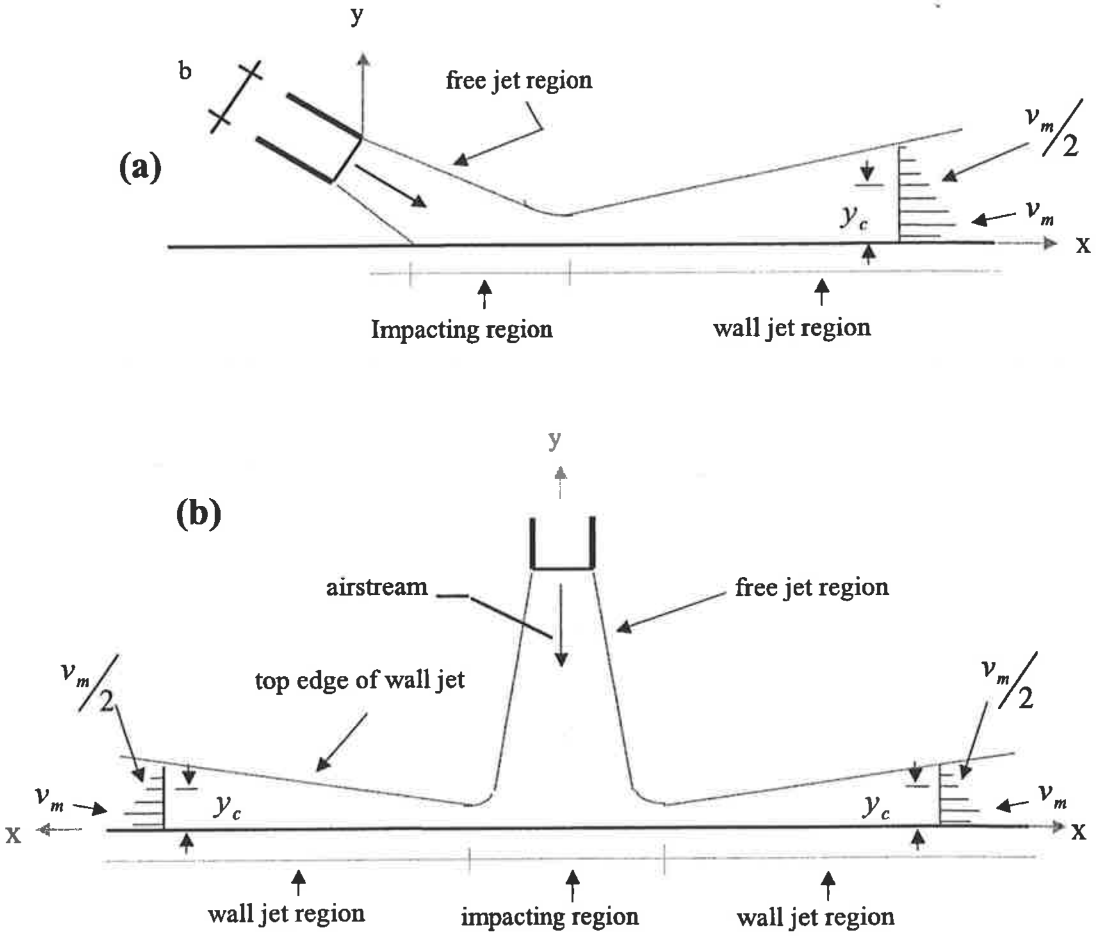


Figure 2.13 Pattern of airflow of a wall jet (a) for an inclined impact and (b) for a perpendicular impact to a surface (Striegl *et al.* 1982)

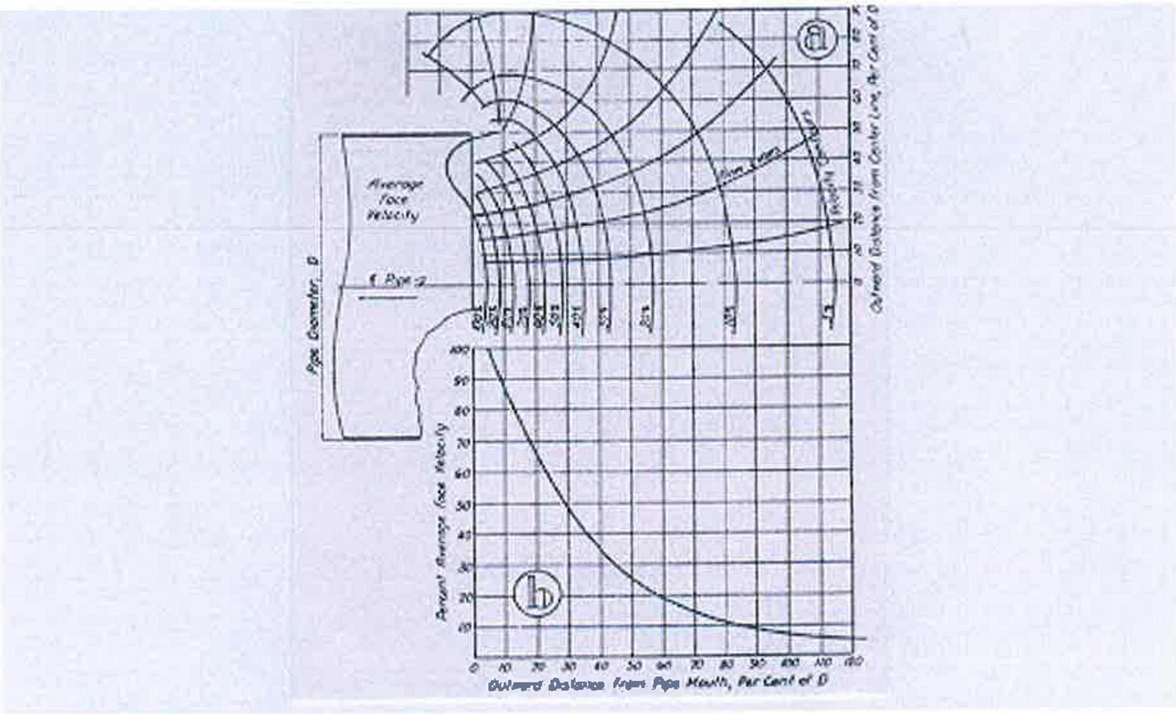


Figure 2.14 Flow lines and velocity contours in a circular suction pipe (Alden and Kane 1982)

Alden and Kane (1982) showed that pressure losses in a tapered head depend on the angle of divergence. As shown in Table A.1 in Appendix A, a 40 to 50 degree angle of divergence provides the least velocity head loss and the greatest coefficient of the entry for both round and rectangular openings. Losses at an entry head, which are usually expressed in percentage of the velocity head, have also been included in the Table A.1 Appendix A.

SMACNA (1976) indicated that in the case of pull flow, close position of a particle to the head is more effective, since the required air volume varies with the square of the distance between the particle and the head face. This is illustrated schematically in Figure 2.15.

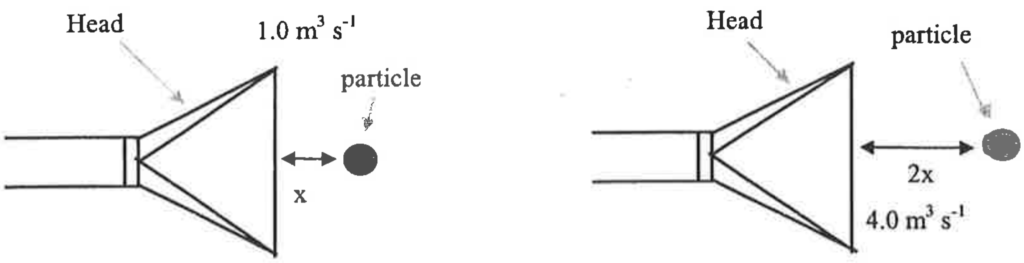


Figure 2.15 Effect of the distance between the head face and particle on required air flowrate (SMACNA)

2.9.4 Airflow Heads

One of the critical aspects of a pneumatic system is designing a suitable head (Alden and Kane 1982). Heads, either pushing or pulling the airflow, are seldom the same shape as the cross-section of the delivery pipe. Shape and size are varied from application to application, but circular and rectangular are the most common shapes (Baturin 1972).

The heads can be modified by the inclusion of converging and diverging tapers to increase efficiency. For example, to pick-up materials or exhaust air a diverging tapered head is recommended; to produce a concentrated jet a converging tapered head is used. The losses in converging tapers with angles of less than 30^{o} between sides are generally smaller than those for flanged pipes (see Table A.1 in Appendix A). Accordingly, coefficients of discharge may be increased and coefficients of resistance decreased by using conical tapers rather than flanges (Jorgenson 1961).

Flanges are important in improving efficiency in suction systems. Alden and Kane (1982) provided velocity contours with and without flanges surrounding a head opening as shown in Fig. 2.16. The flange caused reduction of the flow from the ineffective region by forcing air to flow from the zone directly in front of the head.

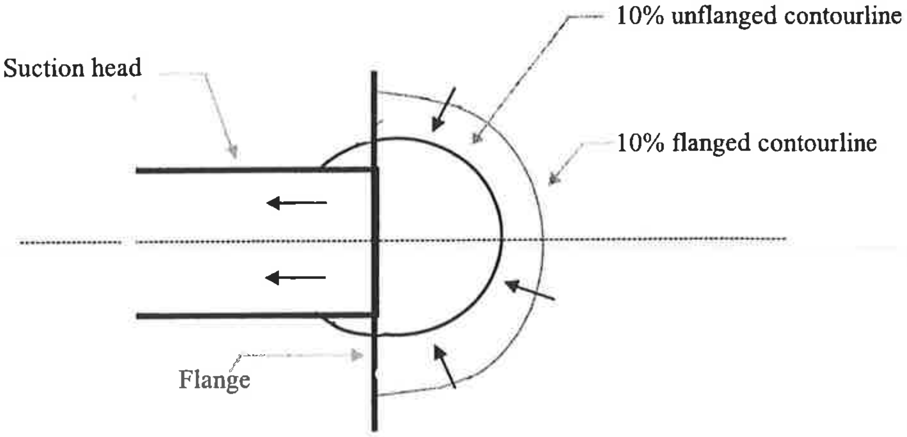


Figure 2.16 Effect of head flanges on velocity contours (Alden and Kane 1982)

From the point of view of harvesting, Price and Lunde (1945) and Coates and Lorenezen (1990) stated that the harvesting heads must be as wide as possible to increase field capacity, and the cross-sectional area of the frontal part of the head must be equal to the conveying pipe's cross-sectional area to provide constant cross-sectional area along their length for a uniform air velocity within them and to eliminate any dead spots.

Moreover, they suggested that the flange width should be such that it intercepts the 10% contour line of the unflanged head. If constructed so, the 30% contour will be pushed outward about 14% and the 10% contour about 9%.

In pneumatic techniques for filbert nut harvesting, Price and Lunde constructed a straight vertical lift head with a rectangular shape at opening and they added a horizontal lip or skirt on both sides of the head to improve the suction flow. The shape and size of the flange around the pick-up heads were emphasised by Parks and Fairbank (1948) as determining head effectiveness for pneumatic almond harvesting. They drew attention to the importance of the height of the suction head in picking up almonds. By experiment they found that around 40 mm above the ground surface was a desirable working height for suction heads in collecting almonds.

Extending the top and side walls of suction heads forward from the air inlet was considered by Coates and Yazici (1991) in jojoba seed harvesting to increase the effectiveness of suction flow in picking up seeds from the ground surface. They modified a suction head with a rectangular opening with flanges on the top and sides to reduce the amount of soil and stones collected and improve jojoba seed collection. The modified head permitted the suction head to be operated 50 to 75 mm above the soil surface, rather than skimming close to it as was commonly practised.

In addition to shape, another critical design requirement is that the head should be able to 'float' vertically (Coates and Lorenzen 1990). This permits the head to clear obstructions and ensures that a constant operational height is maintained.

2.10 Conclusions

Annual medics are important pasture legumes both in Australia and throughout many countries of the world. For medics to be effective in farming systems, a cheap and plentiful supply of medic seed is required.

Over the years, a number of medic seed (pod) harvesting machines have been developed, beginning with the sheep skin roller (Hely 1950). Currently, the most popular machines are the models made by Horwood Bagshaw. Problems with vacuum seed harvesting may include:

- effectiveness of pod collection;
- slow speed of operation, leading to high energy and time requirements and consequently high cost;
- pre-harvest preparation requirement, adding further to cost; and
- damage to fragile surface soil structure and resultant exposure to erosion by wind,

There is an urgent need to evaluate performance and if necessary to investigate methods to improve performance.

The characteristics of airflows that can be created, both blowing and suction, have been reviewed, and the use of pneumatic methods in harvesting several crops has been described. Although pneumatic methods are used in other harvesting enterprises, they can not be considered to constitute a significant component of agricultural harvesting activity. Pneumatic methods are used in some other agricultural operations such as conveying and cleaning. Most fundamental work on the characteristics of airflow and its production comes from the study of industrial ventilation airflow.

No airflow system can be designed without knowledge of the particular characteristics of the product to be harvested, in this case medic pods and soil particles associated with the pods.

2.11 Rationale for Experimental Program and Approach Undertaken

Although there are doubts about the efficiency of the present harvester, the first step must be an evaluation of actual performance and the possibility for further optimising of that performance, specifically to increase speed and reduce deleterious field surface effects. If improvement is not possible to the present system of vacuuming the ground surface, then some alternative system such as blowing pods needs to be investigated. To achieve this aim, a thorough understanding of the characteristics of airstreams is essential as is the way in which pods and other materials respond within the airstream. The theoretical solution needs to be checked by practical tests.

Any procedure that allows differentiation between pods and soil particles at source (ie. before entering the harvester) must be the best solution because (not necessarily in order of importance):

- it will reduce the pneumatic load on the harvester, potentially increasing speed of collection and reducing energy input requirements.
- it will reduce harvester maintenance costs.
- it will result in less surface soil movement and degradation of surface material

The research steps will be:

a) Investigation of harvester performance: A comparison of existing harvesters performance to be carried out together with the influence of factors on the collection of pods. This will involve a field comparison of three harvesters (Chapter 3). The criteria adopted will be pod collection efficiency, machine efficiency, machine capacity and soil displacement.
b) Characterisation of medic pods and soil particles: Various physical and

aerodynamic properties of Paraggio medic pods and typical pasture surface soil will be measured and to assess the relationship to each other in the context of suction and / or blowing flow (Chapter 4).

c) Evaluation of airflow characteristics. The characteristics of airstreams for both blowing and suction flows, such as free flow and with surface impacting, will be studied in detail. In addition, the potential of combined flow is to be examined (Chapter 5).

d) Investigation of aerodynamic behaviour of pods and soil particles. The aerodynamic behaviour of Paraggio medic pods and loose soil in several size categories needs to be examined with a view to separation of pods from soil for selective pick-up (Chapter 6).

e) Finite element simulation of blowing flow. A computer simulation of the airflow from a rectangular head impacting on a surface will be required to provide insight into a physical situation which is too complex for other means of analysis. This analysis will also have the potential to examine airstreams formed by a number of heads acting together leading to suggestions for the design of a new system of pod harvesting (Chapter 7).

Chapter 3

EVALUATION OF CURRENT PRACTICE IN MEDIC SEED HARVESTING

3.1 Introduction

The level and rate of performance of harvesters and the quality of the product depends on the interaction of machine and crop characteristics. Cervinka (1974) studied these effects in the design of grain harvesters to improve the performance of the standard combine. This work focussed on throughput rate and losses.

Harvesting loss, particularly gathering loss is one of the essential criteria when rating a harvesting machine. In a review of mungbean harvester performance, Walsh (1991) reported that on average, harvest losses of 30% were attributed to the front of the harvesting machine. Quick (1972, cited by Walsh 1991) analysed the results of 15 authors who measured soybean harvest losses in U.S.A. He found that gathering losses averaged 9% of yield, which represented 85% of total losses. Tuncks (1981) has identified that about 25% losses in medic seed harvesting to be a basic criteria for adjusting suction head clearance. Although potential gains from harvest research are apparent, little work has been done on pneumatic harvesting techniques for medic seed harvest.

In addition, in medic seed harvesting there is the problem of displacement of fertile top soil and possibly the loss of some of this material as a result of size degradation, to wind action, etc. Tuncks (1981) indicated that the pods entering a harvester may account for only 15% of the total mass taken into the machine, with 10% being vegetable matter and the remaining 75% sand and soil.

This Chapter reports a series of tests designed to determine the general performance of three existing harvesters and assesses the potential to reduce loss of yield and soil disturbance. A second series of tests was designed to determine the effect of varying operating characteristics, to achieve the same aims as in the first tests.

3.2 Definitions

Pod collection efficiency: This is a measure of the capacity of the harvester to collect pods relative to the total pods on the field surface.

$$PC = (1 - \tfrac{L}{Y}) \times 100 \qquad [1]$$

where: PC = pod collection efficiency, %

L = pick-up duct pod losses, kg ha^{-1}

Y = field pod yield, kg ha^{-1}

Harvester field efficiency: This is a measurement of the time spent in collecting pods relative to total operating time in the field. It is expressed by:

$$FE = \frac{T_p}{T_t} \times 100 \qquad [2]$$

where: FE = field efficiency, %

T_p = pick-up time, min.

T_t = total time, min.

Theoretical harvester field capacity: This measures the area of field harvested per unit time by a machine collecting pods continuously over a one hectare field. The theoretical or potential field capacity is calculated with the indicated action width of pick-up duct and forward speed as Equation [3].

$$FC_t = \frac{S.w}{10} \qquad [3]$$

where: FC_t = theoretical field capacity, ha h^{-1}

S = forward speed, km h^{-1}

w = width of pick-up duct, m

Effective harvester field capacity: Since the theoretical field capacity does not take account of field efficiency and it is usually not possible for a machine to be operated with the whole width of the pick-up duct, the effective field capacity is used to give a more realistic measure of field capacity. The effective capacity is calculated as Equation [4].

$$FC_e = FC_t \times FE \qquad [4]$$

where: FC_e = effective field capacity, ha h^{-1}

Effective material capacity: Material capacity is a measure of the mass (kg) of pods harvested per hour and it is calculated by Equation [5].

$$MC_e = FC_e \times Y \qquad [5]$$

where: MC_e = harvester effective material capacity , kg h^{-1}

Y = pod yield, kg ha^{-1}

3.3 Evaluation of Existing Medic Seed Harvesters

The first trial was conducted to evaluate the performance of three current harvesting machines in South Australia. The performance was assessed by:

1) evaluating pod collection efficiency (and associated pod losses) for individual harvesters;

2) determining machine efficiency, machine field capacity and material capacity; and

3) estimating the amount of soil displaced by each machine. In this context displaced soil is that soil not returned to its original location after passage of the harvester.

Objective: The purpose of this test was to investigate the performance of three medic pod harvesting machines.

3.3.1 Experimental Equipment

Current medic seed harvesters

Harvester A: A high capacity pick-up duct Horwood Bagshaw Vacuum Seed Harvester (H. B. Harvester), with action width of 1.23 m, adjusted for medic seed harvesting (45 mm air gap), pulled by a model 4450 John Deere tractor of 104 kW (140 hp) power at the PTO (see Fig. 3.1).

Harvester B: A high capacity pick-up duct H. B. Harvester with a pre-cleaner and action width 1.23 m, drawn by a model 4480 Chamberlain tractor with 90 kW (120 hp) power at PTO (see Fig. 3.2).

Harvester C: The Dutchke's pod collection machine with the width of action 1.86 m, pulled by the 4480 Chamberlain tractor (Fig. 3.3).

A full description of these harvesters is given in Section 2.3.

The Horwood Bagshaw Vacuum Seed Harvesters discharge soil and other unwanted materials from the seed separator mainly via the riddling box, which is located between the pick-up duct and tractor (see Figure 3.4). This discharge is directed onto the previously harvested areas and displaced soil is mainly located here; other soil losses include fine material exhausting directly into the atmosphere and the remaining soil which ends up in the seed bin after threshing.

Dutchke's Harvester discharges soil to the previously harvested areas, similarly to the H. B. Harvesters, but in this case through the perforated cylindrical case of the material handling auger.

Figure 3.1 A high capacity pick-up duct Horwood Bagshaw Vacuum Seed Harvester (Harvester A)

Figure 3.2 A high capacity pick-up Horwood Bagshaw Vacuum Seed Harvester with pre-cleaner (Harvester B)

Figure 3.3 Dutchke's medic pod collection machine (Harvester C)

Figure 3.4 Discharging soil and unwanted material from the riddle box of a Horwood Bagshaw Vacuum Seed Harvester

3.3.2 Crop and Location

This experiment was carried out with Harvester A, Harvester B and Harvester C on *Medicago truncatula* cv. Paraggio seeds in a field that was prepared for harvesting by a seed grower at Balaklava, South Australia in February 1994.

3.3.3 Experimental Procedure

Experimental design: The experimental design was a complete randomised block design with 18 plots in 6 replications. Each plot measured 20 m long and was equal in breadth to the harvester action width. A distance of 3.5 m (equal to 2 passes of the Harvester C) was kept between plots (see plot layout in Fig. 3.5).

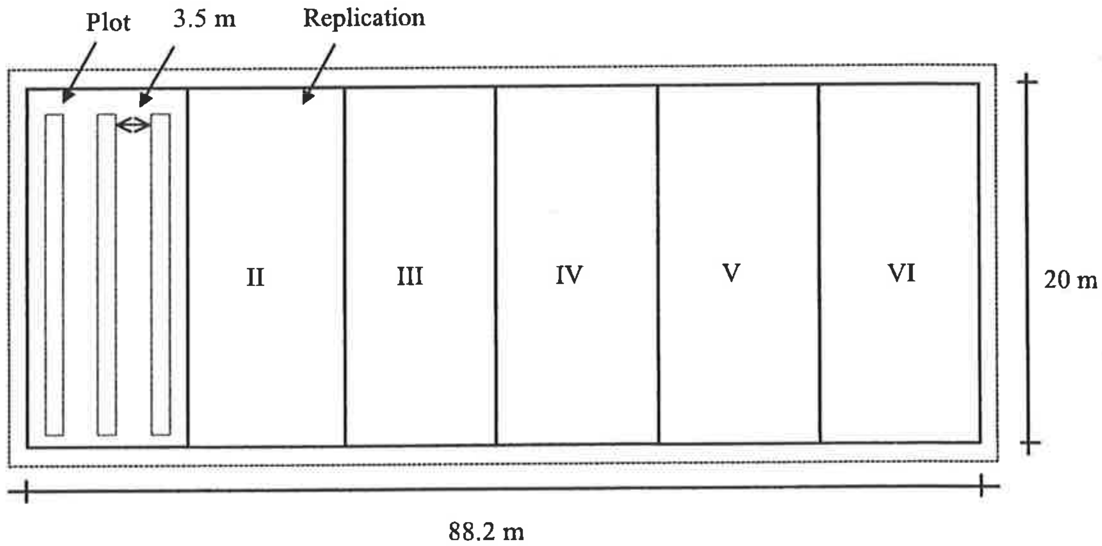


Figure 3.5 Experimental plot layout of field test harvesting

Data analysis: Pod and soil data were analysed by using the software statistical package, Genstat 5. The statistical design of the randomised block design with three treatments was used for analysis of variance. Table 3.1 shows the degrees of freedom available for statistical analysis of the data obtained on harvester performance.

The statistical test was calculated as the ratio of the variance between harvesters and compared with the critical F value with two degrees of freedom and the chosen confidence level, taken from the tabulated F distribution. For further examination, the least significant differences (LSD) multiple comparison method was used to compare each harvester mean to every other.

Table 3.1 The ANOVA table for statistical analysis of harvesting data

Source of variation	Degree of freedom
Replication	5
Harvesters	2
Residual	10
Total	17

Field sampling procedure: A rigid metal frame (quadrat) of 400 × 400 mm dimension was used to define the sample area. Three randomly selected samples were obtained before and another three samples taken after harvesting on each plot. Surface materials (loose surface soil, pods and plant residues) from each sample area were removed with a hand brush and dust pan until hard soil appeared. Typically samples had a mean of 1.8 kg before harvesting.

Samples were sieved in the laboratory for one minute with vibration to separate pods, plant residue and the five soil fractions (10>p>8, 8>p>4, 4>p>2, 2>p>1 and p<1 mm particle diameter).

Pod yield was assessed from the average of the weights of pods in 54 pre-harvest sample areas. Harvesting losses were those pods remaining after harvesting and collected pods were figured by subtracting the weight of remaining pods from the pre-harvesting result. Soil displacement figures (weights) were determined after separating pods and removing other organic material from the mixture by sieving and by hand.

Harvesting speed: The particular harvester ground speeds for each machine were those chosen and normally used by the farmer. In order to determine this operating speed, the time taken to travel 20 m distances at uniform speed was measured by using four replications for each harvester. The average of the four measurements was used to estimate the harvesting speed as given in Table 3.2.

Table 3.2 Action width and ground speed for the three harvesters

Harvesters	Width, m	Av. ground speed $m\ sec^{-1}$	Av. ground speed $km\ hr^{-1}$
A	1.23	0.88	3.16
B	1.23	0.78	2.80
C	1.86	1.20	4.32

Harvesting activity time studies: The time spent on the various harvesting activities for each machine was determined for three pre-measured one hectare field areas, after pre-harvest preparation had been done. Times were measured in seconds and activities included pick-up, turning, unloading and the other miscellaneous work that may occur during the harvest process such as field re-adjustments, cleaning and checking working parts.

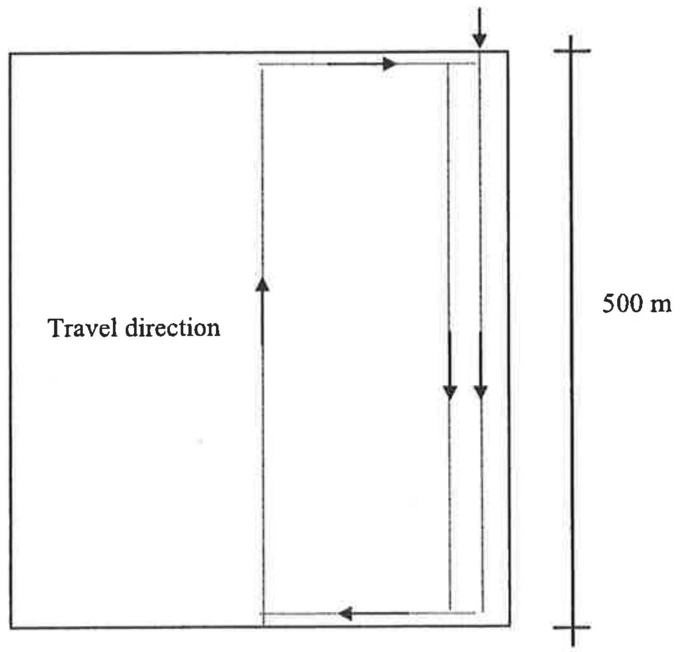


Figure 3.6 Field pattern of one hectare area used to measure the time activities for 3 medic seed harvesters

To cover the one hectare area of length 500 m and to take account of different pick-up duct widths, times were recorded for 18 passes plus 100 m for Harvesters A and B, and 11 passes plus 320 m for Harvester C.

The pattern followed to measure the time activities for all three harvesters is shown in Fig. 3.6.

3.3.4 Results and Discussion

Pod collection: An average pod yield was estimated at 1874 kg ha^{-1} with the seed ratio of 28.9% to pods in terms of mass for the field. The yield estimation was obtained by taking the average of 54 pre-harvest samples. The resulting measurements of harvested pod collection efficiency and pod losses are presented in Table 3.3.

Table 3.3 Average pod yield of the field and harvester performance in pod collection

Description	Harvester		
for treatments	A	B	C
Pod yield of the field (kg ha^{-1})	1845	1886	1892
Harvested pods (kg ha^{-1})	1392 a*	1538 a*	1526 a*
Pod losses (kg ha^{-1})	453	348	366
Pod losses (%)	24.6	18.5	19.4
Pod collection efficiency (%)	75.4	81.5	80.6

* Numbers with the same letters within rows do not differ significantly at 5 percent level based on the LSD test for difference means.

Analysis of variance of the data related to the harvested pods revealed that there was no significant difference in the masses of the pods harvested by the three machines and consequently no significant difference in pod collection efficiency. Pod collection efficiency, which has always been a challenge for seed producers, was 75.4, 81.5 and 80.6 percent for harvesting machines A, B and C respectively.

Harvesting activity time studies: An average of three measurements of time spent on the various harvesting activities by each machine is presented in Table 3.4.

The medic seed harvesting procedure follows a continuous circuitous round corner field pattern, ie. turning times are productive for these three machines. However, to determine a realistic field efficiency, a 5 minute time was included to cover unexpected events and a 20 minute time to cover unproductive time for checking parts, cleaning and adjusting, lubrication and operator personal needs.

Table 3.4 Average activity times and field efficiency for medic seed harvesters

Harvester	A	B	C
Activity times		min ha^{-1}	
Picking-up	171	193	82
Turning	5	5	5
Unloading	18	18	40
Adj.,clean, misc.	20	20	20
Total	214	236	147
Field efficiency, %	80	82	56

Field efficiency as determined by the time study was 80, 82 and 56 percent for Harvesters A, B and C respectively (see Table 3.4). The total harvesting time for Harvester C was considerably lower than for the other machines. This was due to the short pick-up time and a direct result of high forward speed and fairly large pick-up duct width. However, field efficiency of this machine (56%) is not as good as the machines, A and B (80% and 82%), especially because of unloading time. It was noted that the unloading of pods from harvester C was a weakness of that machine. The surface characteristics of pods, especially the existence of spines cause the pods to be compacted together and create a large angle of repose and great resistance to rolling. This factor was not a problem with Harvesters A and B, as they thresh the pods to produce clean medic seeds.

Harvester performance: Table 3.5 shows the results of field capacity and material capacity obtained by Equations [2] through [5].

Table 3.5 Calculated field capacity and material capacity for medic seed harvesters

Description for treatments	Harvesters A	Harvesters B	Harvesters C
Theoretical capacity, (ha h^{-1})	0.38	0.34	0.78
Effective capacity, (ha h^{-1})	0.30	0.27	0.43
Material capacity, (kg h^{-1})	553	509	813
Required harvesting time , (h ha^{-1})	3.3	3.7	2.3

Both theoretical and effective field capacity (and therefore material capacity) for Harvester C were noticeably higher than for the other two machines. Table 3.5, presents also, the total or actual time that would be required to harvest a one hectare medic seed field by each of the harvesters A, B and C, as 3.3, 3.7 and 2.3 hours respectively. Harvester C would certainly appear to be the most effective machine and Harvester B the least effective harvester.

In general, according to Equation [3] the field performance of harvesters is a function of action width and operating speed and it is increased by increasing one or both of them. The pick-up width of the H. B. Harvester, cannot be increased because of power limitations and problems created by operating on undulating field surfaces. Therefore, the performance of these harvesters relies significantly on operating speed. Operating speed is influenced by vacuum capacity; lower vacuum capacity causes the operating speed to be reduced.

Soil displacement: Table 3.6 presents the quantity of soil by size before and after harvesting and the statistical analysis of the results.

The statistical analysis shows that there is no significant difference in the mean soil displacement by the three harvesting machines. Analyses of soil particle size distribution reveals that Harvester B is less damaging to soil particles greater than 8 mm than the other two harvesters. It is notable that the mass of soil with >8 mm particles in both before and after harvest samples (3511-1932 kg ha^{-1}) is greater than for the other machines. This finding highlights the effectiveness of using a pre-cleaner attached to the H.B. Harvester.

This harvester may have picked up more >8 mm soil particles, but the pre-cleaner returned them toward the soil surface before reducing their size and directing them into the thresher.

Table 3.6 Measurement of soil mass before and after harvesting for Harvesters A, B and C

Soil size	Description	A	B	C	Differences
p<1 mm	pre-harvest (kg ha^{-1})	71984	76512	74445	
"	post harvest (kg ha^{-1})	70495	75162	72952	
"	displaced soil (kg ha^{-1})	1489	1351	1492	NS*
p>1 mm	pre-harvest (kg ha^{-1})	20063	22363	22399	
"	post harvest (kg ha^{-1})	20014	22352	22356	
"	displaced soil (kg ha^{-1})	48	11	43	NS
p>2 mm	pre-harvest (kg ha^{-1})	10789	10133	7315	
"	post harvest (kg ha^{-1})	10253	9682	6965	
"	displaced soil (kg ha^{-1})	535	451	351	NS
p>4 mm	pre-harvest (kg ha^{-1})	6999	8084	9394	
"	post harvest (kg ha^{-1})	5467	6660	7748	
"	displaced soil (kg ha^{-1})	1531	1423	1646	NS
p>8 mm	pre-harvest (kg ha^{-1})	3122	3511	3292	
"	post harvest (kg ha^{-1})	1429	1932	1572	
"	displaced soil (kg ha^{-1})	1693	1580	1719	S**
total	pre-harvest (kg ha^{-1})	112955	120602	116844	
"	post harvest (kg ha^{-1})	107659	115787	111593	
	displaced soil (kg ha^{-1})	5296	4814	5251	

* NS indicates no significant difference ($P \leq 0.05$).

S** indicates significant difference ($P \leq 0.05$).

The amounts of 5296, 4814 and 5251 kg of top soil per hectare were displaced by Harvesters A, B and C respectively. This means that these harvesters moved 4.7%, 4.0% and 4.5% respectively of the loose surface soil from its place and lodged the material somewhere on the same field or elsewhere, depending on wind velocity at the time of harvesting.

The average of the field measurements prior to harvesting are presented by mass and percentages in Table 3.7.

Table 3.7Calculated soil classifications by mass and percentage before and after harvesting for Harvesters A, B and C

Soil size and	Pre-harvest		Post-harvest	
harvester	soil mass (kg ha^{-1})	percentage	soil mass (kg ha^{-1})	percentage
p<1 mm				
A	71984	63.7	70495	65.5
B	76512	63.4	75162	64.9
C	74445	63.7	72952	65.4
p>1 mm				
A	20063	17.8	20014	18.6
B	22363	18.5	22352	19.3
C	22399	19.2	22356	20.0
p>2 mm				
A	10789	9.6	10253	9.5
B	10133	8.40	9682	8.4
C	7315	6.3	6965	6.2
p>4 mm				
A	6999	6.2	5467	5.1
B	8084	6.7	6660	5.8
C	9394	8.0	7748	6.9
p>8 mm				
A	3122	2.8	1429	1.3
B	3511	2.9	1932	1.7
C	3292	2.8	1572	1.4
total				
A	112955	100.0	107659	100.0
B	120602	100.0	115787	100.0
C	116844	100.0	111593	100.0

The composition by mass is: 10>p>8 mm (2.8%)g, 8>p>4 mm (7.0%)g, 4>p>2 mm (8.1%)g, 2>p>1 mm (18.5%)g, p<1 mm (63.6%)g. Following harvesting the figures are: 10>p>8 mm (1.4%)g, 8>p>4 mm (5.9%)g, 4>p>2 mm (8.0%)g, 2>p>1 mm (19.3%)g, p<1 mm (65.3%)g, indicating that particles >4 mm and >8 mm have suffered some size reduction, although the magnitude of the change is not particularly big. This size change is due to 'rolling' by the roller/s associated with the collection duct. Further reduction in size may well result from passage through the harvester, but there is no data on this aspect.

With reference to Table 3.8, it can be stated that of the total material entering the Harvesters, 26% to 32% are pods and the remainder soil. The size composition of the soil is not known.

Table 3.8 Performance of Harvesters A, B and C in terms of pod collection and soil displacement

	Harvesters		
Description	A	B	C
Collected pods, kg ha^{-1}	1392	1538	1526
Displaced soil, kg ha^{-1}	5296	4814	5251
Pods to soils	0.26	0.32	0.29

3.4 Effect of Varying Operating Parameters

Objectives: To measure the effect of suction head height and ground speed on pod collection efficiency and displacement of loose topsoil. In addition, the trial aimed to assess the possibility of increasing harvester field capacity by increasing ground speed.

3.4.1 Experimental Equipment

Harvesting machine

The harvesting unit in this series of experiments was another Horwood Bagshaw Vacuum Seed Harvester with a high capacity suction head and no pre-cleaner (Harvester D), the harvesters used in the earlier tests being no longer available. The suction head had an action width of 1.23 m. The power unit was a John Deere 4055 tractor of 94 kW (125 hp) power at the PTO.

In this trial 3 different suction head ground clearances (H_1, H_2 and H_3) were used, as well as 3 different ground speeds (S_1, S_2 and S_3), as given in Table 3.9. The clearance between the suction head and ground was adjusted using a gauge inserted between the roller and the head. Ground speed was determined by measuring the time required to travel a 20 m distance at uniform speed, using three replications.

Table 3.9 Ground speed, suction head height and calculated effective field capacity for Harvester D

Ground speed (km ha^{-1})		Eff field capacity (ha h^{-1})	Height of suction head (mm)	
Speed 1	3.5	0.34	Height 1	40
Speed 2	4.4	0.43	Height 2	55
Speed 3	5.75	0.56	Height 3	70

3.4.2 Crop and Location

This experimental trial was carried out in a field in which pre-harvest preparation had been carried out for harvesting *M. truncatula* cv. Caliph. The experiment was located at Kybunga, South Australia, and conducted in January 1995. An experimental site was selected near the middle of the field of clay loam soil where the surface was reasonably level, free of stone and with only minor undulations or irregularities. The site was divided into a total of 27 plots to accommodate three replications. The width of the plots was that of the harvester action width and the length, 20 metres.

3.4.3 Experimental Procedure

***Field sampling procedure*:** The procedure followed for taking field samples was as described in Section 3.3 but with a quadrat of 300 × 300 mm dimension.

Pod yield, pod losses and soil displacement were estimated in the same way as previously described in Section 3.3.

In addition, the seed output of the harvester was collected at the end of each plot for analysis. Seed collected from the harvester was separated from dust and fine soils using a sieve with a 1.4 mm opening. This was to determine how, if at all, the contamination of cleaned seed was affected by head clearance and speed.

Statistical design and analysis: Data of seeds, pods and soil were analysed by using a factorial randomised block design for three heights and three speeds with three block replicates. The least significant difference (LSD) multiple comparison method was used to compare each treatment mean to every other mean. Table 3.10 shows the degrees of freedom available for the statistical analysis of the data obtained.

Table 3.10 The ANOVA table for statistical analysis of Harvester D performance with varying height and speed

Source of variation	Degrees of freedom
Replicates	2
Speed	2
Height	2
Speed and height	4
Residual	16
Total	26

3.4.4 Results and Discussion

Pod collection: An average pod yield for the field was estimated at 3480 kg ha^{-1} from a total of 81 pre-harvest samples of pods with 27.7% seed to pod ratio.

The result of the analyses of variance of data related to collected pods revealed that there are highly significant differences ($P \leq 0.05$) in the mean of the speed and height effects on Harvester D. Table 3.11 presents the analysis of means of the collected pods by speed, by height, and then by combination of particular speed and height. Where the analysis of variance was significant, means followed by different letters indicate significant differences (LSD $P \leq 0.05$).

Table 3.11 Statistical analysis of effect of ground speed and suction head height on pod collection for Harvester D

Treatments	Mean † of collected pods kg ha^{-1}	Mean of pod losses kg ha^{-1}
S_1	2472 c	1008
S_2	2084 b	1396
S_3	1716 a	1764
LSD ($P \leq 0.05$)	**347.9**	
H_1	2860 c	620
H_2	2276 b	1204
H_3	1136 a	2344
LSD ($P \leq 0.05$)	**347.9**	
$S_1 H_1$	3152 bcdef	328
$S_1 H_2$	3013 bcdef	467
$S_1 H_3$	1251 a	2229
$S_2 H_1$	2861 bcdef	619
$S_2 H_2$	2228 bcde	1252
$S_2 H_3$	1163 a	2317
$S_3 H_1$	2562 bcde	915
$S_3 H_2$	1588 a	1892
$S_3 H_3$	995 a	2485
LSD ($P \leq 0.05$)	**602.7**	

† The means followed by unlike letters in a column show significant differences at ($P \leq 0.05$).

In addition, pod losses associated with each mean were calculated from an estimated pod yield for each treatment area.

Table 3.12 shows the mean pod collection efficiency and mean pod losses expressed as percentages.

The most marked effect was that of increasing head clearance. Low head clearance (H_1= 40 mm) resulted in a mean collection efficiency of 82.2 % (with corresponding pod losses of 17.8 %). This reduced significantly as clearance was increased to H_3= 70 mm (67.4 %). It can be presumed that increasing head height proportionally decreases air stream velocity and therefore the capacity to pull pods into the system.

Table 3.12 Mean pod collection efficiency and pod losses for different ground speeds and suction head heights for Harvester D

Speed	Collected pods (%)	Pod losses (%)	**Height**	Collected pods (%)	Pod losses (%)
S_1	71.0	29.0	H_1	82.2	17.8
S_2	59.9	40.1	H_2	65.4	34.6
S_3	49.3	50.7	H_3	32.6	67.4

Mean pod collection efficiency also reduced with increasing speed. An increase in speed of approximately 64% (3.5-5.75 km s^{-1}) reduced mean pod collection efficiency by approximately 30 % (71.0-49.3%). The cause here probably relates to an overloading of the suction system as the quantity of material entering the suction head is increased. Figure 3.7 (a) shows the relationship between collected pods and ground speed and (b) that between collected pods and suction head height. The graphs indicate clearly the effect of changing head height and operating speed on pod collection.

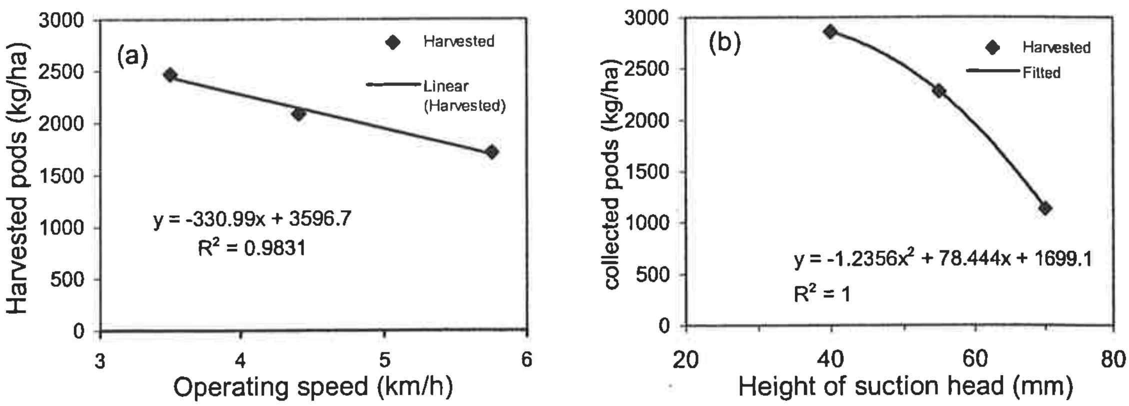


Figure 3.7 Fitted linear regression of ground speed (a) and second order polynomial regression of suction head height (b) on harvested pod yield

Seed harvesting: Table 3.13 shows analysis of the mass of seed and soil collected at the seed bin of the harvester in relation to varying speed and height of the suction head.

The graphs of the best fitted linear and polynomial regressions (Figure 3.8) show near identical relationships effected by operating parameters for seed collection as pod collection.

The amount of soil passing through the harvester into the seed bin is shown in Table 3.13. The soil in the seed bin was separated by passing through a 1.4 mm sieve. It is interesting to note that the quantity of soil in the seed bin reduces more rapidly than seed in relation to speed and head height.

Table 3.13 Statistical analysis of effect of speed and head height on Harvester D output (seed and soil) and percentage of collected seeds to soils.

Treatments	Collected seeds kg ha^{-1}	Collected soil kg ha^{-1}	seed /soil %
S_1	685 c	141.5 b	20.9
S_2	598 b	97.7 a	16.3
S_3	498 a	72.9 a	14.6
LSD ($P \leq 0.05$)	**84.58**	**26.96**	
H_1	799 c	213.2 c	26.7
H_2	642 b	89.3 b	13.9
H_3	341 a	9.6 a	2.8
LSD ($P \leq 0.05$)	**84.58**	**26.96**	
$S_1 H_1$	883 bcdefg	268.7 f	30.4
$S_1 H_2$	788 bcde	141.7 cd	18.0
$S_1 H_3$	385 a	14.1 a	3.7
$S_2 H_1$	826 bcdef	196.3 ec	23.8
$S_2 H_2$	612 bcd	86.6 b	14.2
$S_2 H_3$	355 a	10.3 a	2.9
$S_3 H_1$	686 bcde	174.6 c	25.5
$S_3 H_2$	526 bc	39.5 a	7.5
$S_3 H_3$	282 a	4.5 a	1.6
LSD ($P \leq 0.05$)	**146.49**	**46.72**	

The mean followed by unlike letters in a column show significant differences at ($P \leq 0.05$).

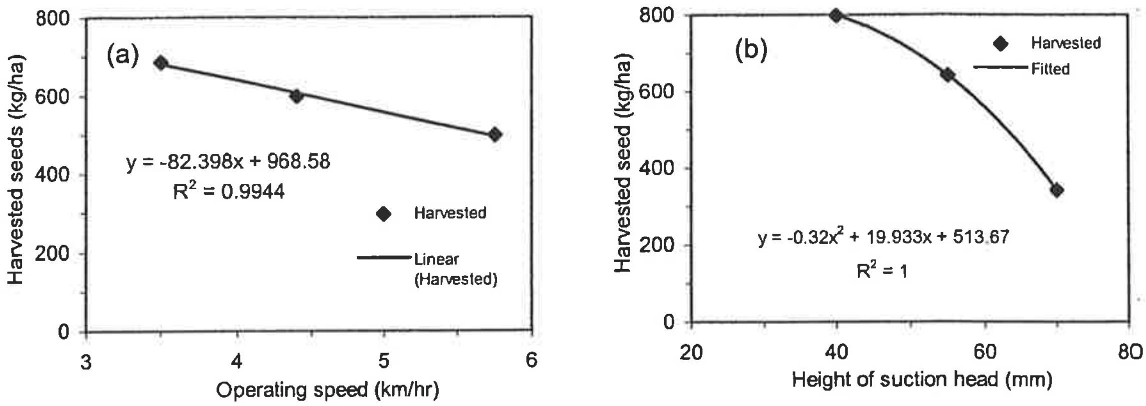


Figure 3.8 Fitted linear regression of operating speed (a) and second order polynomial regression of suction head height (b) on seeds harvested by Harvester D

Field capacity: The calculation of field capacity and material capacity for Harvester D at the three different ground speeds is summarised in Table 3.14. The time required to harvest one hectare of medic pods was calculated as 3.2, 2.6 and 1.5 hours for speeds 1, 2 and 3 respectively. Operating speed has a major influence in the effective field capacity and material capacity of the medic seed harvester. With increasing speed the effective field and material capacity increased, and consequently the harvesting time required for a unit area decreased.

Table 3.14 Field capacity and material capacity for Harvester D at three different ground speeds

	Field capacity ha h^{-1}		Harvesting time	Material capacity
Speed	Theoretical	effective*	hr ha^{-1} *	kg h^{-1} *
S_1	0.4	0.3	3.2	1079
S_2	0.5	0.4	2.6	1357
S_3	0.7	0.5	1.5	1775

* is based on the field efficiency measured in the previous experiment.

Displaced soil: An analysis was conducted on each fraction of the loose soil on the field before and after harvesting, so that the differences for each fraction resulting from altering speed and head height could be clearly seen (Table 3.15).

Analysing displaced soil revealed that there were significant differences ($P \leq 0.05$) due to high speed and greater height, specifically increasing speed reduces soil displacement and in similar ratio to the reduction in collected pods. Increasing head height reduces soil displacement but not as rapidly as occurs with pod collection (see Table 3.16).

Table 3.15 Measurement of total mass of soil before and after harvesting by Harvester D.

	Before harvest kg ha^{-1}	After harvest kg ha^{-1}	Differences kg ha^{-1}
S_1	106301	101578	4723
S_2	111044	106609	4435
S_3	105063	101521	3542
H_1	108203	103184	5019
H_2	103576	99196	4380
H_3	110628	107327	3301
$S_1 H_1$	108982	103992	4990
$S_1 H_2$	100957	95451	5506
$S_1 H_3$	108966	105291	3675
$S_2 H_1$	110694	106493	4201
$S_2 H_2$	105602	101164	4438
$S_2 H_3$	116835	112170	4665
$S_3 H_1$	104934	99066	5868
$S_3 H_2$	104170	100974	3196
$S_3 H_3$	106084	104522	1562

Table 3.17 presents the distribution of the particle sizes of loose soil on the field before and after harvesting performance. It is clear that the percentages of large fractions (10>p>8 and 8>p>4 mm) is reduced slightly and conversely that of particles less than 1 mm is increased.

In comparing the relative proportion of pods and soil entering the harvester in this series of tests with the previous series, it is obvious that the crop yield is much greater here, even though the quantity of soil entering the harvester is similar, consequently the ratio of pods to soil is higher (0.5 relative to 0.3). These figures indicate that the amount of soil material taken in harvester is 67% and 75% respectively of the total intake.

Disturbing soil structure and increasing the potential for soil erosion by wind is a significant problem with the current medic seed harvesting process. Unfortunately, climatic conditions after harvest, such as high temperature at the driest time of the season, and the

Table 3.16 Performance of Harvester D in terms of pod collection and soil displacement on different operating speeds and head height

	Ground speed			Head height		
Description	S_1	S_2	S_3	H_1	H_2	H_3
Col.pods, kg ha^{-1}	2472	2084	1716	2860	2276	1136
Dis. soil, kg ha^{-1}	4723	4435	3542	5019	4380	3301
pod/soil %	52	47	48	57	52	34

Table 3.17 Classification of soil particle size before and after medic seed harvesting performance

	Percentage of soil particle sizes									
Size	**10>p>8 mm**		**8>p>4 mm**		**4>p>2 m**		**2>p>1 mm**		**p<1 mm**	
Treat.	**Bef.**	**Aft.**	**Bef.**	**Aft.**	**Bef.**	**Aft.**	**Bef.**	**Aft.**	**Bef.**	**Aft.**
S_1	4.0	3.6	7.3	5.4	13.7	13.6	17.2	16.7	57.8	60.7
S_2	3.5	2.9	6.5	4.3	13.4	13.3	17.0	17.0	59.6	62.7
S_3	3.6	3.1	7.3	7.2	13.9	14.0	17.0	16.7	58.2	59.0
H_1	3.2	2.6	6.6	5.3	13.3	12.7	17.6	17.5	59.3	61.9
H_2	4.3	3.3	6.4	4.6	14.5	14.6	17.2	17.3	57.6	60.2
H_3	3.1	2.9	6.0	4.4	13.3	13.4	16.9	17.0	60.7	62.3
$S_1 H_1$	3.2	2.7	7.2	5.8	14.0	13.6	17.6	17.7	58.0	60.2
$S_1 H_2$	4.0	3.3	7.4	6.6	13.8	12.2	17.4	17.6	57.4	60.3
$S_1 H_3$	3.8	3.4	6.3	4.5	13.7	13.8	16.2	16.3	60.0	62.0
$S_2 H_1$	2.9	2.8	7.2	6.3	13.8	13.2	17.0	17.3	59.1	60.4
$S_2 H_2$	4.1	3.6	6.8	5.3	14.3	14.9	16.7	16.9	58.1	59.3
$S_2 H_3$	3.7	3.4	6.6	5.9	13.9	13.6	16.7	17.0	59.1	60.1
$S_3 H_1$	3.5	3.2	6.5	6.1	13.2	13.0	17.6	17.9	59.2	59.8
$S_3 H_2$	4.4	4.1	6.7	6.1	15.0	15.2	16.7	16.9	57.2	57.7
$S_3 H_3$	3.7	3.5	6.4	6.1	14.3	14.3	17.1	17.3	58.5	58.8

Total lack of protection from vegetation increase the likelihood of soil erosion by wind. The author had first hand experience of the potential for wind erosion during the conduct of the experiment. A wind of 8.5 m s^{-1} (measured at 0.3 m above the soil surface) developed towards the end of the experiment and soil on the recently harvested area began to move freely. At times the whole surface was moving with the wind. Serious erosion usually starts with wind speeds of about 8.0 m s^{-1} and erosion force increases with the cubic of the wind speed (Hunt and Gilkes 1992). This problem is well recognised by medic seed growers but management expenditure to reduce the risk is still needed.

The current procedure to protect against this problem is to plough the field immediately following medic seed harvesting. Seed growers recognise the need to plough the harvested field, but since the harvesting job itself is slow and ploughing requires additional time, and the total harvesting time available is very restricted, this important step in protection against soil erosion is often not performed. Ploughing on some alternative passes perpendicular to the dominant wind direction is helpful to decrease the effect of wind erosion and overcome the time shortages. This is done by some growers and Figure 3.9 illustrates this protection work on a Paraggio medic field after harvesting seeds by H.B. Harvester at Balaklava.

Figure 3.9 Furrowing on some alternative passes perpendicular to dominant wind to protect against wind erosion after harvesting Paraggio medic seeds at Balaklava

3.5 Conclusions

A summary of the performance of three medic seed harvesters (Table 3.18) reveals the following.

Table 3.18 Summary of results of medic seed harvester performance

Description	H.B. Harvester A	H.B. Harvester B	Dutchke's Harvester C
width of action , m	1.23	1.23	1.86
operating speed, km h^{-1}	3.16	2.80	4.3
collection efficiency, %	75.4	81.5	80.6
field efficiency, %	80	82	56
effect.field capa., ha h^{-1}	0.3	0.27	0.43
harvesting time, h ha^{-1}	3.3	3.7	2.3
material capacity, kg h^{-1}	550	510	810
soil displacement, %	4.7	4.0	4.5

a) Harvesters B and C may have slightly higher pod collection efficiency (in the range of 75- 81%).

b) Harvester C is markedly superior to the other two machines in effective field capacity and material capacity, i.e. it is about 30% faster than the H.B. Harvesters.

c) Harvester B creates less soil damage than the other two machines. It is presumed that the inclusion a pre-cleaner reduces the velocity at the head opening.

d) Overall, Harvester C has the best combination of features. This machine in particular could be further developed by the addition of a seed thresher to improve field efficiency. However, it is noted that this machine incorporates blowing as well as suction.

e) The performance of H.B. Harvesters is greatly influenced by adjustment of the pickup head clearance and the operating speed.

It was found that increasing speed resulted in a reduction in pod collection efficiency. The effect of increasing speed may be more economical, provided that a reduced income from loss of crop does not exceed savings. Increasing speed by 64% resulted in an increase in pod losses of 74.8%. The conclusion is that increasing speed will lead to a reduction in profitability.

The purpose of increasing the height of the suction head is to reduce the collection of the surface soil. Increasing the head height from 40 mm to 70 mm certainly reduced the amount of soil collected to a very low level, but it also increased pod losses by a factor of 4. Obviously, velocities at the head were too low to be effective.

The net conclusion of these tests is that harvesters are probably being operated at near optimum levels and that improvements will be possible only if the basic technique is changed.

It can be expected that, under normal operating conditions 5% of the loose surface soil will be ingested into the machine and moved from one location to another, exposing it to a greater erosion potential. Analysis of the size distribution of this ingested soil indicates that approximately 65% is less than 1 mm diameter, with a further 15-20% within the range 1 mm to 2 mm diameter.

Chapter 4

PHYSICAL PROPERTIES OF MEDIC PODS

4.1 Introduction

Aerodynamic properties are important design criteria for pneumatic harvesting of products from the ground surface (Hawk *et al.* 1966). This is particularly the case in medic seed harvesting because pods have to be lifted from the field surface by an air stream. Techniques for determining physical properties of other crops have been studied, for example Mohsenin 1986 (various), Makanjuola 1972 (melon seed), Shepherd and Bhardwaj 1986 (pigeon seed), Dutta *et al.* 1988 (oil bean seed), Oje and Ubbor 1991 (oil bean seed) and Deshpande *et al.* 1993 (soybean).

The methods of measurements of physical properties were selected for simplicity, accuracy of results and wide acceptability. Tests have been carried out on medic pods at harvesting moisture content and include shape, size, volume, density and terminal velocity. In addition, some properties of the soil associated with the harvesting of medic pods were also examined.

4.2 Materials and Methods

Mature *M. truncatula* cv. Paraggio pods were used for all measurements in this study. The crop was grown in the 1993-94 season in the Balaklava region of South Australia by a specialist seed producer. For the tests, 50 kg of pods were obtained and cleaned in an air screen to remove all foreign matter such as stones, soil, dust, organic matter and light or spoiled pods without seeds.

In addition, about 100 kg of loose top soil (0 - 10 mm) was collected from the same field for soil tests.

4.2.1 Determination of Pod and Soil Moisture Content

Although medic seed harvesting is done during warm days and pods are mature and sun dried, the moisture content of pods was determined because of its importance in determining physical properties. Moisture content was determined using a standard method developed by the ASAE Physical Properties of Agricultural Products Committee (1994). Three randomly selected 15 gram samples of pods were placed in a Memmert air forced oven set at 130 °C for two and half hours after weighing. The samples were then cooled in a desiccator, weighed and the moisture content for pods calculated. The three moisture content measurements were then averaged. The same procedure was applied to determine the moisture content of the loose soil collected from medic field surface. The moisture content of pods and soils was maintained by keeping the samples in sealed plastic bags for physical property determinations.

4.2.2 Determination of Pod Shape

Pod shape is potentially important in the movement of the pod in an air stream. One hundred pods, randomly selected, were visually assessed to determine the closest geometric shape.

4.2.3 Determination of Pod and Soil Particle Size

Assessment of medic pod size was conducted in two ways. In the first method, the whole

50 kg of pods was divided several times until six samples each containing 500 g were obtained. Then the pod size distribution was assessed using commercially available round hole screens on a shaking mechanism. The screens used were 9.53, 7.94, 6.25, 4.75 and 3.97 mm and the Endicott test sieve shaker was run for approximately five minutes per sample. Samples were weighed using a Precisa electronic balance with 0.001 g accuracy.

The second method offers greater accuracy. A sample of 100 pods was randomly picked from multiple sub-samples of half kg mass. This was achieved by counting any 9 pods and selecting each 10th pod, until finally 100 pods were randomly selected. For each of the 100 pods, length (major axis) and thickness or diameter (minor axis) were measured with a micrometer to an accuracy of 0.01 mm. Micrometer measurements were not affected by the presence of spines. Spines may be up to 3 mm in length relative to a barrel diameter of 6 mm.

Soil particles were sieved into five groups: 5.5>p>4.75, 4.75>p>3.97, 3.97>p>2.00 2.00>p>1.40 and p<1.4 mm. The same type of sieves were used as described for pods, but with only one minute of shaking to prevent reduction to smaller sizes. The percentage of each group relative to total material was determined to be approximately, 3, 7, 8, 19 and 63% respectively.

4.2.4 Determination of Projected Area of Pods

The projected area or frontal area of pods is potentially important in determining drag force and ultimately the movement of pods in an air stream. In order to find this information, ten randomly selected pods from each size range were assessed. The applied technique is based on measurement of the area recorded by a video camera, with the image transferred to a PC screen for analysis using a Vision Analysis software.

4.2.5 Determination of Volume, Mass and Density of Pods

The mass of one thousand pods was determined by weighing 10 samples, each containing 100 pods, converting to a mass for 1000 pods and averaging the 10 weighings. For detailed analysis of the frequency distribution off mean three samples each contains 100 pods were weighed in 0.01 g. accuracy , and classified in seven groups, in range of (0.03-0.04), (0.05-0.06), (0.07-0.08), (0.09-0.10), (0.11-0.12), (0.13-0.14), (0.15-0.16) grams. Then by statistical method the average frequency for each group was determined.

Bulk density is defined as the ratio of the mass of a sample of substance to its total volume. It was determined by the method followed by Dutta *et al.*(1988) to determine the physical properties of a protein grain known as gram (*Cicer arietinum* L.). This involved filling a 500 ml container with pods from a certain height (15 cm), striking off the top level and then weighing the contents. This measurement was done with six replications using pods at the maintained moisture content.

The true density of pods is defined as the ratio of the mass of a sample of pods to the solid volume occupied by the sample. The volume was determined by liquid displacement as described by Mohsenin (1980) for seeds and grains with irregular shape. In order to overcome the problem of water permeability of pods, acetone, $(CH_3)_2CO$, 0.7857 g ml^{-1} density at 25 $^{\circ}$C, was used in this experiment. Care was taken to minimise the time period in acetone to reduce uptake by the pods and a consequent change in volume. Ten sub-samples of 20 g mass were randomly selected from the 50 kg mass of pods. Samples were weighed to 0.001 g accuracy and placed into a measuring cylinder which contained a known volume and weight of acetone. The change in weight of the cylinder was measured and the new volume recorded.

4.2.6 Determination of Pod and Soil Terminal Velocity

The blower type apparatus shown in Figure 4.1 was employed to obtain terminal velocity information for the pods and soils using the procedure that Hawk *et al.* (1966) and Muller *et al.* (1967) established for grains.

The apparatus consists of a fan, an electronic speed-controlled motor (Australian Electrical Industrial, 15 hp, 2915 RPM) and an air flow tube. This tube comprised two sections, the first of 600 mm length to smooth the air flow, then a 400 mm length test section of approximately 200 mm inside diameter. The first section is made up from pressure rated plastic pipe and the testing section from a clear acrylic to allow viewing of the relative movement of particles in the air stream.

In order to determine accurately the balancing velocity, it is necessary to maintain an air velocity that is essentially uniform over the entire cross section of the tube. This was accomplished by installing some fine screens between the two sections. A model VelociCalc 8355 portable air velocity meter reading to 0.001 m s^{-1} and a 15 second time constant was used to measure the air velocity in the testing section. A description of the air velocity meter can be found in Chapter 5.

Figure 4.1 Equipment used to generate terminal velocity information for medic pods and associated soils in an air stream

Measurement of the terminal velocity of pods was conducted in two ways; the first of these was to place a sample of 50 g of pods obtained by sieving on the screen. This work was carried out for four size groups. In the second method, terminal velocity was determined for individual pods taken from different size categories. Ten pods of each size were selected randomly and then placed on the screen between the two sections of the vertical airflow, the velocity was determined separately for each pod. Fan speed was increased until the velocity caused the pod to be suspended with little or no vertical movement. The velocity that maintained the pod in this position was the terminal velocity (sometimes referred to as balancing velocity). An average of six readings of air velocity taken at points across the air flow tube was used to determine the magnitude of the terminal velocity.

To generate terminal velocity data for soils, it was necessary only to use the four size categories ($5.65>p>4.75$, $4.75>p>3.97$, $3.97>p>2$, $2>p>1.4$ mm) whose terminal velocities were close to pod terminal velocity. Measuring terminal velocity for soil particles smaller than 1.4 mm was ignored, since openings of screen, which used in terminal velocity equipment were larger than soil particles. The procedure was the same as that used with pods.

4.3 Results and Discussion

Results of the various experiments conducted to determine the various physical properties and aerodynamic characteristics of Paraggio pods and associated soils are presented below.

4.3.1 Moisture Content of Pods and Soils

The average value of moisture content measured on a wet basis for the pods was found to be 9.8% and for loose soils, 2.1 %.

4.3.2 Shape of Pods

Measurements of pod dimensions clearly indicate that a cylindrical or barrel shape is the most common, and the ratio of long axis to diameter was 1.17, although the cross-sectional area at one end of the cylinder is smaller than other end. The barrels feature mainly 4 - 6 clockwise spirals of spines; with this variety the spines are almost straight and unhooked.

4.3.3 Size of Pods

Figure 4.2 shows the distribution by sieve fraction size. It is clear that more than 68 % of pods are in the range of 6.25 - 7.93 mm hole diameter.

Figure 4.3 gives the pod size distribution by measurement of dimensions. Measurements indicate that 58 % of pods are in the range of 6.30-7.29 mm in length. A further 10% lie with the range of 7.3-8.29 mm.

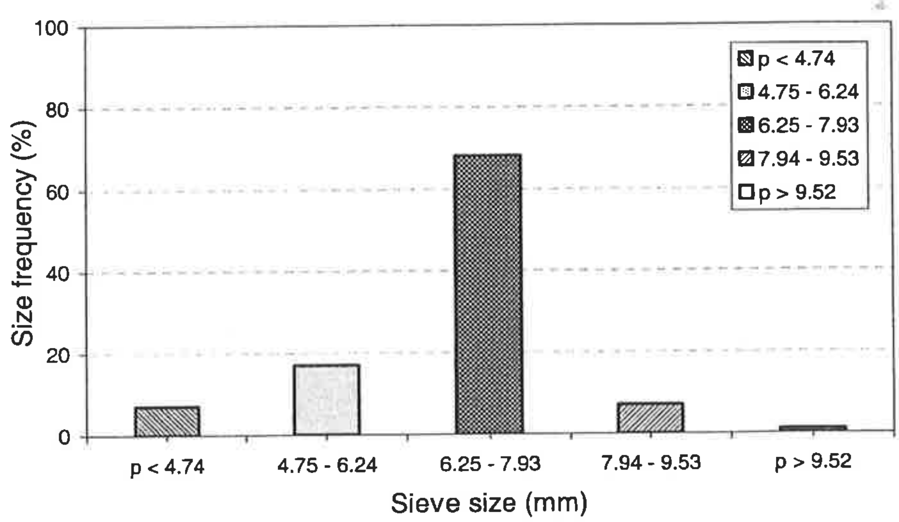


Figure 4.2 Size frequency distribution of Paraggio medic pods based on sieve analysis

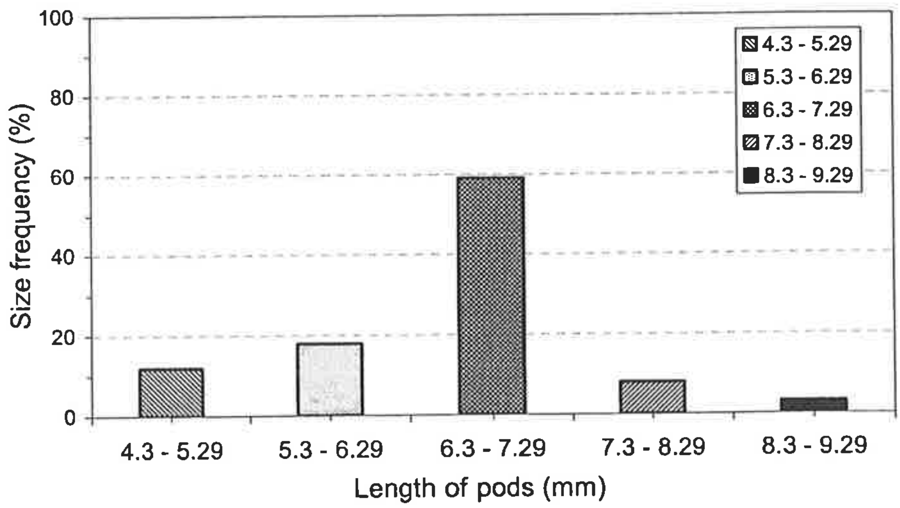


Figure 4.3 Size frequency distribution of Paraggio medic pods based on micrometer measurement of largest dimension

Although the size ranges for the two sets of measurements do not exactly correspond, both results indicate that approximately 70 % of pods lie in the size range 6.00 to 8.00 mm.

The average sizes of the two measured dimensions of the pods were found to be:

major axis or length: 6.95 mm; standard deviation 3.75 mm;

minor axis or diameter: 5.95 mm; standard deviation 2.05 mm.

4.3.4 Projected Area of Pods

The average projected area of medic pods and the ratio of pod mass, to projected area relative to size range are presented in Table 4.1. Figure 4.5 shows the relationships between size range and average mass, average projected area, and the ratio of mass to projected area.

Table 4.1 A summary of size range, average mass, average projected area and ratio of mass to projected area of Paraggio pods

Size range (mm)	Ave. projected area (mm^2)	Average mass (g)	Mass/projected area ($g\ mm^{-2}$)
9.29-7.94	52.85	0.14	0.00267
7.94-6.25	46.38	0.11	0.00245
6.25-4.75	41.29	0.08	0.00190
4.75-4.00	28.92	0.05	0.00169

4.3.5 Mass and Density of Pods and Soils

The average mass of the ten measurements was determined to be 78.8 g per 1000 pods. The distribution of mass for individual pods was determined as shown in Figure 4.4. It is clear that about 70% of Paraggio pods have individual masses in the range of 0.05-0.1 g and about 22% greater than 0.1 g.

The average values of bulk density obtained for pods and different soil particle sizes are presented in Table 4.2. It is clear that there is a significant difference between the bulk densities of pods (338 $kg\ m^{-3}$) and soil particles (820 to 1212 $kg\ m^{-3}$), with pods having a bulk density of less than 40 % that of the soil. This bulk density is also less than that of some grains such as wheat (770 $kg\ m^{-3}$) or barley (618 $kg\ m^{-3}$) (Mohsenin 1980; ASAE Standard 1994).

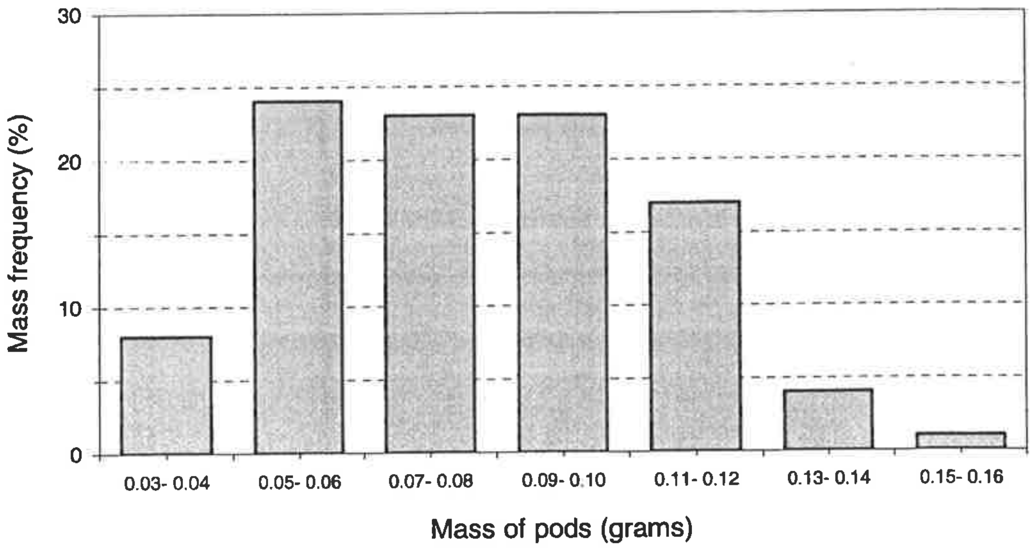


Figure 4.4 Frequency distribution of mass of Paraggio medic pods calculated by individual weighing

Table 4.2 Average bulk density for pods and different sizes of the soil

Item and size range (mm)	Average bulk density kg m^{-3}	Standard deviation
Pods	338	2.09
5.5> soil particle>4.75	820	9.65
4.75>soil particle>3.97	827	22.5
3.97>soil particle>2.00	851	14.6
2.00>soil particle>1.40	868	22.4
1.40>soil particle<1.00	1212	4.4

The average value of true density was found to be 781 kg m^{-3} for pods, with a standard deviation of 12.9 kg m^{-3}. This contrasts with the figures for some grains such as wheat, determined to be 1409.6 kg m^{-3}.

Specific gravity is by definition the ratio of the mass of any volume of pods to the mass of the same volume of water. This was calculated to be 0.78 for medic pods.

4.3.6 Terminal Velocity of Pods and Soils

The mean and standard deviation of the terminal velocity for each size range of pods and soil particles are presented in Table 4.3. Terminal velocity measurements revealed that the air velocity necessary to suspend pods is in the range of 5.1 - 6.5 m s^{-1} and for soil velocities up to 9 m s^{-1}. In both cases, terminal velocity increases with size. For soil particles equal in diameter to pods in the range 6.24>p>4.75mm, the velocity is 8.44 m s^{-1}

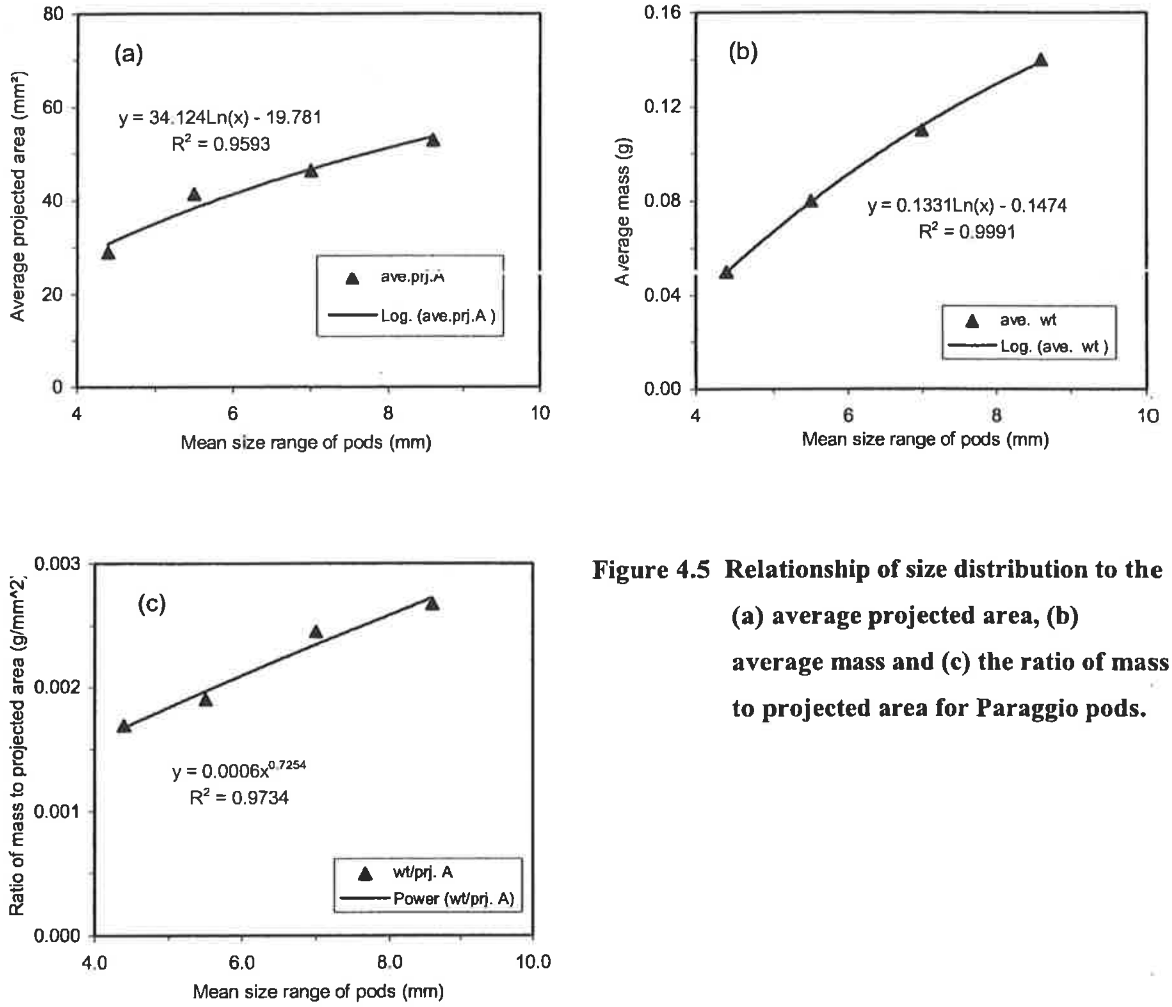


Figure 4.5 Relationship of size distribution to the (a) average projected area, (b) average mass and (c) the ratio of mass to projected area for Paraggio pods.

compared to 5.57 m s^{-1} for the average particle size of 5.5 mm, and it is expected that the difference increases proportionally with increasing size (see Figure 4.6). Of particular note, however, is the observation that particles of soil with sizes of less than 3 mm have terminal velocities which are the same as pod velocities. Thus it can be predicted that collection of pods will be complicated by the presence of soil with particle sizes of 3.0 mm or smaller.

Figure 4.6 presents the relation between the average terminal velocities of different size of pods and soil particles. Several regression models were fitted between the dependent variable (air velocity in m s^{-1}) and independent variable (size) of pods or soil particles (in mm). A logarithmic regression model provided the best fit for expression of relationships between pods and soils with terminal velocity separately.

Table 4.3 Means and standard deviations of terminal velocities of Paraggio pods and loose soil particles based on particle size

Particle size (mm)	Paraggio pods		Soil particles	
Mean of range	Terminal velocity (m s^{-1})	Stand. deviation (m s^{-1})	Terminal velocity (m s^{-1})	Stand. deviation (m s^{-1})
p> 9.29	6.43	0.2	-	-
8.6	6.25	0.15	-	-
7.1	6.0	0.15	-	-
5.5	5.57	0.3	8.90	0.08
4.37	5.16	0.16	8.16	0.07
3.0	-	-	6.57	0.09
1.7	-	-	4.06	0.07

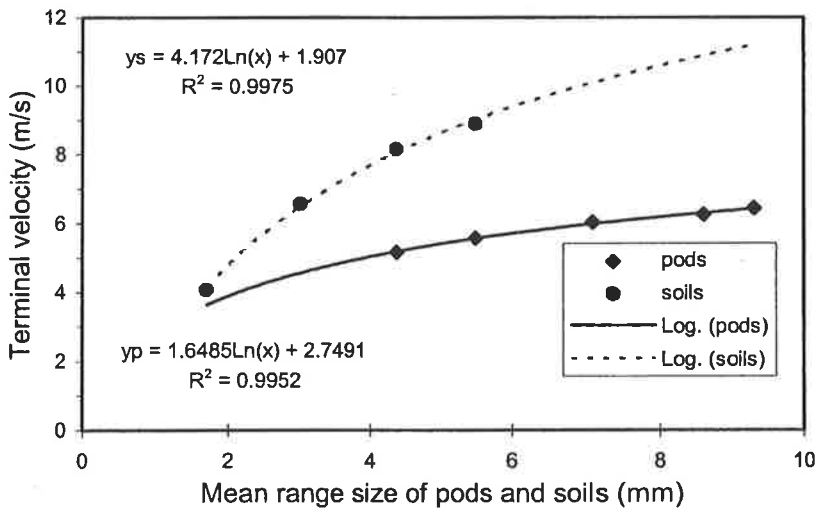


Figure 4.6 Terminal velocities for size ranges of Paraggio pods and soil particles

4.3.7 Drag Coefficient of Pods

An airstream at pod terminal velocity is needed to keep the pod suspended at a given point. In order to initiate motion of the pod on the field surface in the direction of the air velocity, it is expected that the velocity must be greater than the experimental value to compensate for unsymmetrical drag and frictional contact forces.

The drag force F_d at the terminal velocity v_t is numerically equal to the weight of the pod W and it is calculated by Equation [4.1].

$$c = \frac{2mg}{A_p \rho v_t^2} \qquad [4.1]$$

where: c = drag coefficient, dimensionless

v_t = terminal velocity, m s^{-1}

m = mass of the pod, kg

g = acceleration due to gravity, m s^{-2}

A_p = projected area of the pod on a perpendicular to airstream, m^2

ρ = density of air, 1.18 kg per m^{-3} at 20°C

v_t = terminal velocity, m s^{-1}

By substituting the physical properties determined for Paraggio pods in Equation [4.1] the drag coefficient was calculated to be 0.56 for large and 0.52 for small sizes of pods. These figures are in the range of the published values for several agricultural products given in Table 2.7.

4.4 Conclusions

Effective harvesting requires the capacity to move pods and possibly soils and the ability to discriminate between pods and soil particles. The extent to which this is possible depends on the aerodynamic characteristics of pods and soils. The properties of the pod mass will vary with size and density in a particular growing season. The properties of the soil mass and particle size will depend on harvesting preparation. Both will be affected by moisture at the time of harvesting (the reason for requiring very warm and dry days are used to harvest medic seeds). For the pod and soil sample collected, the moisture contents were approximately 10% and 2% respectively.

Both pods and soils exist in a range of sizes. Pods which are close to a spherical shape exist mainly within the range of 4.0 to 9.0 mm diameter (large dimension) with approximately 70% being in the 6.25-7.93 mm size range. Analysis of soil sizes obtained during harvest tests indicates a range of less than 1 mm up to greater than 8 mm but with 80% in the range up to 2 mm diameter. Soil particles can be approximated to spherical shapes. It is noted that on the basic of size alone most pods can be separated from the top loose soils.

A comparison of the size frequency distribution of pods to the mass of individual pods gives an indication that the mass of smaller pods is relatively greater would be expected from size; consequently a range of terminal velocities can be expected.

In addition, the investigation of various physical properties of Paraggio medic pods revealed the following.

a) Visual assessment indicated that cylindrical or barrel shape is the common shape for Paraggio medic pods. The barrel feature consists of 4-6 clockwise spirals with some straight and unhooked spines.

b) The projected area of most pods is in the range of 28.9-53 mm^2. An estimated projected area of a 2 mm diameter soil particle is approximately 3 mm^2.

c) The mass of 1000 pods was 78.8 g. The bulk and true (kernel) densities were determined as 338 and 781 kg m^{-3} respectively. In comparison with most agricultural products, medic pods are lighter than most other grains and are also much lighter than similar sized soils.

d) The terminal velocity for medic pods was determined to be in the range of 5.5-6.5 m s^{-1}. The relationship between terminal velocity and size is different for pods and soil particles. The terminal velocities of soil particles are greater, almost double that of the same size pods. However, soil particles in the 2 -3 mm size range have terminal velocities which correspond to those of the full range of pod sizes and this must be an important consideration in efforts to separate soil from pods prior to entry to a harvester. There is also an important implication for pre harvesting field preparation, namely that any process which causes reduction of soil size should be avoided.

Chapter 5

EXPERIMENTAL STUDIES OF AIRFLOW TECHNIQUES FOR MEDIC POD HARVESTING

5.1 Introduction

The field investigation of harvesters (Chapter 3) and measurement of pod and soil physical properties (Chapter 4) have indicated that there is potential for improvement of technique provided that airstream velocities can be closely controlled. It is also apparent that suction heads give rise to very rapid velocity gradients and that control of velocity in the practical situation is very dependent on field topography.

A great deal of research has been done on air flows involving jets in agricultural and nonagricultural systems (Liu *et al.* 1996), but much of the information relates to ventilating systems. The research undertaken should ideally provide data on which a new design could be proposed.

The general purpose of this work was to characterise airflow, especially in terms of control of velocity, both blowing and suction, to increase collection efficiency and reduce soil displacement. The specific objectives of this research were to determine:

- The effect of head shape on airflow pattern for free blowing and suction flow.
- The effect of face velocity, head height and head angle on axial velocity for blowing and suction taking into account the effect of surface impact.

5.2 General Objectives, Equipment and Procedures

5.2.1 General Objectives

In investigating the application of pneumatic techniques to harvesting of medic seeds, the characteristics of airflows both in blowing and suction, in free flow and when restricted by a solid body (such as a surface), needed to be clarified. The study should focus on practical parameters of head size and shape, location and inclination likely to be used in a medic harvester. Investigation of the potential for combining blowing and suction flow into a single airstream needed to be examined.

5.2.2 Equipment and Procedures

Air velocities were measured using either a pitot-static tube connected to an inclined manometer or an air velocity meter, VelociCalc model 8355 (see Figure 5.1 a), manufactured by Thermal Systems, Inc. (TSI). This instrument was recalibrated as recommended in the operation and service manual. Velocity measurements were obtained using a 20 second time constant. In this mode an average reading for 20 measurements at one second intervals was obtained to help reduce the problem of fluctuating readings which occurred due to turbulence and other factors.

The velocity meter is a constant temperature anemometer (TSI Incorporated 1992). The probe contains two sensors, an air velocity sensor and a temperature compensation sensor. The temperature compensation sensor causes the velocity sensor to maintain a temperature slightly higher than the ambient level. As air flows past the velocity sensor it is cooled and its resistance is reduced. The power then required to return the velocity sensor to its correct temperature is recorded as an airstream velocity. The velocity sensor is small and delicate, and consequently requires protection, ie. a housing through which the airstream passes.

The probe can have its own special characteristics which compound measurement errors in what may already be a difficult airstream measuring situation because of the presence of turbulence, solid materials, etc.

Although it was hoped that the probe would have the ability to define airstream direction as well as velocity, this proved not to be the case. To be effective in defining direction the probe would record a maximum velocity when pointing directly at the airstream direction as stated in the operation and service manual (see Figure 5.1b for probe orientations). The actual results obtained in a uniform airstream free of complications are presented in Tables 5.1 and 5.2.

(a)

(b)

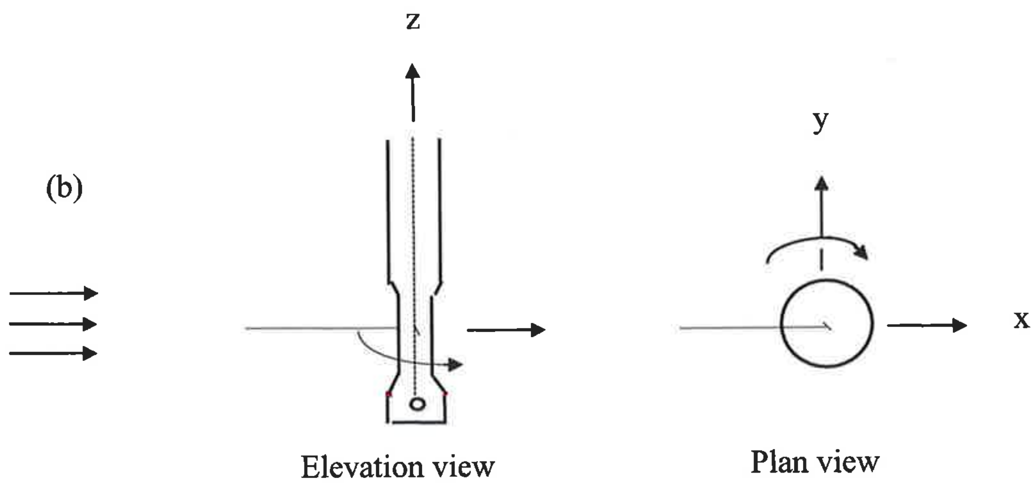


Figure 5.1 Air velocity meter (VelociCalc) and its probe used for air velocity measurements

Table 5.1 Air velocity measurements obtained by rotating probe about 'z' axis

Orientation	0	30	60	90	120	150	180
Air vel. m s^{-1}	31.30	33.30	10.90	7.95	7.55	34.20	31.20

Table 5.2 Air velocity measurements obtained by rotating probe about 'y' axis

Orientation	0	30	60	90	120	150	180
Air vel. m s^{-1}	31.30	35.40	6.30	7.30	14.20	33.20	31.40

The principal advantage of the VelociCalc meter, together with its processing unit, is its capacity to collect a large amount of data rapidly.

Pitot-static tubes have long been used to measure fluid velocities and determine stream direction. The tube has a double cylinder construction (see Figure 5.2) which allows a measurement of the stream total pressure through a hole aligned with the airstream direction directly into the inner tube, and of static pressure through a hole or holes into the outer tube. The location of these lattice holes means the pressure is recorded in a direction which is perpendicular to the flow direction. The difference between the two pressures is the velocity (or dynamic) pressure, and by using a water filled manometer, the velocity of the airstream is determined from the equation below:

$$v = \sqrt{2gh\rho_w / \rho_a} \qquad [5.1]$$

where: v = air velocity, m s^{-1}

g = acceleration due to gravity, 9.81 m s^{-2}

h = vertical height of water column, m.

ρ_a = air density, kg m^{-3}

ρ_w = water density, kg m^{-3}

The reading of a pitot-static tube is sensitive to yaw angle, this angle being the inclination of the airflow to the tube axis. In particular it can be seen that the maximum dynamic head is obtained at 0° yaw angle; at about 10° the output recorded is approximately 2% down, then reducing rapidly. A 2% difference is easily observed on an inclined manometer.

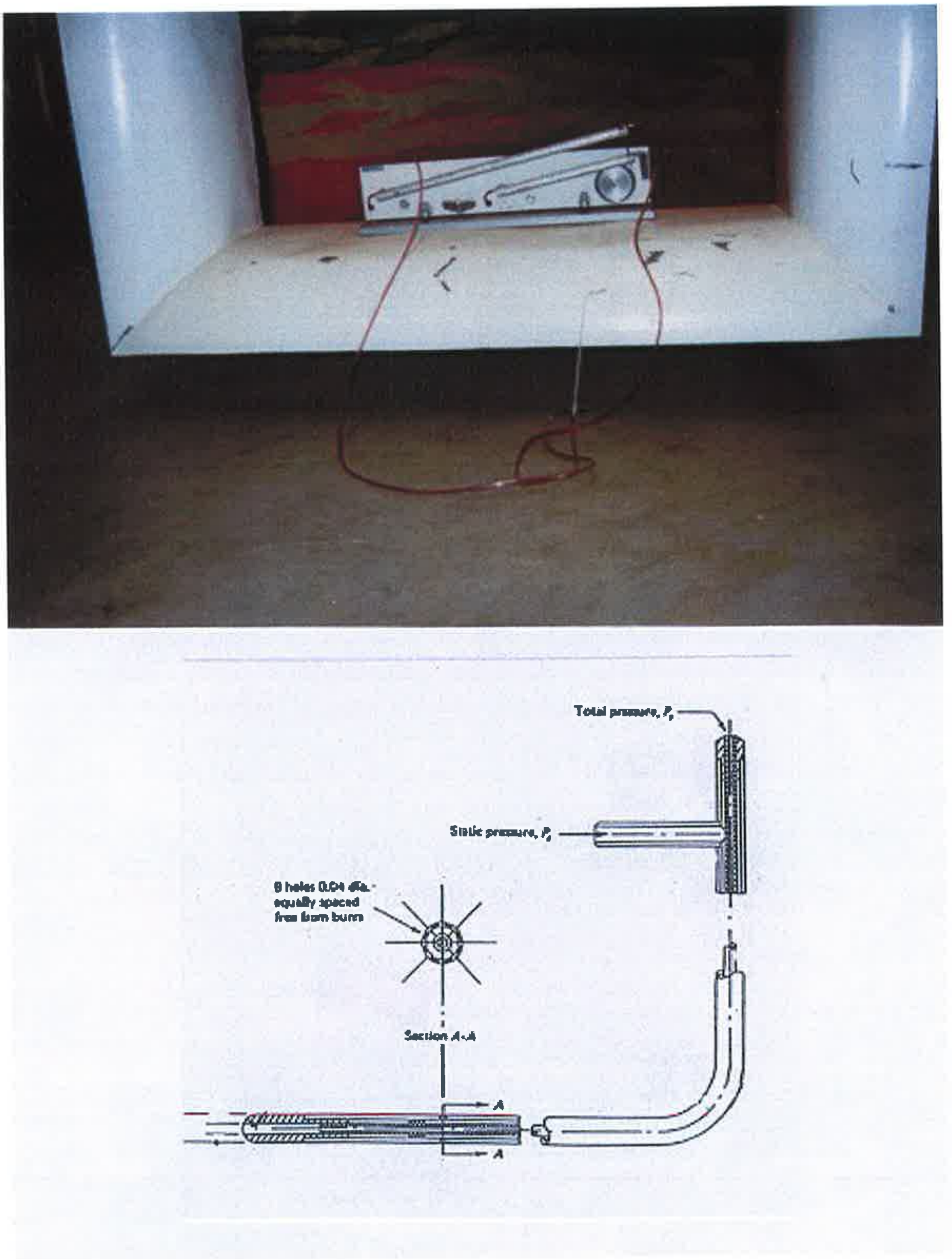


Figure 5.2 Typical manometer and pitot-static tube used for velocity measurements

The major disadvantage of the pitot-static tube lay in the difficulty resulting from its shape, especially given the emphasis on measurements at or near a surface and in the case of suction airflow, close to the head.

The conclusion of the investigation of velocity measurement techniques carried out during measurement of the effect of head shape on a free jet was that the VelociCalc probe was best suited to the measurement of velocity given the fluctuations taking place and that airstream direction was reasonably axial. However, where airstream direction needed to be determined, the pitot-static tube should be used.

It was decided that all measurements with the VelociCalc probe would be taken with the probe in fixed orientation, so that subsequent corrections for orientation could be applied if necessary. Invariably this meant an orientation such that measurements were in a direction parallel to the axis of the airstream.

Experimental work was carried out using the equipment described in Table 5.3.

5.3 The Effect of Head Shape on a Free Jet

This effect was investigated in both blowing and suction flow separately. The most common shapes of heads, circular and rectangular, were investigated.

5.3.1 Blowing Flow

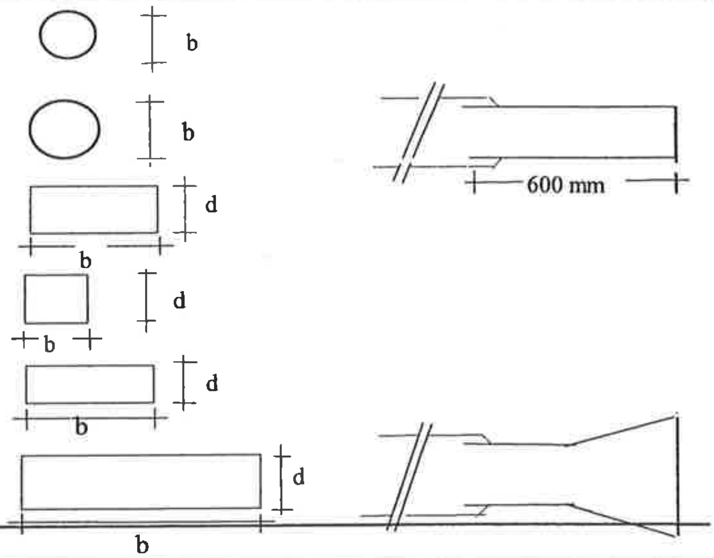
Objectives: The object of this test was to investigate the effect of head shape on the structure of a blown air jet.

Experimental equipment: Initial tests were conducted to investigate the free jet structure produced by circular and rectangular shape heads. This test was performed with fan (A), circular head (A) and rectangular head (D) (see Table 5.3 for dimensions). The two heads have approximately equal area.

Table 5.3 Description of fans, heads and ducts used for airflow experimental works

Fans	Type of fan	Blade dimension (mm) Dia.	Width	Airflow $m^3 s^{-1}$	Electrical power supplied
Fan (A)	paddle	270	70	0.4	single phase
Fan (B)	paddle	270	140	0.52	three phase

Heads†	Material	Face view	Top view
Circular (A)	P.V.C.		
Circular (B)	P.V.C.		
Rectangle (C)	Metal sht.		
Square (F)	Metal sht.		
Rectangle (D)	Metal sht.		
Rectangle (E) ‡	Metal sht.		



Head	(A)	(B)	(C)	(D)	(E)	(F)
Face diam. mm	80 (dia.)	93 (dia.)	43 × 154	50 × 100	84 × 420	82 × 82
Face area mm'	5026	6793	6622	5000	35280	6724

Connecting ducts	Specifications
Duct (A)	Length of flexible plastic pipe of 100 mm diameter and P.V.C. storm water pipe of the same diameter used for heads (A), (B), (C), (D) and (F).
Duct (B)	Length of flexible plastic pipe of 200 mm diameter and P.V.C. storm water pipe of the same diameter used for head (E).

† The head for each experiment was mounted on the experimental unit so that its height and angle could be varied independently.

‡ This head was constructed in dimensions preferred by SMACNA (1976) to minimise entry losses.

Experimental procedure: Heads were connected to the fan with a horizontal orientation so that a free jet was generated. The velocity decay and velocity profile were determined using the pitot-static tube at the head face and at the seven different cross sections with distances of 100, 200, 300, 400, 600, 800 and 1000 mm from the face. The horizontal velocities in the lateral plane were measured at intervals of 10 mm relative to the axis. Air velocity measurements were obtained with face velocity 40 m s^{-1}.

Experimental results and discussion: Figures 5.3 and 5.4 show the results of measurements of velocities produced by circular head (A) and rectangular head (D) respectively at different cross sections.

Figures B.1 and B.2 in Appendix B are dimensionless velocity distributions of jets delivered from circular and rectangular blowing heads. The dimensionless velocity distribution is established by expressing the ratio of the local velocity, v to the velocity at the head exit, v_0, that is $\frac{v}{v_0}$, and the ratio of the local distance from jet axis, y to the head diameter, b, that is $\frac{y}{b}$.

Figures 5.3 and 5.4 show the similarity of the velocity profiles in all sections of an air jet both for circular and rectangular heads in that free jet spreads with distance from the head with the maximum velocity at the centreline decreasing ie the velocity profile flatten. This result is in agreement with previous investigations (Abramovch 1963; Randall 1971; Tanaka and Tanaka 1976). In each case a jet defined by the region for which velocity is not less than half the face velocity and having a width approximately the same as the head dimension extends to a distance of 800 mm for the two smaller head dimensions and 600 mm in the case of the 100 mm head dimension.

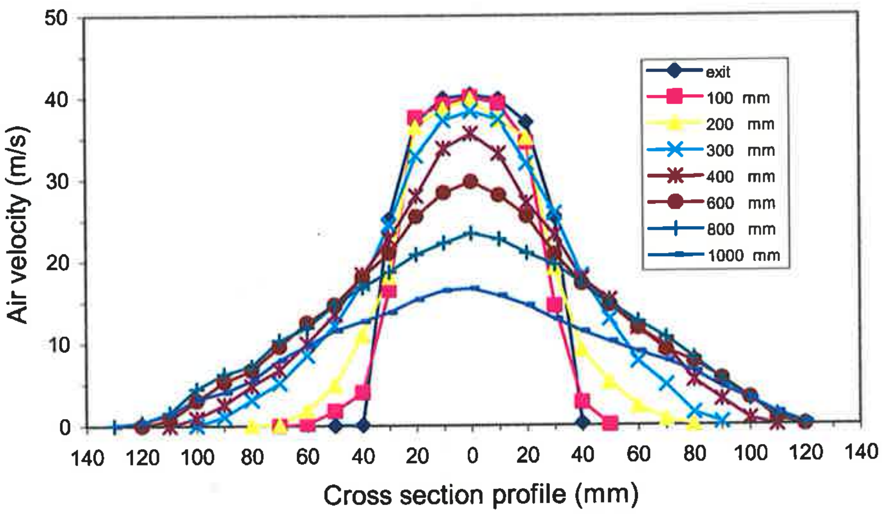
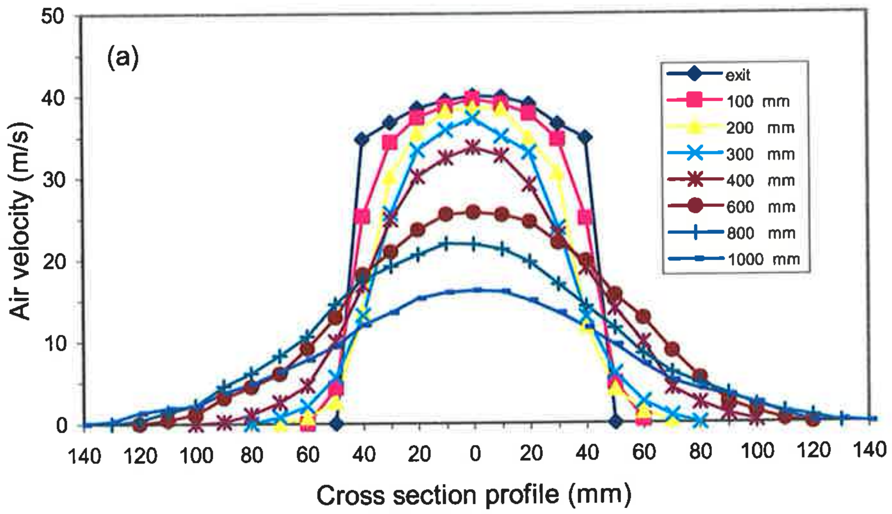


Figure 5.3 Velocity profiles at different sections of the jet discharged from circular head A



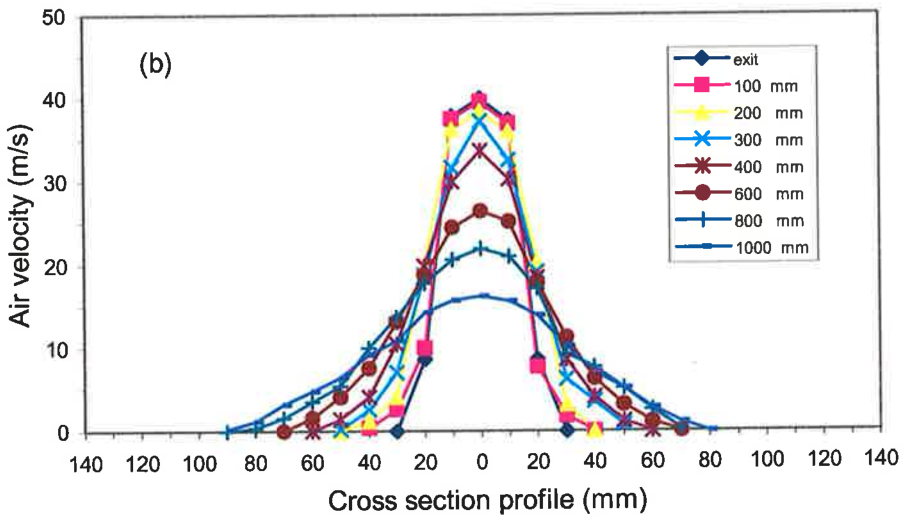


Figure 5.4 Velocity profiles at different sections of the jet discharged from rectangular head D, (a) in a direction perpendicular to the breadth, (b) in a direction parallel to the breadth

Figure 5.5 shows the decay of jets issuing from circular and rectangular heads in terms of the maximum velocity at the centreline with distance from the blowing head.

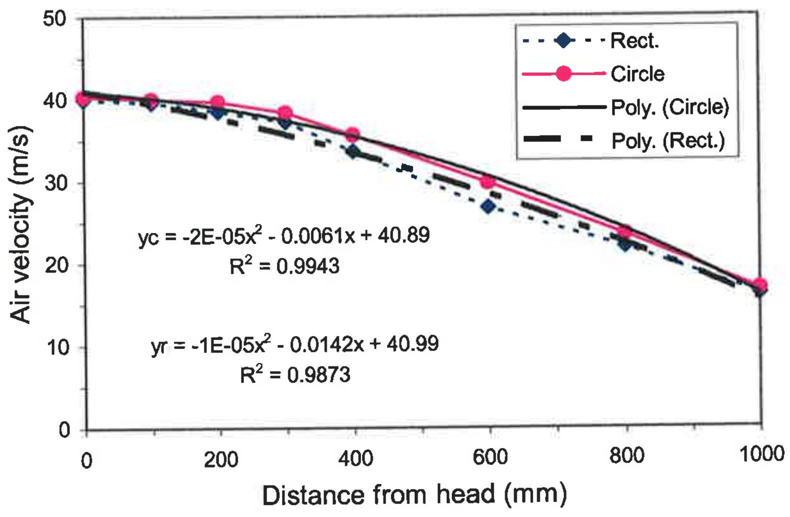


Figure 5.5 Velocity decay for jets delivered from circular and rectangular heads

It is clear that there is a high correlation ($R^2 = 0.99$) for a polynomial relationship between axial velocity and the distance from the head for both circular and rectangular heads.

Figure 5.6 presents the jet spread for circular and rectangular heads.

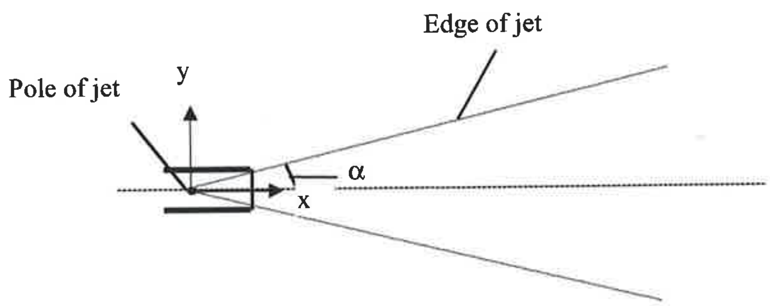


Figure 5.6 Pole position for a free jet

The regression equation for the axial velocity and the lateral velocity profile of heads (A) and (D) was determined using Excel 5.0 software and spread angle was calculated as in Table 5.4.

It can be seen that the shape of blowing head has little effect on the decay of velocity and the angle of spread is similar for circular and rectangular heads provided that the spread is determined relative to the periphery of the head and the pole defined in Figure 5.7.

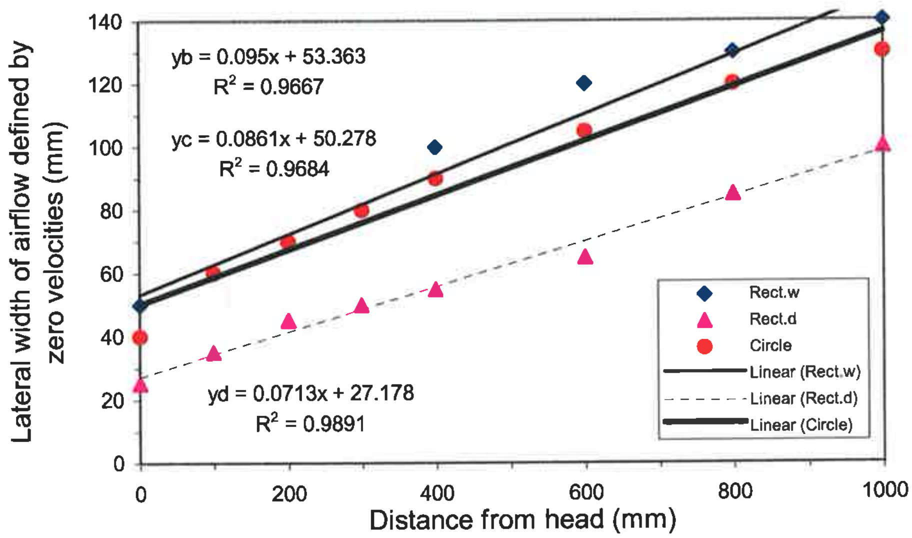


Figure 5.7 Jet spread for jets delivered from circular and rectangular heads

Table 5.4 Equations of jet spread from circular and rectangular heads assuming linear divergence

Type of head	Equation of spread	R^2	Angle of spread (degrees)
Circular	$y = 0.0861x + 50.278$	0.97	$\alpha = 4.9$
Rectangular (width)	$y = 0.095x + 53.363$	0.97	$\alpha = 5.4$
Rectangular (depth)	$y = 0.0713x + 27.178$	0.99	$\alpha = 4.1$

where: y = lateral distance, mm

x = axial distance from pole position, mm

α = angle of spread, degrees.

In conclusion, whilst it is apparent that jet characteristics relate directly to the width of the head and there are implications for three dimensional airflow, if the application seeks a wide jet, then a rectangular head is preferable to one that is circular.

5.3.2 Suction Flow

Objectives: The objective of this test was to investigate the effect of head shape on the suction airflow.

Experimental equipment: This was identical with the previous test except that the equipment was attached to the inlet side of the fan.

Experimental procedure: This test was conducted with an air velocity of 50 m s^{-1} at the head face. Measurements were taken at 10 mm intervals on sections parallel to the face at distances of 70, 90 and 110 mm from the head face as illustrated in Figure 5.8.

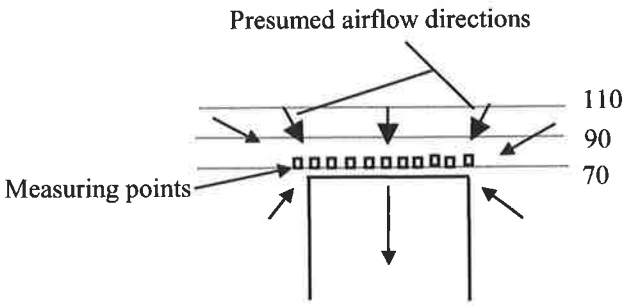


Figure 5.8 Position of measuring points during suction flow

All measurements were taken in a direction perpendicular to the head face. The shape and dimensions of the pitot-static tube prevented measurements right at the face.

Experimental results and discussion: Figures 5.9a and 5.9b show the velocity profile for suction flow from a circular and a rectangular head. Low magnitudes of velocity on both sides of the centreline refer only to the component of velocity in the axial direction, all that was measured.

The centreline velocity plotted in Figure 5.10 was obtained using the TSI velocity meter. The figure shows the very fast decay of suction flow axial velocity; airflow at the face was approximately 50 m s^{-1} at the centreline, and dropped to approximately 25 m s^{-1} at 70 mm and approximately 5 m s^{-1} at 110 mm from the face.

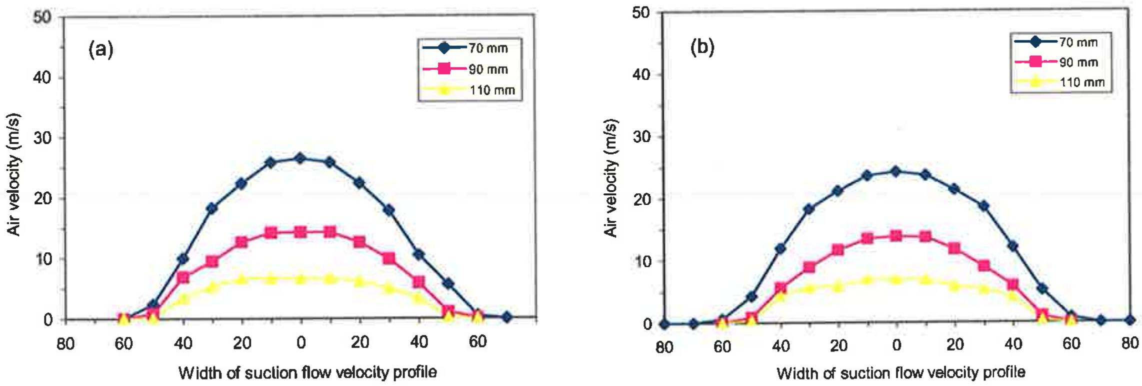


Figure 5.9 Suction flow profiles for sections parallel to the face, velocities parallel to head axis for (a) circular head and (b) rectangular head, section parallel to width

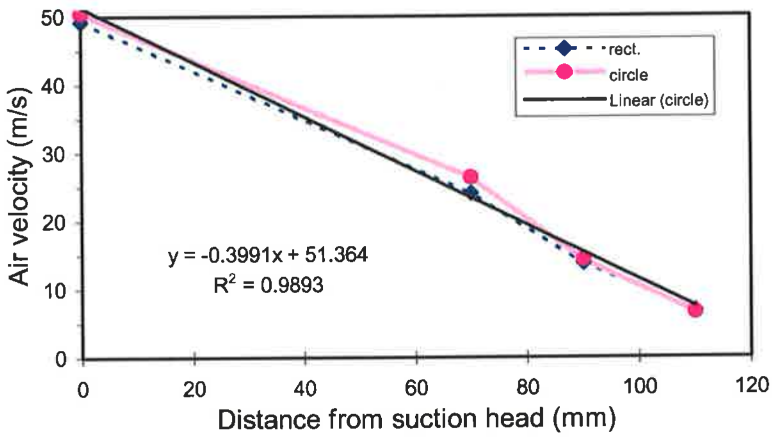


Figure 5.10 Velocity decay for suction flow from circular and rectangular heads

In addition, Figure 5.10 presents the suction flow velocities at the centrelines of the heads. The best equation to fit those lines was found to be the linear equation [5.2].

$$y = -0.3991x + 51.364 \qquad R^2 = 0.9893 \qquad [5.2]$$

where: y = air velocity, m s^{-1}

x = axial distance from head, mm.

Figure 5.11 clearly indicates the fundamental difference in nature between the velocity characteristics of blowing and suction.

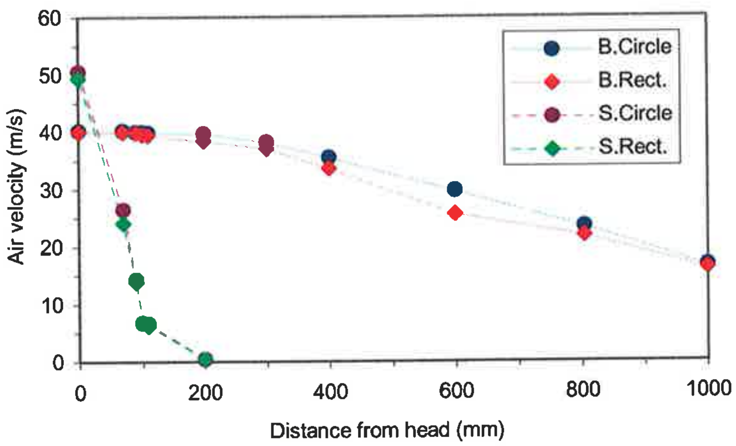


Figure 5.11 Comparison of suction flow and blowing flow for circular and rectangular heads

In summary it can be seen that the suction flow decreases to 10 % of head face velocity at a distance about equal to the head dimension, whereas the blowing velocity reduces to almost half of the initial velocity at a distance approximately 10 times the head diameter. This result, which is in good agreement with the findings of SMACNA (1976), will assist in the design of medic pod harvesting systems.

5.4 The Effect of Head Shape on a Wall Jet Produced by Perpendicular Impact on a Surface

These are the airflows created when the flow impacts on a surface which is perpendicular to the axis of the head (see Figure 2.13b). The effect was investigated for both blowing and suction modes.

A wall jet is a phenomena associated with a blown air jet and is created when a free jet impacts on a surface. In suction flow the air stream will be in associated with a surface but is unlikely to be uniquely associated with that surface. Where the term wall jet is used in conjunction with suction flow in this thesis, it is used in a more general sense in denoting an interest in the movement of the airstream along a surface.

5.4.1 Blowing Flow

Objectives: The object of this test was to investigate the effect of head shape on the structure of a blown jet impacting perpendicularly on a surface.

Experimental equipment: The test was conducted with fan (A) and three heads, square (F), circular (B) and rectangular (C) as defined in Table 5.3.

Experimental procedure: Heads were mounted in the experimental unit with the axis perpendicular to a concrete floor at heights of 10, 30, 50 and 70 mm.

Blowing through the downward oriented heads generated jets of air adhering to the floor and spreading radially outwards from the area beneath the head. The radial velocity for the airflow was determined for each head, while the average head face velocity with a head height of 70 mm for the three heads was almost the same at 26.5 m s^{-1}.

Radial flow air velocities were measured using the velocity meter to a distance of approximately 270 mm from the edge of each head beginning at the projected periphery of the head. Measurements were taken at 30 mm intervals with the probe held perpendicular to the surface and in contact with the surface. For the circular head, two sets of mutually perpendicular traverses were used. For the rectangular head one traverse was perpendicular to the width (designated Rect.b in Figure 5.13) and the other perpendicular to the depth (Rect.d).

Experimental results and discussion: Maximum radial wall jet air velocities for the three different shape heads at four head heights are shown in Figure 5.12.

The general form of air velocity decay relative to distance is similar for all three heads at the four different heights. In particular, head height has little effect on velocity within the range of head heights investigated. This is an interesting result, because the greater height substantially increases the exit area and an anticipated corresponding reduction in velocity does not occur at the elevation used for measurements. The explanation must be that the wall jet is confined to the surface of impact.

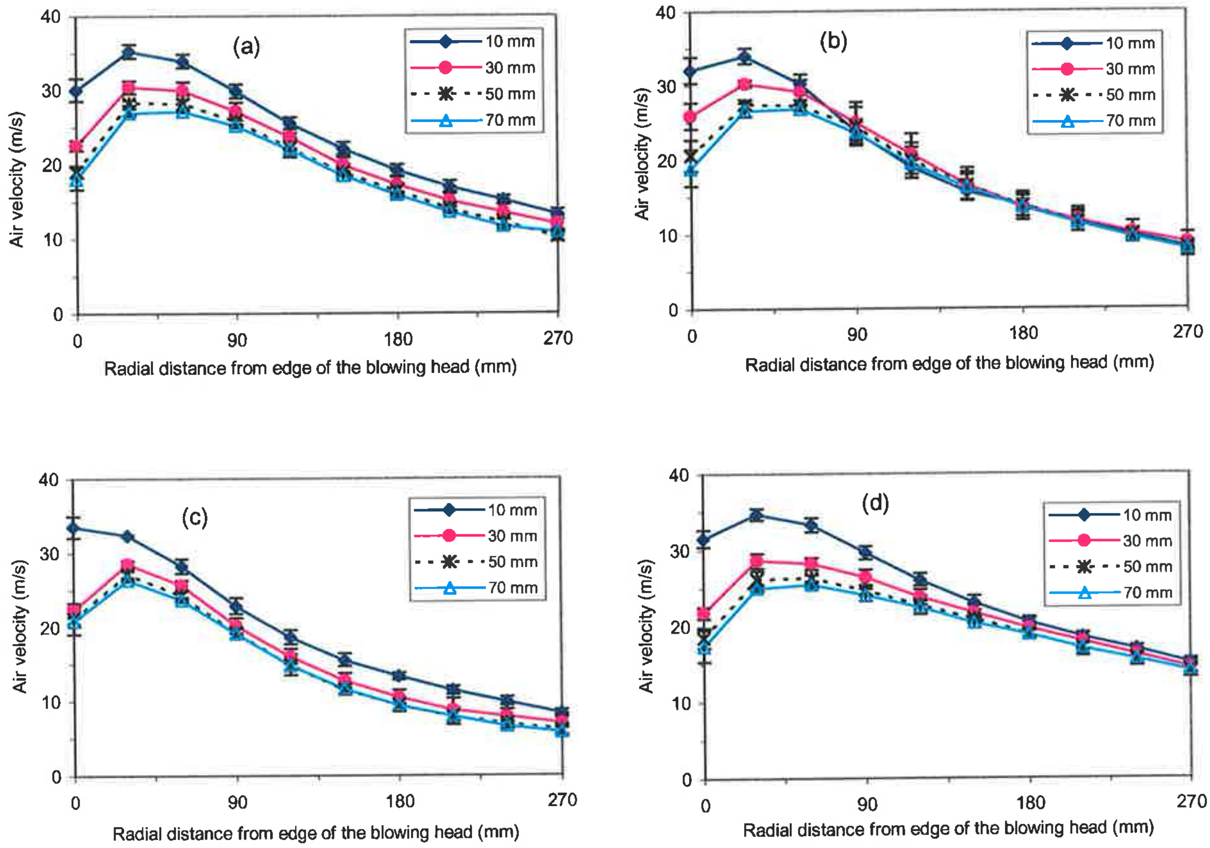


Figure 5.12 Blown air velocities of radial flow produced by four different levels of set-up height (10, 30, 50 and 70 mm from surface), for heads: (a) square, (b) circular, (c) rectangular perpendicular to width and (d) rectangular perpendicular to depth

A comparison of radial velocities produced by the different shapes of heads (which are all of similar area) is illustrated in Figure 5.13. The shape of head has a significant effect on the velocity at distance from the head. If a harvester is to use a head which is blowing in a direction perpendicular to the ground surface, then the highest velocity will be produced in the direction perpendicular to the least dimension.

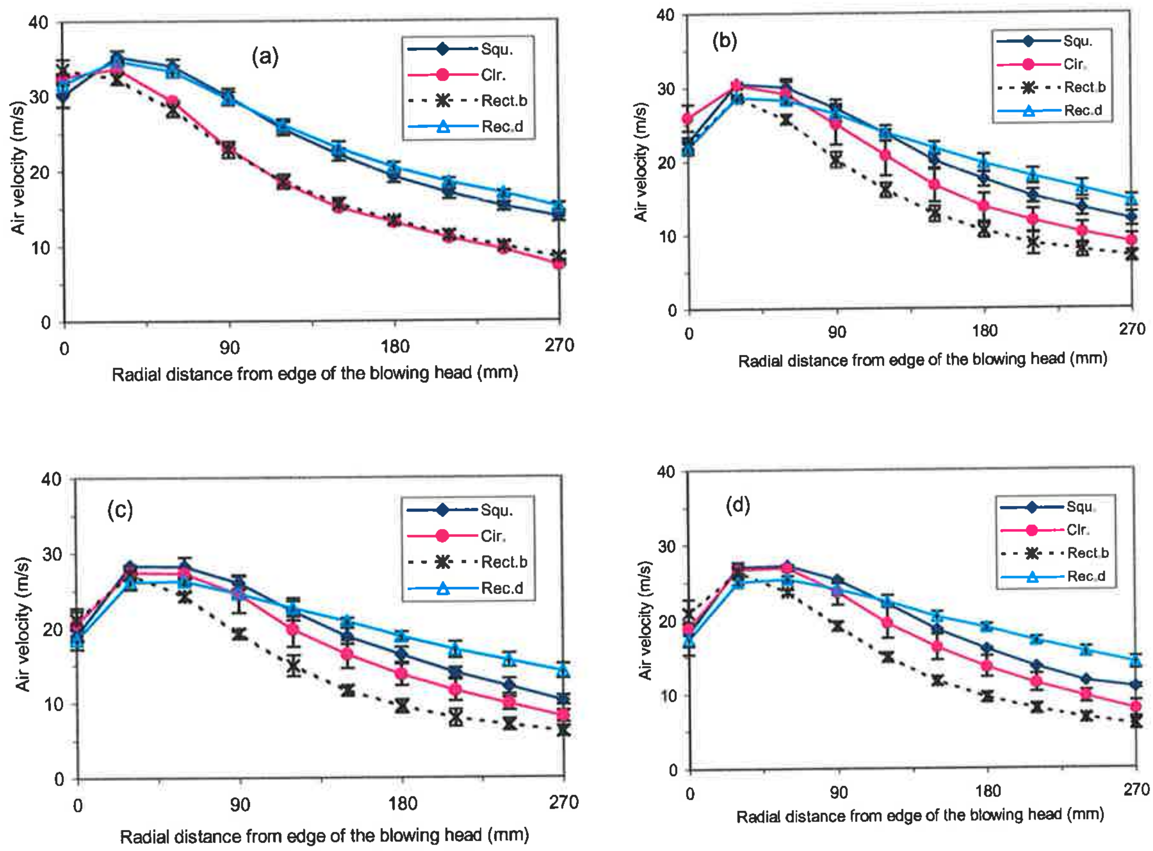


Figure 5.13 Blown air velocities of radial flow for square, circular and rectangular heads at set-up heights of (a) 10, (b) 30, (c) 50 and (d) 70 mm

5.4.2 Suction Flow

Objectives: The object of this experiment was to investigate the effect of head shape on the structure of a suction airflow restricted by a perpendicular surface.

Experimental equipment: This was identical with the previous test except that the equipment was attached to the inlet side of the fan.

Experimental procedure: The previous experimental procedure was followed, with average head face velocity 25.3 m s^{-1}.

Experimental results and discussion: Maximum radial air velocities for three different shapes of head at four head heights in suction flow are presented in Figure 5.14. As shown, the general form of suction velocity profile is similar for all heads. However, in contrast to the previous case, velocity is sensitive to head height beneath the projection of the head periphery, where it is approximately inversely proportional to head height.

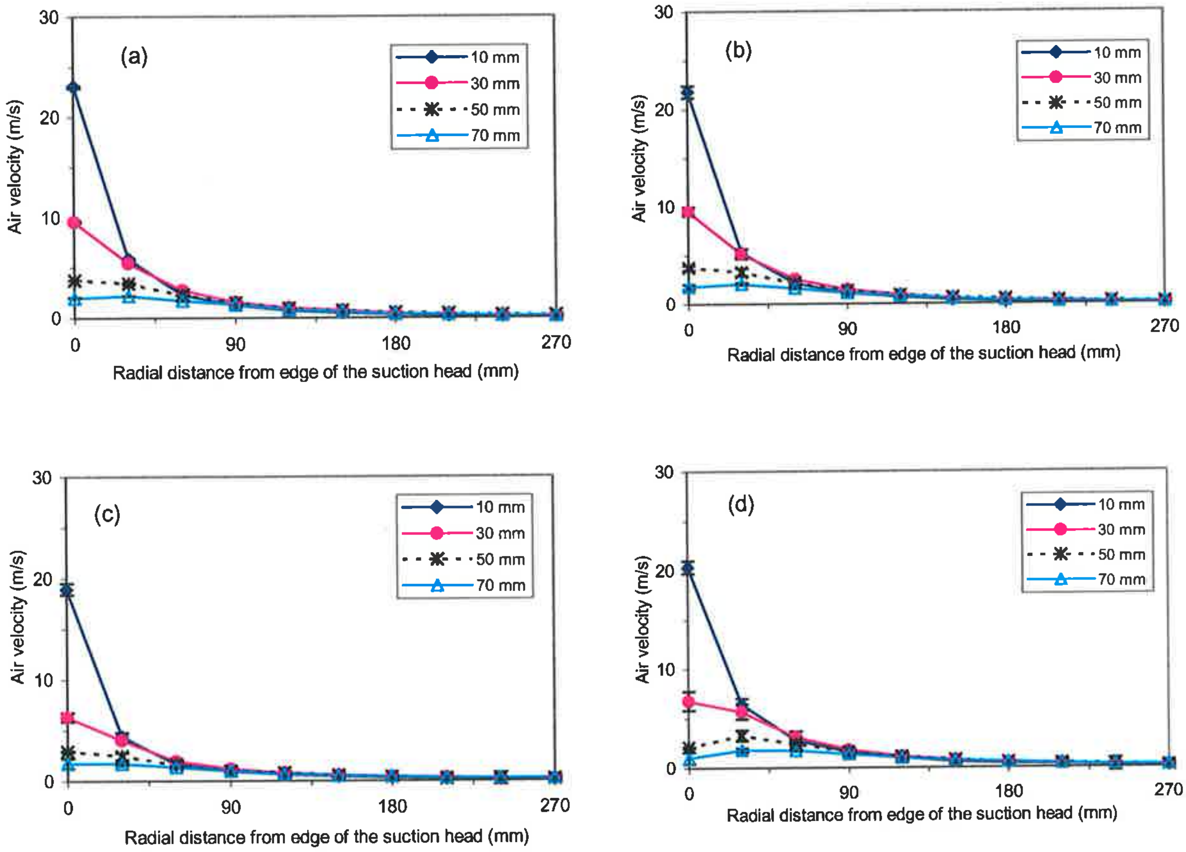


Figure 5.14 Suction radial flow velocities produced by four different levels of set-up height (10, 30, 50 and 70 mm from surface), for heads: (a) square, (b) circular, (c) rectangular perpendicular to breadth and (d) rectangular perpendicular to depth

With reference to Figure 5.15, head shape does not appear to be of importance in influencing suction velocities.

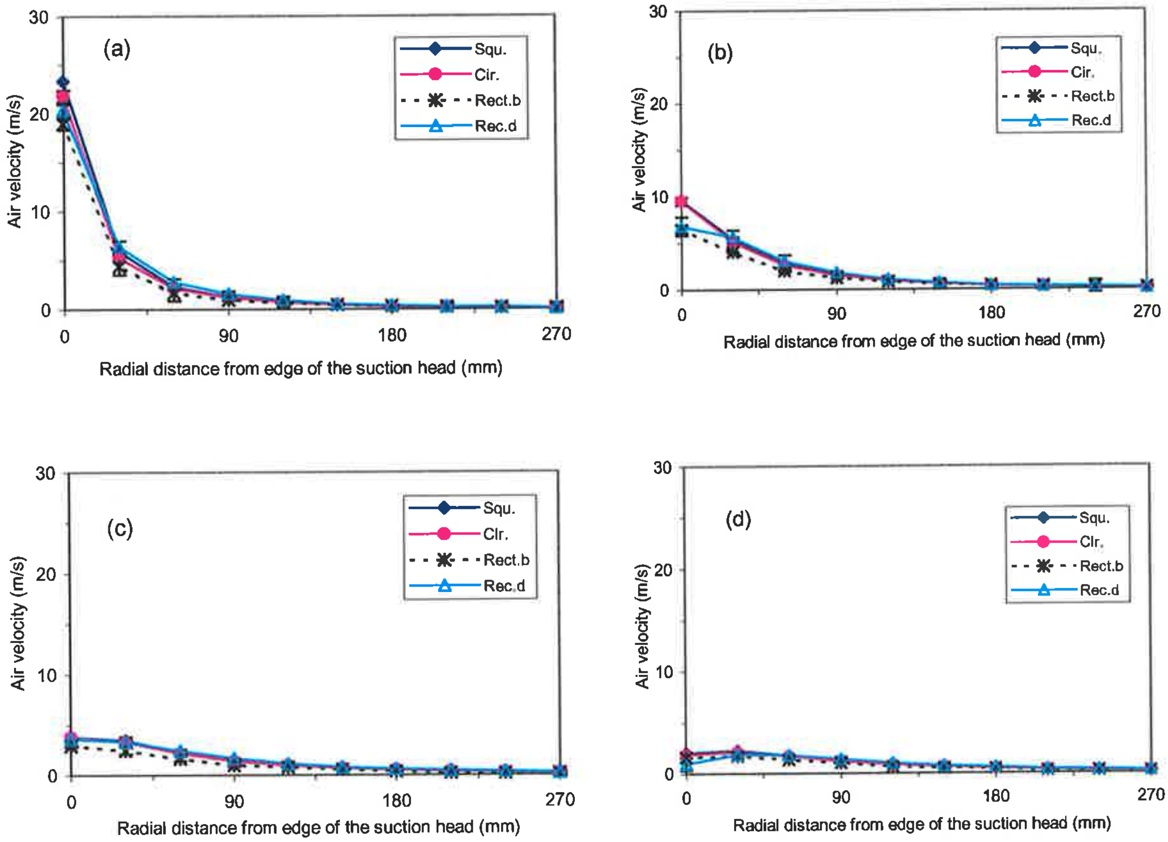


Figure 5.15 Suction radial flow velocities produced by square, circular and rectangular heads at set-up heights (a) 10, (b) 30, (c) 50 and (d) 70 mm

5.5 The Effect of Head Height and Orientation on the Restricted Airflow Produced by Inclined Impact on a Surface

These are airflows created when the flow impacts on a surface which is inclined to the head. The effect was investigated for both blowing and suction modes.

5.5.1 Blowing Flow

Wall jets produced by inclined jets have the potential to be very useful in ground harvesting systems for pushing the crop in a specific direction to make a windrow for subsequent harvesting by suction or other mechanical means.

Objectives: The objective of this study was to determine the effect of head height and head angle on a wall jet produced by an airstream restricted by an inclined surface.

Experimental equipment: The experimental unit consisted of the fan (B), and head (E) (see Table 5.3) with the required connecting duct. The head was mounted on the experimental unit so that its height and angle could be varied independently.

Experimental procedure: The orientation of the head was selected as:

Height effect: Constant head face velocity 9.7 m s^{-1} and head angle 43° with heights: 80, 100, 120, 140, 160, 180, 200 and 220 mm (see Figure 5.16).

Angle effect: Constant head face velocity 12.2 m s^{-1} and 100 mm head height with 20, 32, 35, 40, 45, 55 and 61 degrees of angle (see Figure 5.17).

The head face velocities were indicated by averaging seven different readings of velocity on the horizontal centreline of the head.

Air velocities were measured in all tests using the VelociCalc with the probe held vertically resting on the concrete surface at the centreline of the wall jets at 100 mm intervals starting from 100 mm to a distance of 1500 mm from the head.

Head heights were measured in mm from the ground surface to the bottom edge of the head. Head angles were measured as the angle between the lower surface of the head and the ground surface.

Experimental results and discussion: The velocities obtained are plotted with respect to head height and head angle in Figures 5.18 and 5.19 respectively.

The relative location of the head and velocity measurement points used to determine the velocity data presented in Figure 5.18 is given in Figure 5.16. With reference to a head height of 80 mm, the first measurement (6 m s^{-1} at 100 mm) is just into the issuing air stream in a complex situation. The measurement at 200 mm indicates a velocity measured in a horizontal direction approaching a maximum velocity of an estimated 14.8 m s^{-1}. This velocity then decreases to approximately half this value (7.4 m s^{-1}) at 800 mm. Remembering that the face velocity was 9.7 m s^{-1}, it is obvious that there has been a

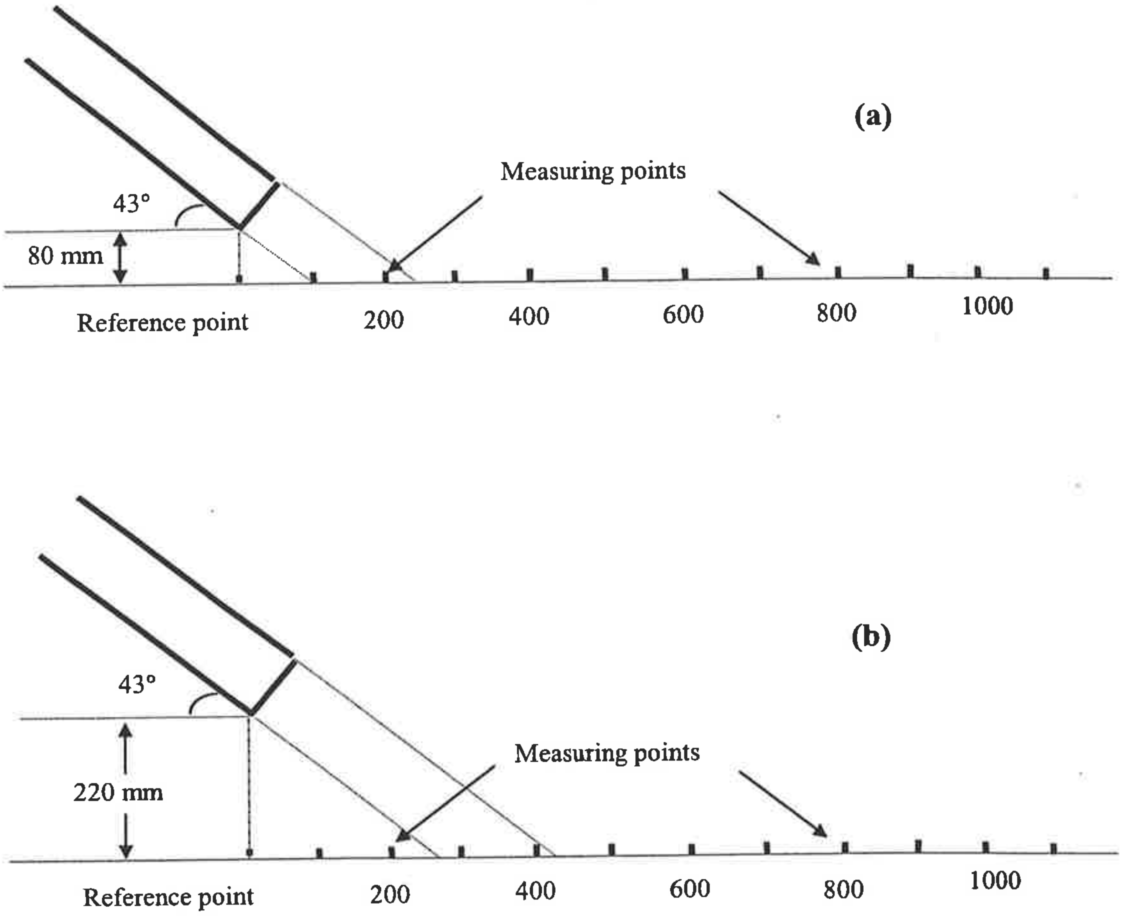


Figure 5.16 Location of head and points for velocity measurement, head angle 43° and heights of (a) 80 and (b) 220 mm

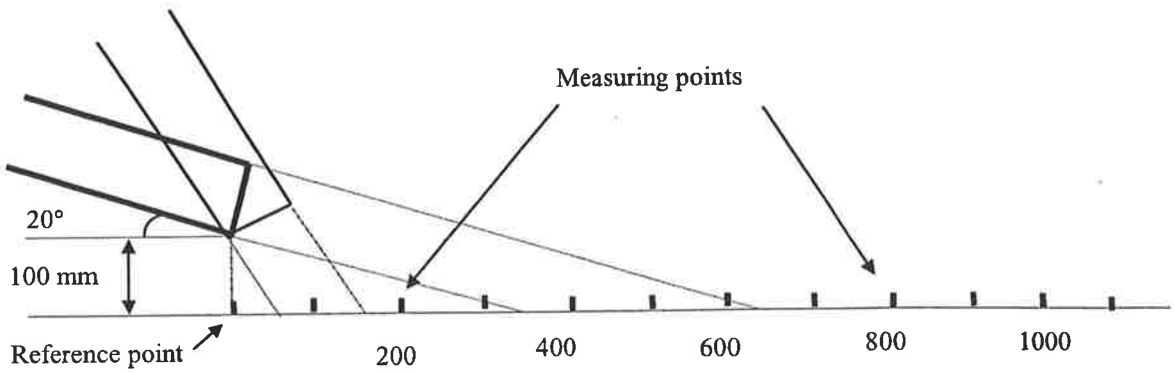


Figure 5.17 Location of head and points for velocity measurement, head angles of 20 and 61° for height of 100 mm

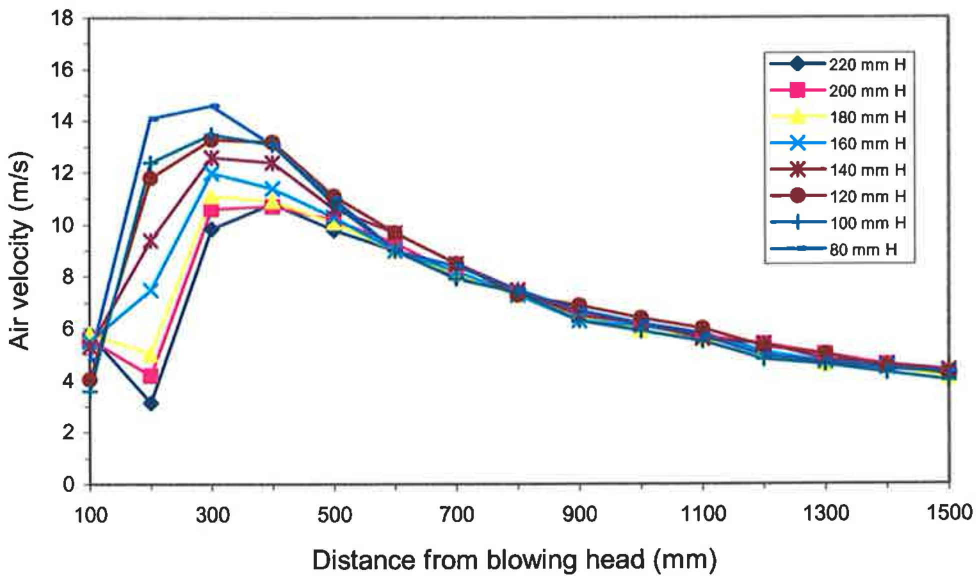


Figure 5.18 Effect of head height on wall jet centreline, head angle 43°, head heights 80 to 220 mm

substantial redistribution of velocity within the airstream.

With a head height of 220 mm the maximum value of centreline velocity is 10.8 m s^{-1} at the 400 mm measuring point.

Finally, it is apparent that the difference between the centreline velocities for the different head heights diminishes rapidly with distance and beyond the 500 mm point the velocity is much the same for all head heights.

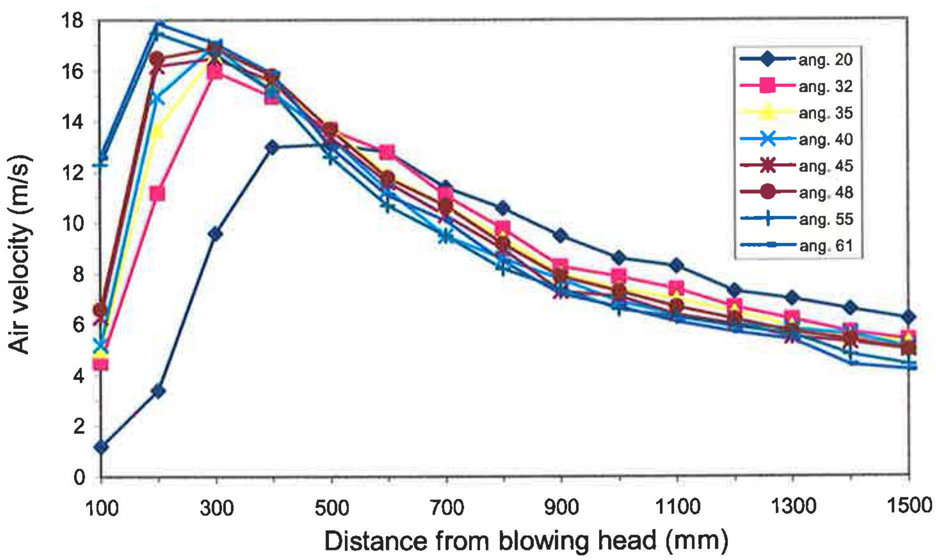


Figure 5.19 Effect of head angle on wall jet centreline velocity, head height 100 mm, head angles 20 to 61 degrees

The result of varying head angle for a fixed height (Figure 5.19) further highlights the fact that the maximum horizontal velocity occurs in the wall jet just beyond the projected area of the head on the surface and that the velocity for angles of greater than 20° exceeds the face velocity.

5.5.2 Suction Flow

Objectives: The objective of this study was to determine the effect of head height and head angle on a suction airflow restricted by an inclined surface.

Experimental equipment: This was identical with the blowing test except that the equipment was attached to the inlet side of the fan.

Experimental procedure:

Height effect: To examine the effect of height, the head angle was fixed at 35 degrees, and the face air velocity was 12.7 m s^{-1}. Head heights were: 10, 20, 25, 30, 40, 45, 50 and 80 mm from the test surface (see Figure 5.20).

Angle effect: In order to evaluate the angle effect, the head set-up angles were 30, 35, 39, 43, 46, 49, 52 and 64 degrees from the horizontal surface, while the height was fixed at 30 mm and face velocity was 12.4 m s^{-1} (see Figure 5.21).

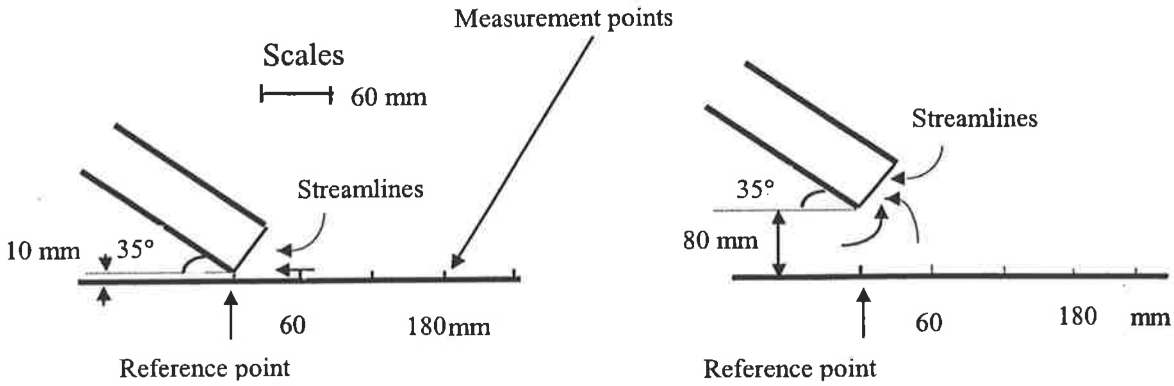


Figure 5.20 Location of head and points for velocity measurements, head angle 35°, head height 10 and 80 mm

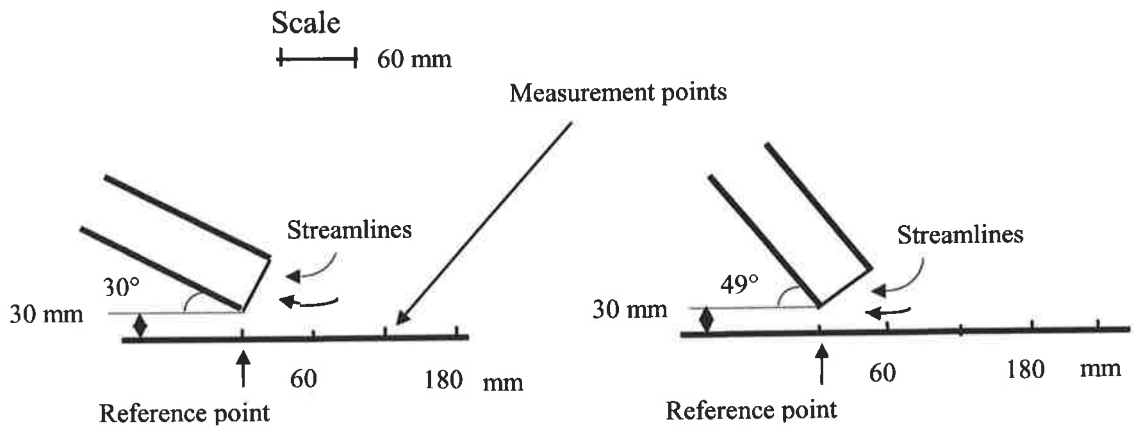


Figure 5.21 Location of head and points for velocity measurements, head height 30 mm, head angles 30° and 49°

Experimental results and discussion: Air velocity at the centreline as affected by head height and head angle is shown in Figures 5.22 and 5.23, respectively.

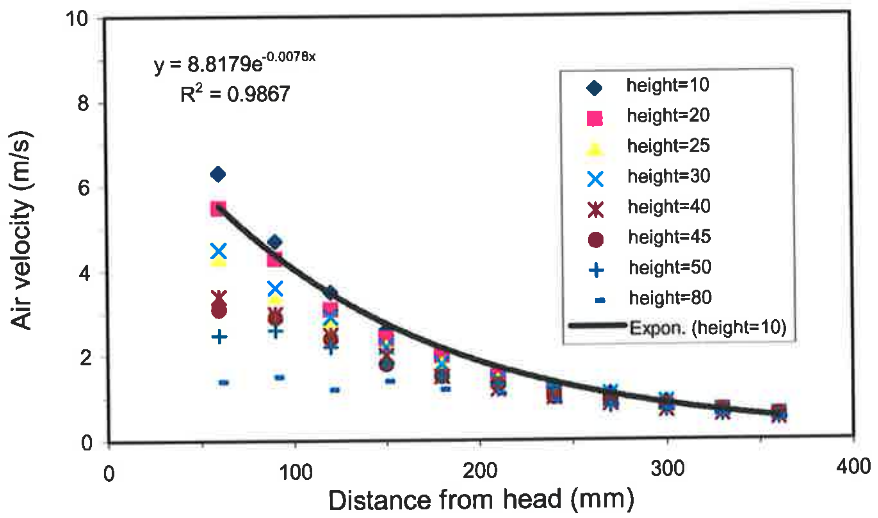


Figure 5.22 Effect of head height on wall jet centreline velocity, head angle 35°, head face velocity 12.7 m s-1

The results presented indicate clearly that velocity diminishes rapidly with distance from the head, this being the case as head height increases. The maximum velocity achieved in this case was 51% of face velocity. This compares to 7% achieved in the case of a perpendicular suction head and reflects the greater 'free' space around the head.

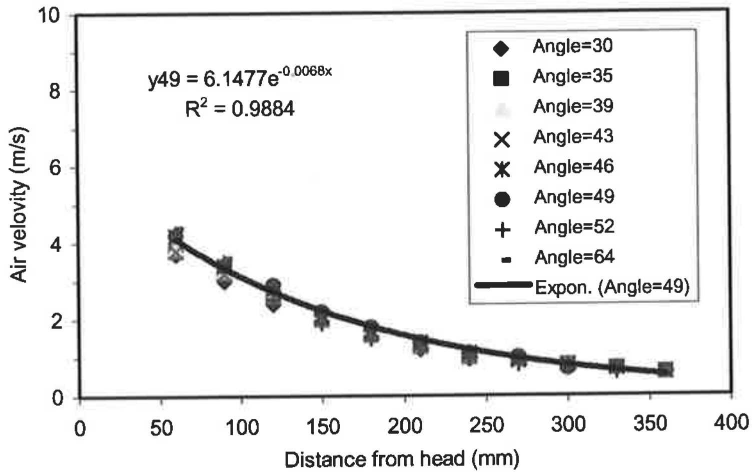


Figure 5.23 Effect of head angle on wall jet centreline velocity, head height 30 mm, face velocity 12.4 m s^{-1}

Changing the head angle at a height of 30 mm has little effect on velocity magnitude. Already magnitudes are down to small levels and distance from the head to the measuring points does not vary much from angle to angle.

5.6 Examination of wall jet characteristics

The design of any system which incorporates blowing necessitates a good knowledge of the characteristics of the wall jet created. A series of tests was undertaken to provide the detailed knowledge of the wall jet produced by a regular rectangular head, and then a further experiment to determine how a diverging head would affect the wall jet produced.

5.6.1 Wall Jet Velocity Profiles Produced by a Rectangular Head

Objective: To determine the air velocity profiles produced by an inclined jet from a rectangular head for planes perpendicular to the surface.

Experimental equipment: This experiment was conducted with head (D) and fan (A).

Experimental procedure : The head was set up at a height of 120 mm above a concrete surface with an angle of 33 degrees relative to the horizontal surface (see Figure 5.24). The average air velocity at the head face was measured as 18.1 m s^{-1}. Air velocities were measured at eight locations at 100 mm intervals. Lateral profile measurements at ground elevation were taken at 50 mm intervals and vertical measurements at 20 mm intervals. Mcasurcmcnts for the horizontal profile were obtained by holding the probe vertically and for the vertical profile, horizontally.

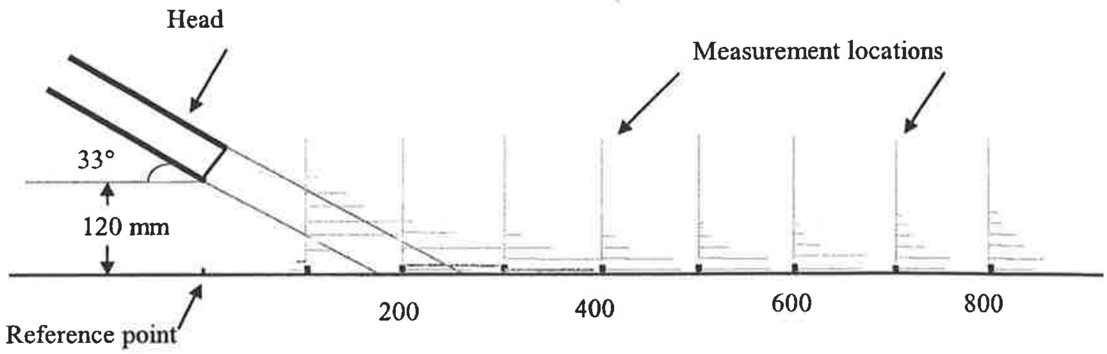


Figure 5.24 Airflow pattern of an impacting jet issued from rectangular head (D) with head height 120 mm and head angle 33 degrees

Experimental results and discussion: Air velocities in the direction parallel to the surface were obtained for horizontal and vertical traverses at a distance up to 800 mm from the head are presented in Figures 5.25 to 5.27.

The dimensionless velocity profile Figure B.3 at appendix B can be compared to Figure B.2a for a free jet, and the centreline velocity profile Figure 5.26 to Figure 5.5 for the equivalent free jet.

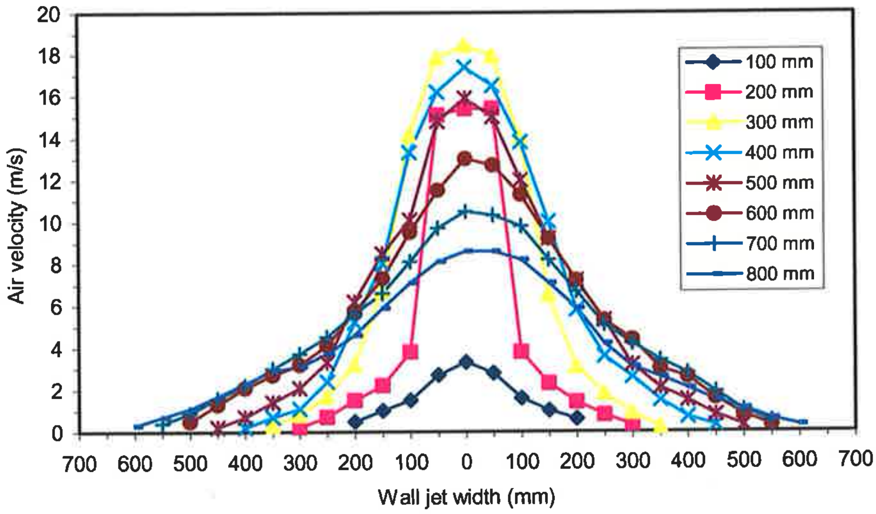


Figure 5.25 Velocity profiles at different sections of a wall jet produced by an inclined rectangular head (D)

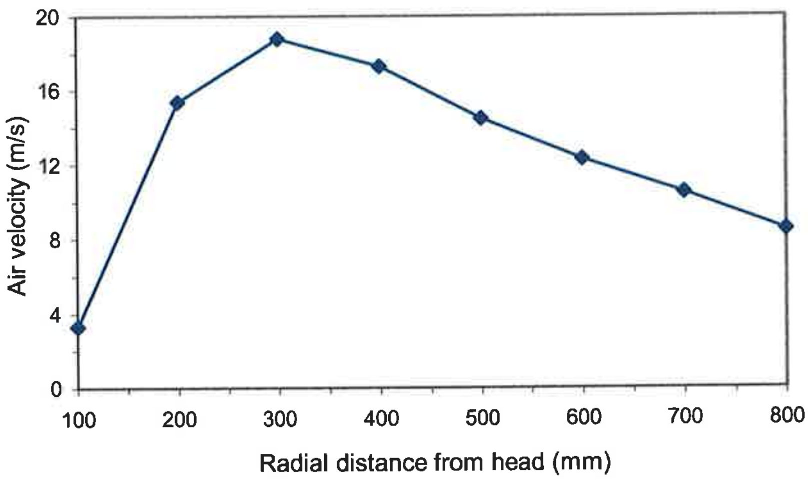


Figure 5.26 Centreline velocity profile of wall jet on the floor surface with head (D)

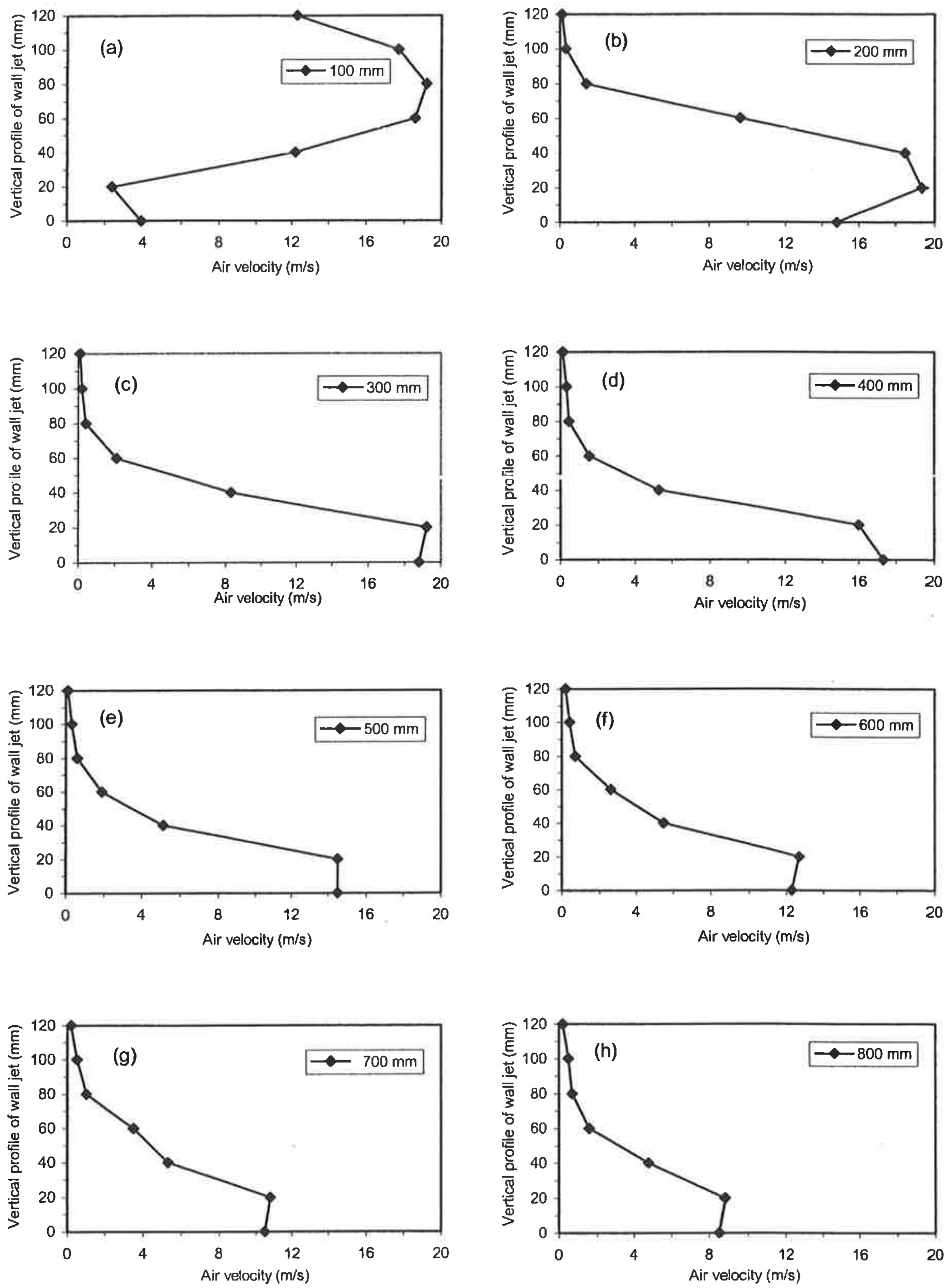


Figure 5.27 Vertical velocity profiles at different cross sections of a wall jet produced by an inclined rectangular head (D), (a) at 100 mm, (b) 200 mm, (c) 300 mm, (d) 400 mm, (e) 500 mm, (f) 600 mm, (g) 700 mm and (h) at 800 mm from head

As a result of the horizontal and vertical traverses of air velocities an interesting picture of the wall jet produced by an inclined impacting head begins to emerge:

1) The jet issuing from the head has the same characteristics as a free jet with the jet maintaining dimensions similar to the head.

2) Following impaction, the new jet (ie. wall jet) develops a horizontal width which exceeds that of the free jet. A comparison of the dimensionless velocity profile for the free jet (Figure B.2 Appendix B) and inclined wall jet (Figure 5.25) clearly indicates this.

The vertical profiles of the wall jet (Figure 5.27) indicate that the jet has a height of approximately 50 mm outside of the zone of impaction. The maximum velocity is greatest at the mid-height of the jet, although by only about 0.5 m s^{-1} more than the velocity along the surface.

The nature of the airstream beneath the issuing jet is unclear.

Two additional tests were carried out to clarify the direction of airflow following impaction. Both tests were conducted with head (D), 100 mm head height and constant head face velocity (average 18.10 m s^{-1}). The inclination of the head relative to the ground was 25° in test one and 45° in test two.

The configuration of tests and their results are illustrated in Figure 5.28 (a) and (b) for 25° and 45° inclination respectively.

Figure 5.28 indicates clearly that the airstream produced by an inclined impacting jet flows in the reverse direction in the zone beneath the inclined issuing jet. The velocities however are significantly lower than those of the wall jet (of the order of 29 %). The point at which the reversal occurs seems to correspond approximately to the projection of the lower side of the head onto the surface. Possibly at some smaller angle there might be a venturi effect so that no reverse direction occurs.

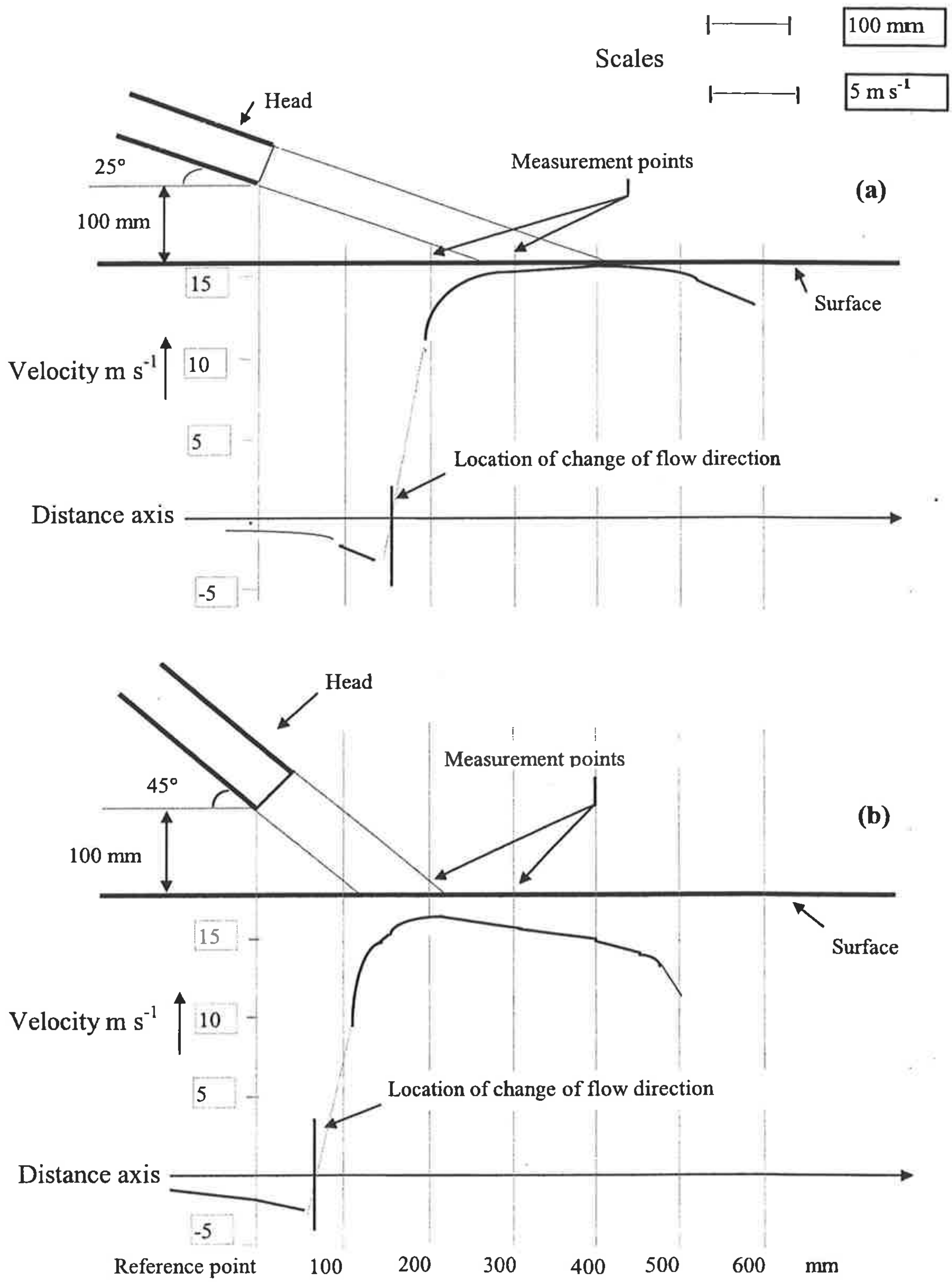


Figure 5.28 Illustration of centreline velocity and velocity directions relative to zone of impacting, head height 100 mm, (a) head angle 25° and (b) head angle 45°

A further series of tests were carried out, but with the emphasis on velocity directions.

This series was conducted with head (D), 120 mm height, 33° angle and 18.10 m s^{-1} face velocity. The pitot-static tube was used to clarify the airstream direction of the wall jet on the ground surface at two lateral sections (400 and 800 mm from head) with measurements at 100 mm intervals. The airstream direction was determined by drawing lines parallel to the pitot-static tube while it indicated the greatest magnitude.

Experimental results and discussion: The configuration of the test and its result is illustrated in Figure 5.29. The data indicates that the wall jet is wider than that of a free jet and that there is no single focus rather the jet radials centre from a region extending 600 mm from the head.

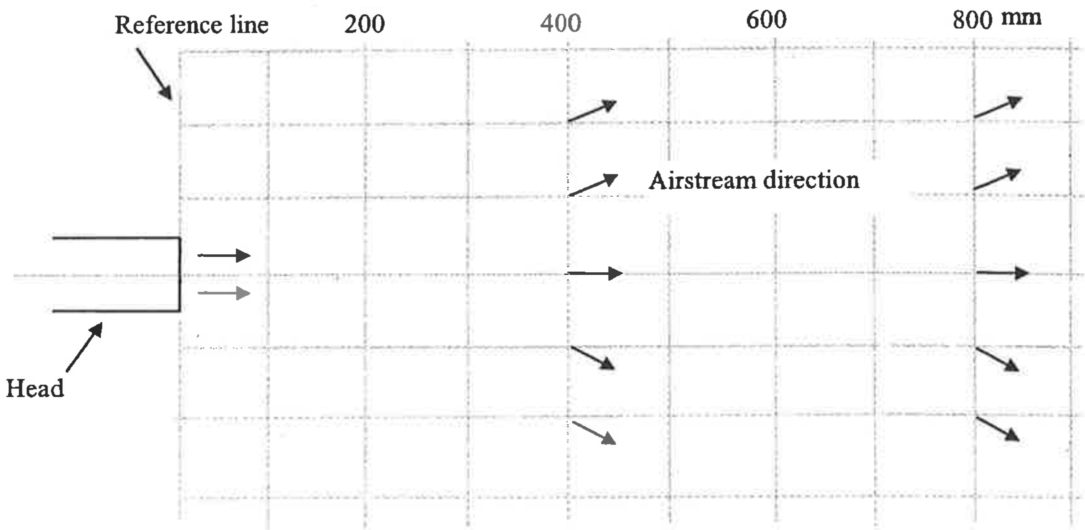


Figure 5.29 Plan view of airstream direction of the wall jet issued from head (D) angle 33° and height 120 mm

5.6.2 Wall Jet Velocity Profile Produced by a Diverging Rectangular Head

Objective: To determine the change in wall jet profile if the head has a divergement shape.

Experimental procedure: The head (E) was set up at a height of 100 mm and an angle of 45° relative to ground surface. Centreline air velocities were measured at eight locations at 100 mm intervals when the air jet was delivered average 12.0 m s^{-1} at the head face. Lateral profile measurements at ground surface were taken at 50 mm intervals and vertical measurements at 30 mm intervals. To obtain the horizontal measurements the velocity meter probe was held vertically and for the vertical profile horizontally. The surface of ground was Smooth concrete.

Experimental results and discussion: The results of air velocity traverses both horizontally and vertically obtained for distances up to 800 mm from the head are presented in Figures 5.30 to 5.32. The dimensionless velocity profile related to this head is illustrated in Figure B.4 in Appendix B. The obtained results from head (E) can be compared with head (D). It was felt necessary to determine whether a head of this shape (the SMACNA recommend shape for suction flow), gave rise to different profiles.

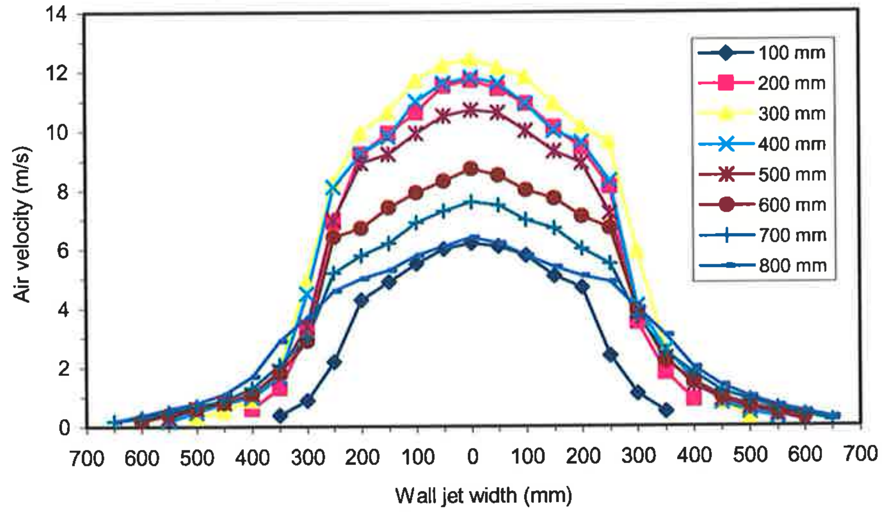


Figure 5.30 Velocity profiles at different sections of a wall jet produced by an inclined rectangular head (E) parallel to the width

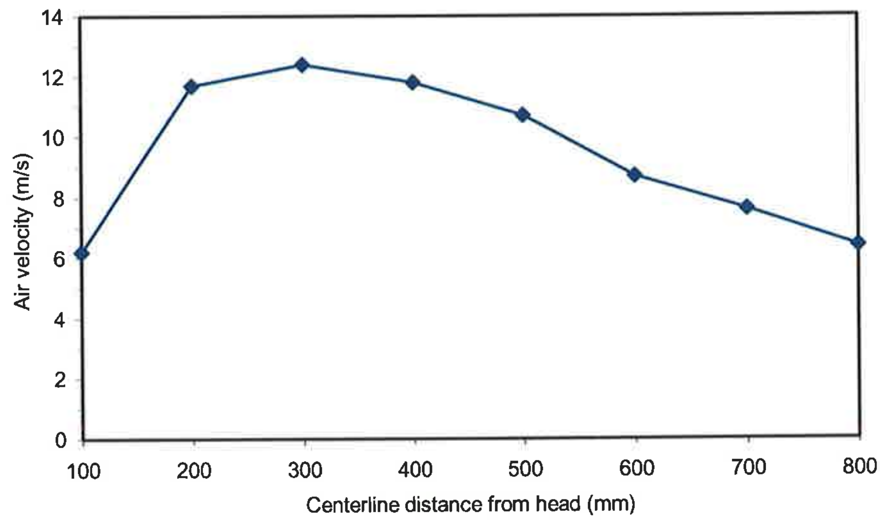


Figure 5.31 Centreline velocity profile of wall jet on the floor surface with head (E)

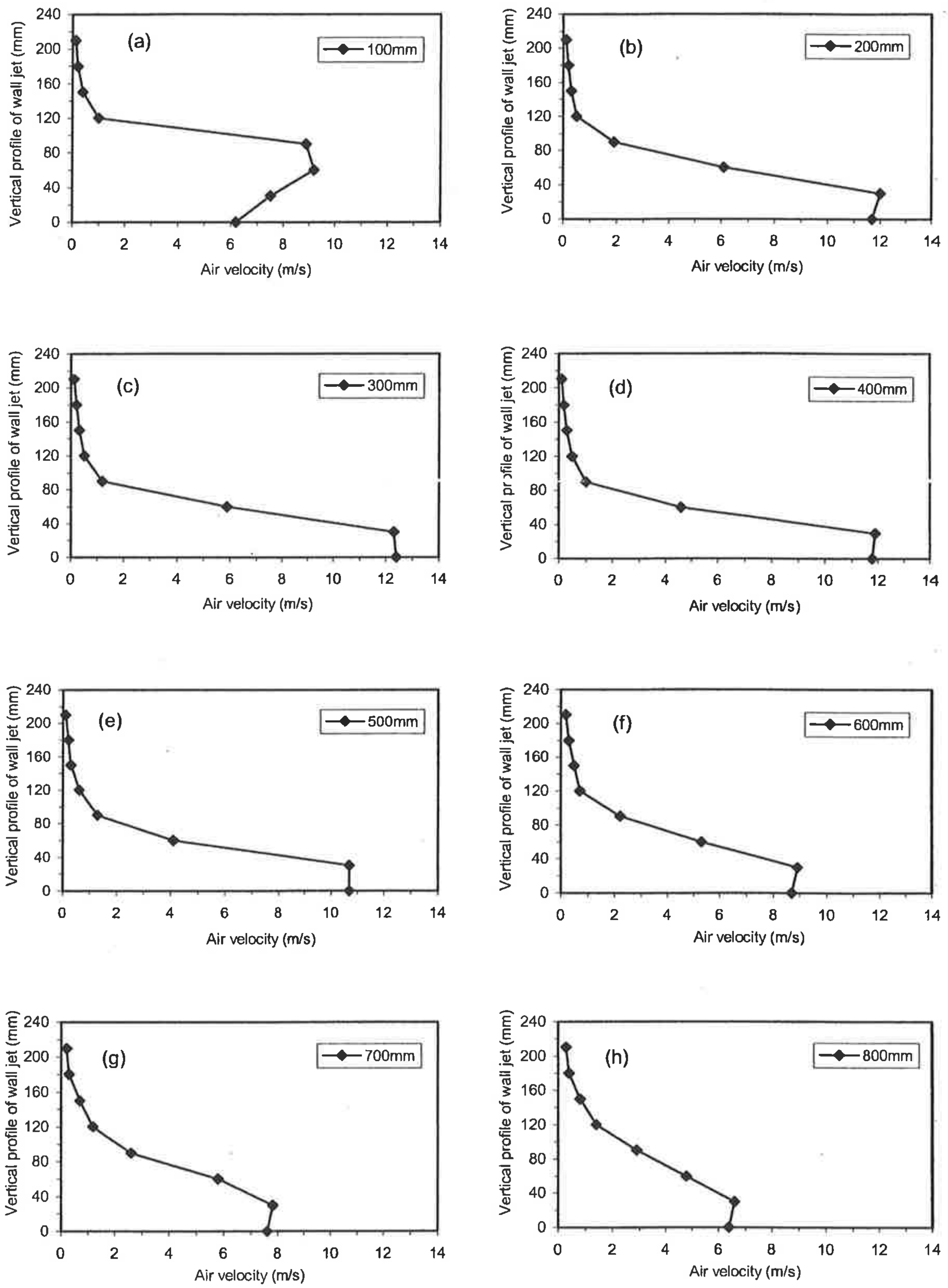


Figure 5.32 Vertical velocity profiles at different cross sections of a wall jet produced by an inclined rectangular head (E), (a) at 100 mm, (b) 200 mm, (c) 300 mm, (d) 400 mm, (e) 500 mm, (f) 600 mm, (g) 700 mm and (h) at 800 mm from head

Summary of the approximate jets taken from a comparison of Figure 5.25 for head (D) and Figure 5.30 for head (E) allows a direct comparison of the two jets (see Figure 5.33). The size of the jets is based on a cut-off of 20% of maximum value.

In comparing the generalised velocity profiles (Figures B.3 and B.4 Appendix B) it is apparent that the profile of the rectangular head is flatter and wider than that the diverging head.

A comparison of the vertical velocity profiles (Figure 5. 27 and 5.32) shows that there is no fundamental difference in performance of rectangular and diverging head.

The different nature of the two velocity profiles does allow some later choice in any combination of blowing heads.

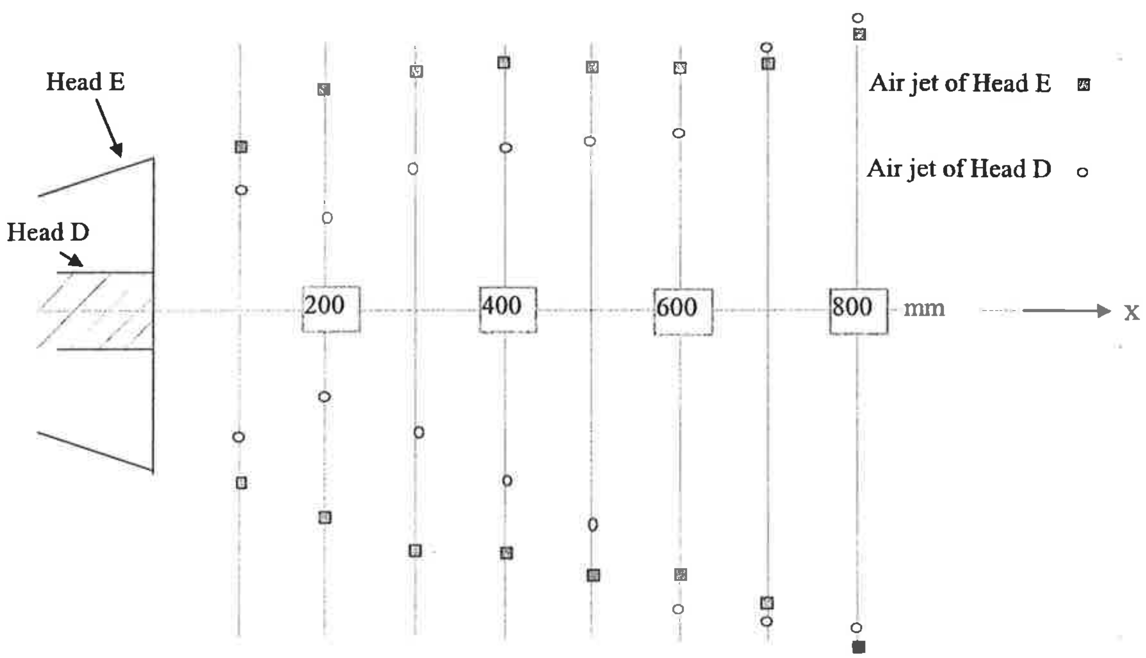


Figure 5.33 Plan view of wall jets issued from head D (height 120 mm, angle 33° and face velocity 18.1 m s-1) and head E (height 100 mm, angle 45° and velocity 12.0 m s-1)

5.7 The Effect of Combining Free Flow Blowing and Suction Flows

The following studies were directed to determining whether combining a blowing head with a suction head (push-pull system) would have a particular effect on the resultant airflow, specifically in terms of the airflow profiles.

Objective: To confirm that the net effect of combining a blowing head with a suction head could be predicted from the separate characteristics of the two types of flow.

Experimental equipment: This experiment was conducted with identical rectangular heads (D). One was connected to the outlet of fan (A), and the second one was connected to the inlet of fan (B). Appropriate connection ducts were used with the heads. Velocities were determined from pitot tube measurements.

Experimental procedure: The test was set up as in Figure 5.34, with the two heads 300 mm apart in the same straight line. All measurements were taken in a direction parallel to the common axis. Measurements were taken every 10 mm laterally from the centreline in a direction parallel to the long dimension (width) of the heads for sections 200, 100 and 70 mm from the suction head. Measurements were taken first for each fan operated separately, then for both together.

Three sets of velocities were determined, one each for the separate flows, and then for the combined flow.

The blowing fan was set so that the average air velocity at the head face was 12 m s^{-1} and the average air velocity at the suction head was adjusted to 36 m s^{-1}.

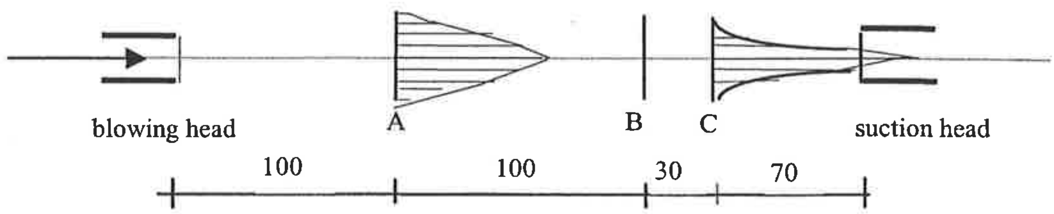


Figure 5.34 Schematic (plan view) of velocity measurement locations for combined blowing and suction flows

Experimental results and discussion: The results of operating the blowing head separately, operating the suction head separately and operating both together are presented in Figure 5.35.

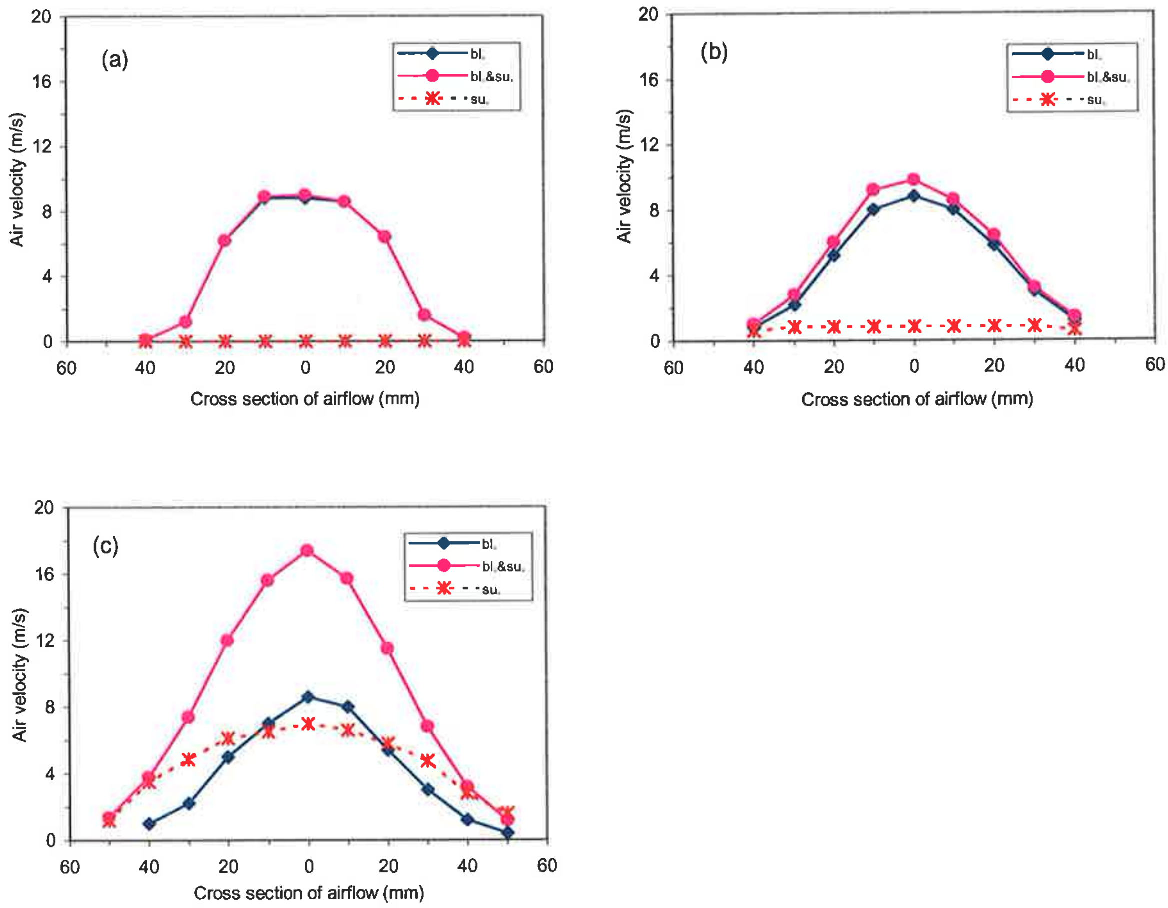


Figure 5.35 Velocity profiles produced by blowing and suction heads operated separately and together at locations (a) 200 mm, (b) 100 mm and (c) 70 mm from the suction head.

From the results presented in Figure 5.35 and as expected, combining the two air flows only becomes significant close to the suction head. With reference to the 70 mm section, the combined airflow is not exactly as predicted from the two flows; the combined velocity for the centreline and on the readings either side is greater by approximately 2 m s^{-1} than the sum of the two separate effects. This is at the expense of the velocities, 30 mm and greater from the centreline.

5.8 Conclusions and Possible Harvesting Pneumatic System Design

The aim of this investigation of airflow characteristics has been to examine in detail the actual velocity distributions that could be used to improve on the present suction technique. Free jets, vertically impinging jets and inclined impacting jets produced by blowing heads have been quantified, together with the equivalent airflows produced by suction heads.

A free jet (ie. a jet issuing into an air mass without obstruction) is predictable in relation to face opening geometry. The jet will have a slow and defined change in velocities parallel to the axis. The jet will be relatively narrow. If the face velocity is 40 m s^{-1}, beyond the initial region of constant velocity, the magnitude will reduce at the rate of approximately 5 % of maximum velocity per 100 mm. There is a similarity of velocity profile at different sections of free air jets issued from a circular and a rectangular head. This case is true in terms of decreasing axial velocity by increasing distance from those heads.

A free suction head of the same dimensions as a blowing head has a very different characteristic. It will exhibit a very steep velocity gradient and inhale air all around the opening, ie. it does not operate only over a narrow 'beam'. Velocity will reduce at a rate, in the order of 75 % per 100 mm.

Experimental work confirmed the similarity of velocity profile at different sections of free air jets issuing from circular and rectangular heads.

Any jet impacting on a surface will produce a wall jet ie. one that moves only along that surface. Vertical impact from a rectangular head will produce a radial wall jet that in magnitude reflects the opening shape, but velocity changes are predictable and slow.

A vertical flow suction head (of the type used in the H.B. Harvester) has a very localised effect. Because of the rapid change of velocity it is very difficult to control velocity magnitude.

An inclined impacting jet has many good characteristics. The wall jet produced at the ground surface by a rectangular head is more or less independent of head height and angle. The centerline velocity will reduce at approximately 5% of maximum velocity per 100 mm and the jet is wider than that of a free jet. In the tests undertaken with the 100×50 mm rectangular head the wall jet had a height of about 20 mm at near constant velocity. Above this height the velocity diminished very rapidly. This means that it is possible to create a carpet like-blown airstream.

An inclined suction head produces an airstream which is more or less independent of head angle, but head height is important. This head suffers from the disadvantage that the velocity at ground elevation is very low because of the large area of free face.

The net conclusion is that blowing jets have the potential, either singly or in some pattern, to produce airflow at specific velocities in particular locations, ie. velocities can be set to move pods and or soils to a particular location in a reasonably predictable way.

As the size of soil of which makes up approximately 80% of that taken into a H.B. Harvester has a velocity for movement which is less than that of the pods, there is no advantage in attempting to use a combine blowing and suction system. No separation at source would be possible.

Velocity discrimination is difficult with a suction head. Any suction head would need to be vertical or near vertical to minimise energy losses.

Chapter 6

EXPERIMENTAL STUDIES OF THE APPLICATION OF AIRFLOW TECHNIQUES TO THE COLLECTION OF MEDIC PODS AND THEIR SEPARATION FROM OTHER MATERIALS

6.1 Introduction

Ground harvesting of medic pods by means of an airstream could be considered as a pneumatic conveying system. Humphries *et al.* (1979) conducted experiments to study the effect of pressurised air on several agricultural products with the intention of using the information in the development of a pneumatic conveyance system.

To make appreciable improvement in pneumatic harvesting, it is necessary to know the aerodynamic behaviour of the crop and associated materials when subjected to an airstream. Blowing flows, suction flows and (on occasion) a combination of them have been investigated for harvesting or conveying some agricultural products. Liang and Kirschbaum (1982) reported on the aerodynamic properties of macadamia nuts and the corresponding air velocities required for pneumatic harvesting. The aerodynamic behaviour of Jojoba seeds and like-sized stones was studied by Coates and Yazici (1990) in both suction and blowing systems. They determined the influence of air velocity at the head face, head height and inclined head angle on the distance at which seed motion was initiated to establish an optimal set of conditions to facilitate seed and stone separation during harvesting.

It was considered in preious studies that optimising the collection of medic pods would be achieved by collecting as many pods as possible whilst minimising the amount of non-pod material entering the harvester. This might be achieved by separating pods and other materials into several fractions, before the collection takes place. This would also minimise fertile top soil displacement, increase the economic life of the harvester and decrease energy required for harvesting.

It was the purpose of these studies to characterise the aerodynamic behaviour of medic pods in both blowing and suction flows when moving along a surface, and also to study the behaviour of pod and soil particle mixtures.

6.2 Materials and Equipment

Pods and soils: The physical properties of the medic pods (*M. truncatula* cv. Paraggio) and soils used in these experiments had already been established (see Chapter 4). Pods and soils had been collected from the same medic field. Soil was sieved into five fractions: p>4.75 mm, 4.75>p>3.97 mm, 3.97>p>2 mm, 2>p>1.4 mm and p<1.4 mm. The largest fraction (p>4.75) was not included in the experiments because of high density and high terminal velocity. Also, working with soil of size p<1.4 mm proved to be too much of a practical problem when performing tests. Therefore, the three middle fractions were used in experiments.

Equipment: The experimental work was performed using Fans (A) or (B) and rectangular heads (D) or (E) separately or together with appropriate ducts (see Table 5.3).

Air velocities were determined using the VelociCalc air velocity meter, with a 20 second time constant. Average head velocities were determined from five equally spaced point readings along the centreline of the long axis of each head.

Head heights and head angles were measured as previously described in Chapter 5.

Surface distances were measured from the reference point established as the vertical projection from the bottom edge of the head to the surface.

An electronic Precisa balance reading to 0.001 g was used to weigh the samples.

6.3 Determination of Air Velocities Required to Cause Pod Movement Along a Surface

6.3.1 Objectives

To determine the range of airstream velocities required to move pods along a surface under the effect of (a) blowing and (b) suction. The sample contained pods of all sizes, typically 4.0 mm to 8.0 mm diameter (see Chapter 4).

6.3.2 Experimental Procedure

The 40 g samples of pods were arranged into a rectangular area of 100 × 150 mm on a timber surface directly in the airstream path produced by head (D) at approximately 400 mm for blowing and 20 mm for suction. The head was placed directly on the surface as illustrated in Figure 6.1.

The airstream velocity was increased until some movement occurred. With each increment in velocity, pods remaining in the rectangular area were weighed. The remaining sample was increased to the original 40 g and spread over the surface for the next subjecting airstream. Velocities were determined for point A and termed "effective velocity" (see Figure 6.1).

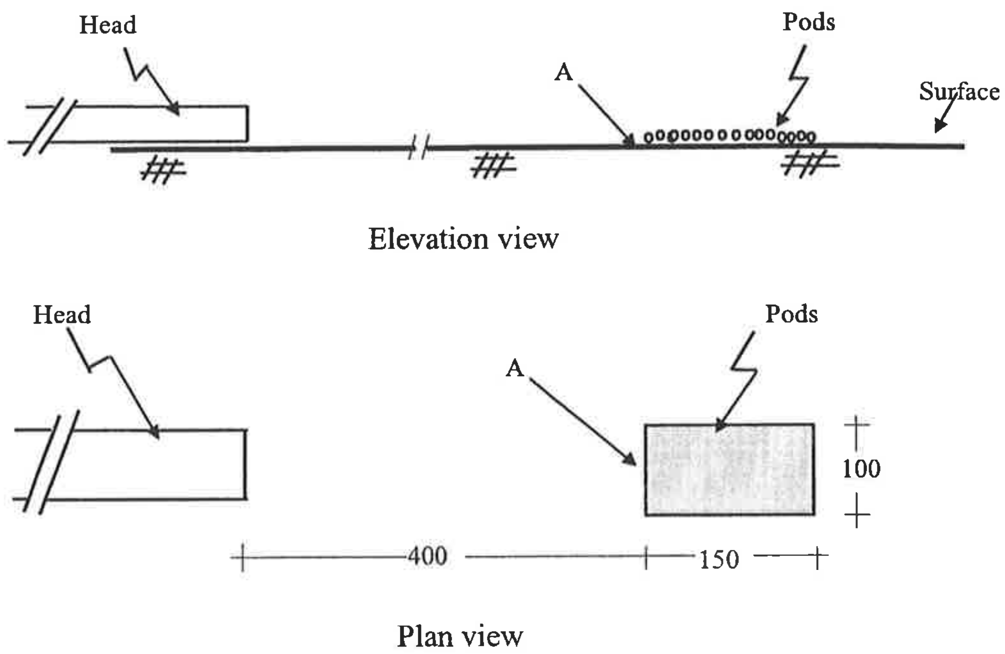


Figure 6.1 Schematic of experimental equipment and material set-up to determine the air velocity required for movement of medic pods in blowing air.

6.3.3 Experimental Results and Discussion

Figures 6.2 and 6.3 show the air velocity required to move the pods and the best fit equation for the two cases. Data for these figures are given in Tables C.1 and C.2, Appendix C. It was observed that pods moved along the surface during motion.

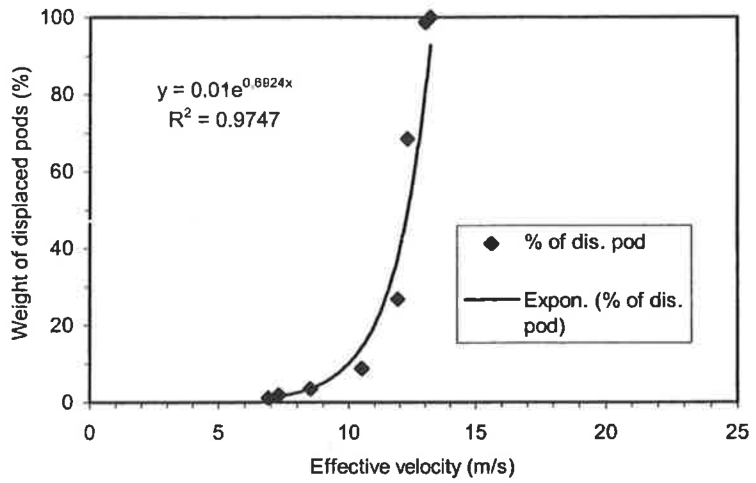


Figure 6.2 Air velocities required to move medic pods in blowing airstream

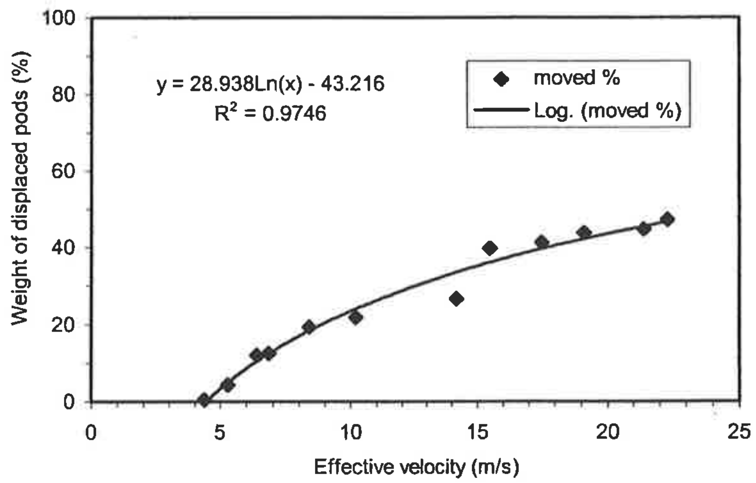


Figure 6.3 Air velocities required to move medic pods in suction airstream

The interaction of varying pod aerodynamic characteristics and airstream characteristics is complex, especially for suction flow.

The results obtained indicate the effective air velocities at point A for a blowing range between 7 and 13 m s^{-1}. 50% of the pods were displaced at 12 m s^{-1}; the remainder were moved in the range of 12-13 m s^{-1}. In suction flow, pod movement began at an effective air velocity at point A (20 mm from head) of approximately 5 m s^{-1}. Increasing the velocity to the maximum possible gave an effective velocity at point A of 22.3 m s^{-1}. At this velocity only pods within the first 75-80 mm moved (47% by weight) because of the extremely rapid drop-off in velocity in the suction situation.

Whilst it is clear that these results reflect the different nature of the velocity decays of blowing and suction flows, it is notable that pods move under suction flow at lower velocities than under blowing. Under suction flow, 10% of pods move with an effective velocity of 6 m s^{-1}, and under blowing, at 10 m s^{-1}. The reason here is assumed to be the nature of pod movement at these velocities ie. by rolling along the ground. In suction there is no impediment to individual pods moving towards the head; in blowing the movement of individual pods is resisted by the next layer of pods. It is noted that the terminal velocities recorded in free fall were in the range 5.2 to 6.4 m s^{-1} (see Chapter 4).

6.4 The Effect of Head Parameters on the Movement of Medic Pods and Associated Soils.

The following series of tests follows the pattern of the airflow tests presented in Chapter 5, namely head height and head angle were varied together with face velocity. In this context, it is possible to determine the face velocities necessary for different head settings.

6.4.1 Blowing Flow

6.4.2 *Objectives:*

The objectives of this experiment were:

- to investigate the distance at which motion of medic pods or soil particles takes place for different head settings; and

- to determine an optimal head height and angle which will provide opportunity for separation of pods and other materials.

Materials and experimental equipment: They were as described previously, in Section

6.2.

Experimental procedure: 40 g samples of pods and soil fractions were used separately in this experiment. In each case the sample was spread over the rectangular area (see previous test) on a concrete floor as shown in Figure 6.4. The sample was moved towards the head until on starting the airflow, displacement occurred. The distance from the reference point to the front edge (A) of the sample was termed the effective distance and the related airstream, as effective velocity.

Three different sets of tests were conducted by considering head orientations that were achieved from experimental studies of airflow techniques (Chapter 5). In the first set, eight different velocities (10.1, 12.1, 12.8, 13.7, 14.4, 15.4, 16.1 and 17.0 m s^{-1}) were used at a head angle of 28° and a head height 100 mm.

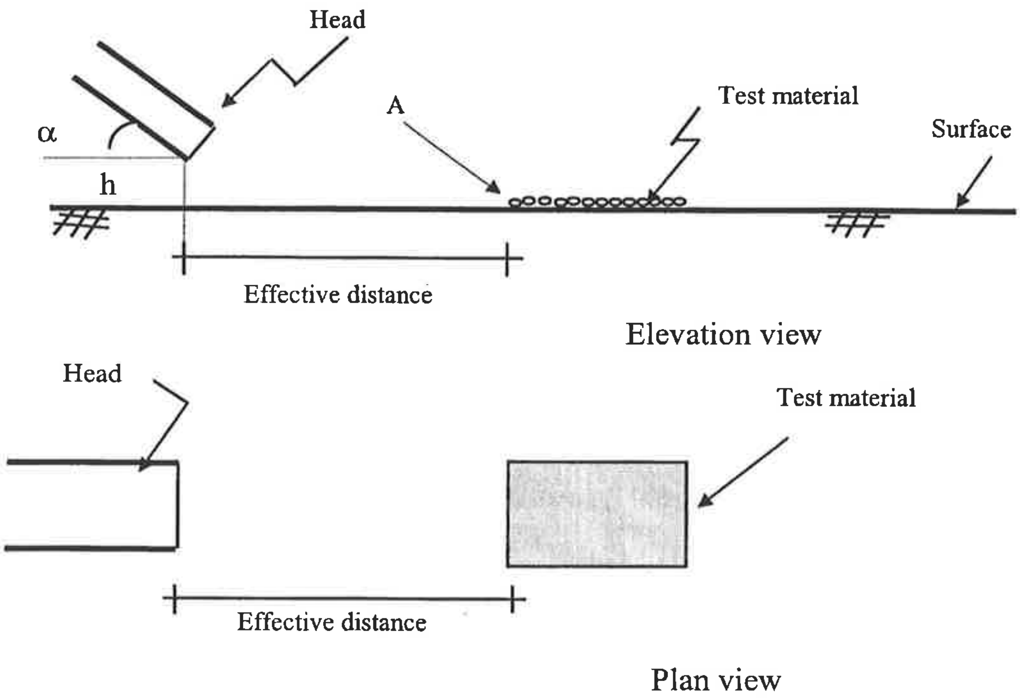


Figure 6.4 Schematic of experimental equipment and material set-up to test the effect of head height and angle on the movement of medic pods in blowing flow

In the second set, the effect of head height was examined by fixing face velocity at 16.4 m s^{-1} and head angle at 32°. Head heights were varied from 80 to 180 mm. Finally, the effect of head angle on the motion of pods and soils was studied by fixing head face velocity at

13.0 m s^{-1}, head height at 100 mm, and varying angles from 14 to 48 degrees.

Results and discussion: The results have been presented in Figures 6.5 to 6.7.

Effect of velocity: This is illustrated in Figure 6.5.

The effective distances at which the pods and soil fractions begin to move for a face velocity of 12 m s^{-1} are approximately:

soil particles, 4.75>p>3.97 mm	400 mm	effective velocity		11.2 m s^{-1}
soil particles, 3.97>p>2 mm	420 mm	"	"	10.7 m s^{-1}
pods	520 mm	"	"	9.2 m s^{-1}
soil particles, 2>p>1.4 mm	600 mm	"	"	7.9 m s^{-1}

Conversely the face velocity necessary for motion if each were at an effective distance of 600 mm are:

soil particles 2>p>1.4 mm	12.0 m s^{-1}
pods	14.0 m s^{-1}
soil particles 3.97 > p > 2 mm	16.0 m s^{-1}
soil particles, 4.75 > p > 3.97 mm	17.5 m s^{-1}

These results of course have been related to head face velocity and as such have direct practical application, but it needs to be emphasised that the actual air velocity affecting pods and soil fractions itself varies with distance for centreline velocity. It is also necessary to remember that the velocity varies relative to airflow axis.

Effect of head height: Figure 6.6 indicates that the effective distance is independent of head height for the range studied. This result conforms to the variation in axial velocity with varying head height (see Figure 5.18).

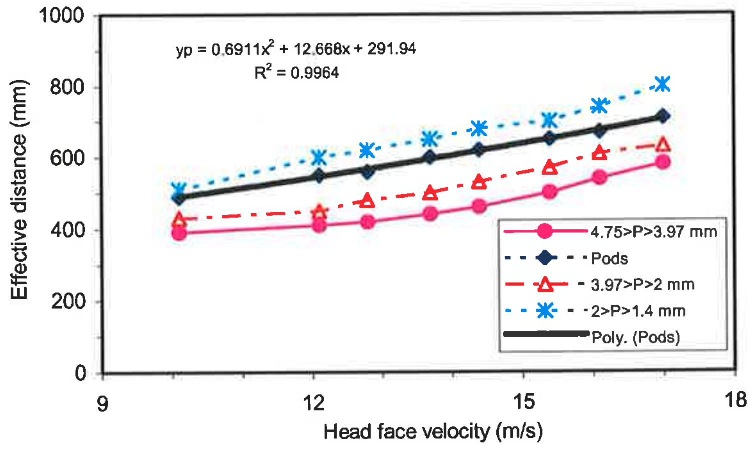


Figure 6.5 The influence of head face velocity on effective distance of medic pods and associated soils at blowing flow (head with 100 mm height and 28° angle)

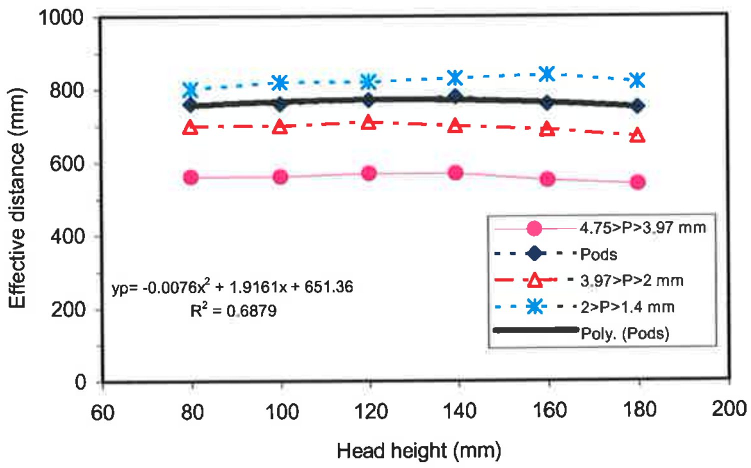


Figure 6.6 The influence of head height on effective distance of medic pods and associated soils at blowing flow (head with 32° angle and 16.4 m s^{-1} velocity)

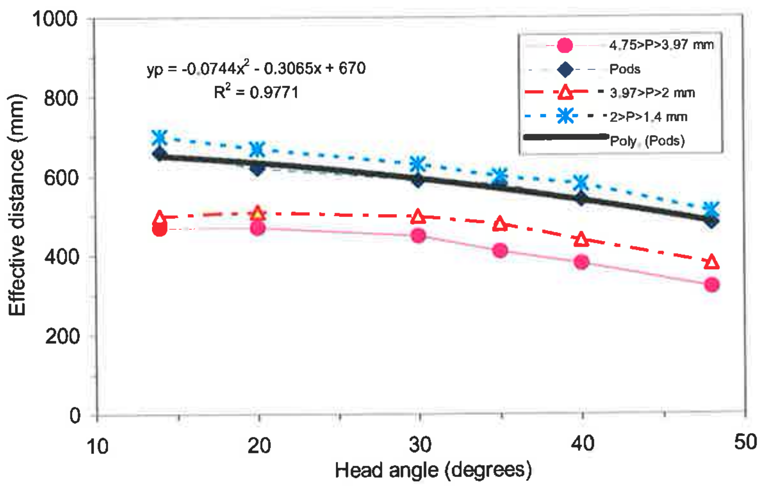


Figure 6.7 The influence of head angle on effective distance of medic pods and associated soils at blowing flow (head with 100 mm height and 13.0 m s^{-1} velocity)

Effect of head angle: The influence of head angle is shown in Figure 6.7. With reference to Figure 5.21, it can be seen that axial velocities are only slightly affected by head angles of 32° and over, but smaller angles do have appreciable effects up to considerable distances, reducing the maximum velocities achieved. This is why effective distance diminishes with increasing head angle.

The variation in velocities required to move particles allows the potential to separate pods from various sizes of soil particles. Those soil particles that are not separated from the pods at the selected velocity could be separated using screens located within the machine because of the size difference.

6.4.3 Suction Flow

Objective: The objectives of this experiment were:

- to investigate the distance at which motion of medic pods or soil particles takes place for different head settings; and
- to determine an optimal head height and angle which will minimise soil displacement.

Materials and experimental equipment: The materials were identical to those of the previous test and head (D) was used, but with fan (B). Figure 6.8 illustrates the set-up of the head.

Experimental procedure: 40 g samples were again used and three sets of parallel experiments were performed. However, it should be noted that the geometry of suction flow tends to constrain the freedom of taking measurements.

In the first set, velocities of 24.1, 29.5, 35, 38 and 41 m s^{-1} were used to study the effect of head face velocity on pods and soils for a head angle of 38° and height of 60 mm.

In the second set, the effect of head height was examined by fixing face velocity at 35 m s^{-1} and head angle 38°. Head heights were set at 0, 6, 9, 11 and 15 mm. To study the effect of head angle on the motion of materials, head face velocity and head height were fixed at 33.6 m s^{-1} and 10 mm respectively, and angle varied from 17 to 48 degrees.

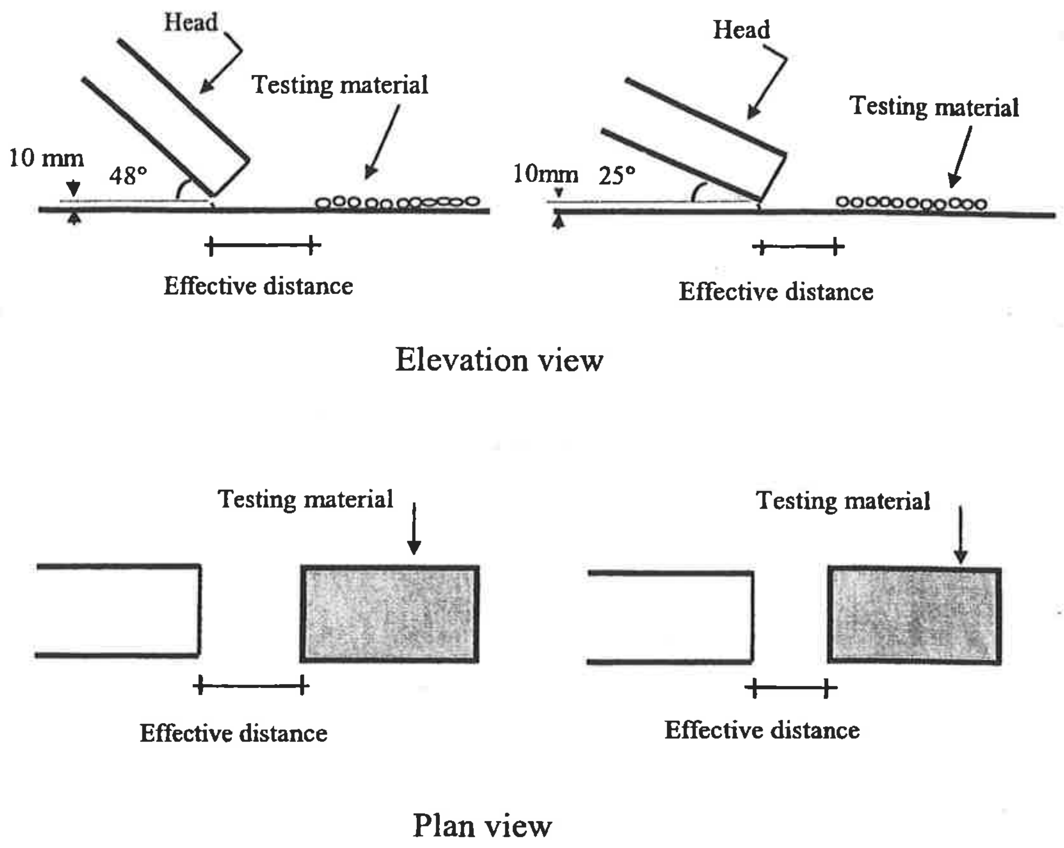


Figure 6.8 Schematic of experimental equipment and material set-up to test the effect of head height and angle on the movement of medic pods in suction flow

Results and discussion

Effect of velocity: Figure 6.9 shows the results obtained with varying face velocity. It is worth viewing the geometry of the test, as in Figure 6.9, while remembering the method, namely the sample is moved closer and closer to the head until it is affected (this is effectively what happens as a harvester advances). Increasing face velocity increases the distance at which materials will be sucked into the head. However it can be noted that with velocity less than 30 m s^{-1} there is no chance for soil particles greater than 3.97 mm to be picked up.

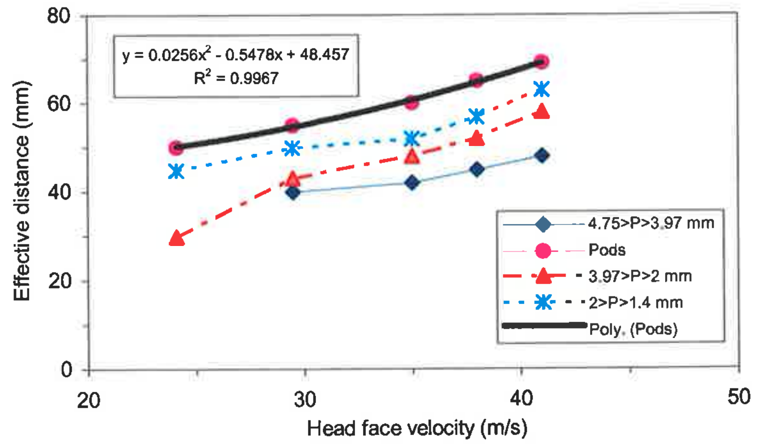


Figure 6.9 The influence of head face velocity on effective distance of medic pods and associated soils in suction flow (head with 60 mm height and 38° angle)

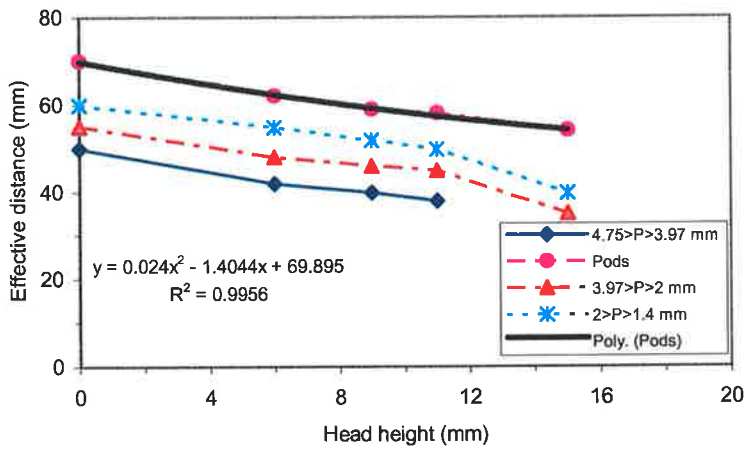


Figure 6.10 The influence of head height on effective distance of medic pods and associated soils in suction flow (head with 38° angle and 35 m s^{-1} velocity)

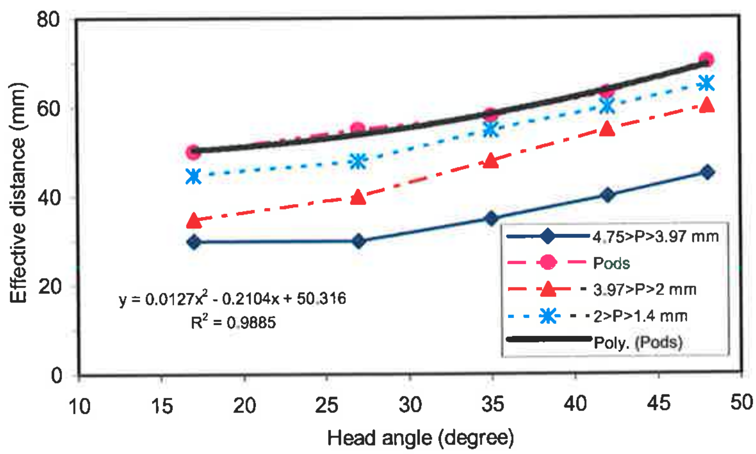


Figure 6.11 The influence of head angle on effective distance for medic pods and associated soils in suction flow (head with 10 mm height and 33.60 m s^{-1} velocity)

For a face velocity of 35 m s^{-1} the effective distances are:

soil particles 4.75>p>3.97 mm	40 mm
soil particles 3.97>p>2 mm	47 mm
soil particles 2>p>1.4 mm	50 mm
pods	60 mm

Conversely, the face velocities for motion of each fraction at an effective distance of 50 mm are:

pods	24 m s^{-1}
soil particles p>1.4 mm	29 m s^{-1}
soil particles 3.97>p>2 mm	36 m s^{-1}
soil particles p>3.97 mm	44 m s^{-1}

Of particular note is the fact that the relative order of response between pods and soil particles p<1.4 has changed from the previous test.

Effect of height: With reference to Figure 6.10, the effective distance reduces as head height increases. This is consistent with a velocity profile that reduces rapidly from the centreline.

Effect of head angle: Figure 6.11 shows that increasing the head angle increases the effective distance. This can be explained through the increase in velocity achieved as the upper edge of the head face moves closer to the ground surface.

Collection of pods relative to other material is possible given the large variation in velocities that cause movement of the individual materials. However, this situation is partially offset by the rapid nature of velocity changes associated with suction.

6.5 Feasibility of Pod and Soil Separation

Results from the aerodynamic behaviour of medic pods and associated soils indicated that there is a difference in terms of effective distance between pods and soils in blowing and suction flow. It seemed that this difference could be used to selectively windrow the medic pods. For example, a "constant" blowing effective velocity of 10 m s^{-1} will move pods and a "constant" suction velocity of 6 m s^{-1} will collect pods.

6.5.1 Pod and Soil Mixture Displacement

Objective

The purpose of these experiments was to determine whether windrowing could separate medic pods from other material sufficiently for subsequent selective suction.

Materials and Equipment

In order to assess the feasibility of separation, medic pods and loose soil with particles 3.97>p>2 mm were used in this experiment. This group of soil particles was selected, the aerodynamic behaviour is close to that of pods and requires a higher velocity.

Fan (A) and a rectangular head unit (D) were used in this trial. The VelociCalc air velocity meter and an electronic scale were employed to measure the velocities and weights, respectively.

Experimental Procedure

The blowing head was mounted with 100 mm height and 45° angle on the experimental unit on the concrete surface. The area along the centreline of the blowing jet was marked at 250 mm intervals for a 2 m length in 8 regions starting 100 mm from the head reference point. To prevent material spreading around, the area was confined with two side walls of 150 mm height and 500 mm separation (see Figure 6.12).

A mixture of equal masses of pods and soil particles was spread over the first four regions. The tests were performed for mixtures of total mass 80, 160, 240 and 320 g (an 80 g sample corresponds to 6400 kg ha^{-1}) in each 250 x 500 mm region.

The test samples were subjected to blowing airflow with a 16.70 m s^{-1} face velocity. With this velocity pods could be expected to be affected within the region 100-450 mm. Material on each region was sieved and weighed separately to find the accumulated mass of each material on the different region. This test was done with three replications.

Figure 6.12 Experimental equipment and material set-up to test possible separation in a blowing situation

Experimental Results and Discussion

Figure 6.13 is a photograph of the result of blowing the mixture of pods and soil particles (120 g pods and 120 g soils). Figure 6.14 is an indication of the location of blown material relative to the test regions. The results are presented in detail in Table 6.1 and Figure 6.15.

With reference to Figures 6.14 and 6.15 and Table 6.1, the displacement of the material mostly occurs in the first region as well as in the first half of the second region and that the displaced material has started to lodge in the second half of the second region and in the third region. It is noted that more soil is moved from the first region and that the amount of soil in the second region exceeds that of the pods but that the quantity of pods in the third region is slightly greater than that of soil. These features are confusing. The differences in behaviour between pods and soil particles is small, typically less than 5%; consequently it is concluded that separation between pods and this size of soil particles is unlikely. These tests however do indicate that an increasing amount of material on the surface reduces the movement of material at any particular velocity.

Figure 6.13 Material lodgement after being subjected to a blowing airstream (160g pods and 160 g soils)

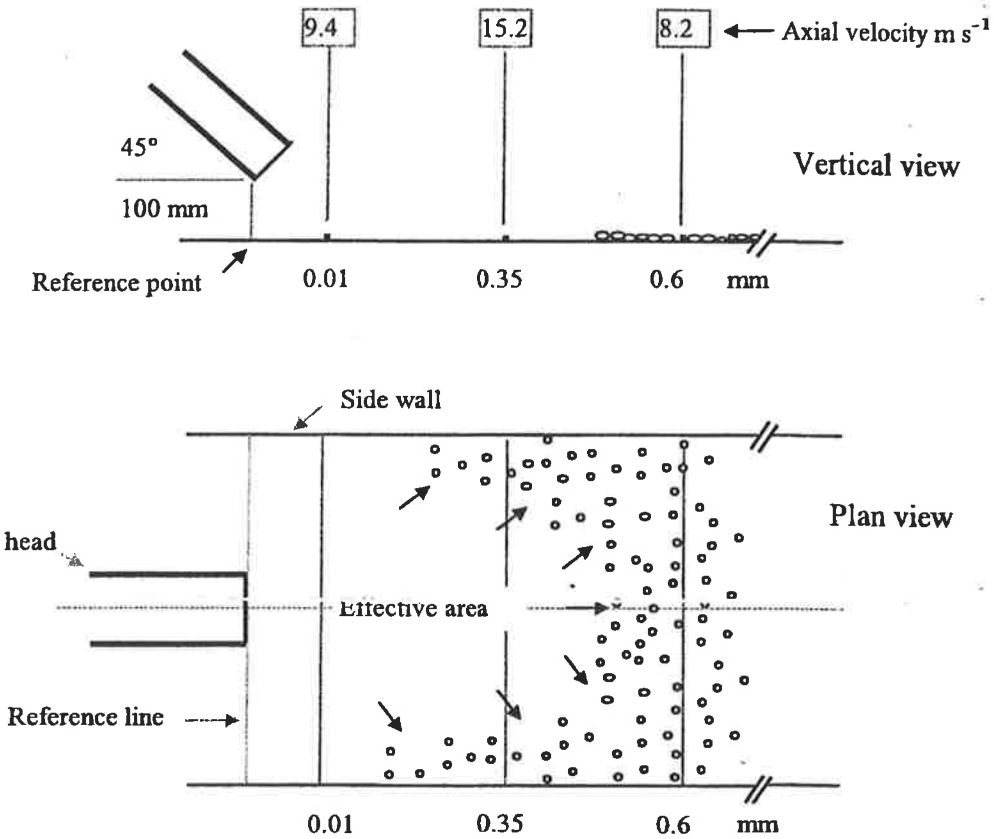


Figure 6.14 Schematic view of experimental result from windrowing medic pods and soil particles greater than 2 mm

Table 6.1 Accumulated mass of medic pods and soils at different distances from the blowing head (face velocity 16.7 m s^{-1}, height 100 mm and angle 45°)

	Accumulated mass of testing material in each testing zone (g)							
Dist.(m)	40 P*	40 S**	80 P	80 S	120 P	120 S	160 P	160 S
0.0 - 0.35	6.9	4.0	32.0	23.9	54.2	37.9	86.3	57.5
0.35 - 0.6	35.4	49.2	82.6	103.1	128.6	155.6	180.0	212.6
0.6 - 0.85	66.9	55.2	110.3	98.3	162.6	151.9	205.9	185.3
0.85 - 1.1	46.7	44.0	85.9	85.4	126.2	126.9	160.9	169.0
1.1 - 1.35	2.0	1.0	2.1	2.6	2.3	2.0	1.8	2.7
1.35 - 1.6	1.0	0.9	1.9	1.6	1.6	1.8	1.6	2.0
1.6 - 1.85	0.5	0.7	1.1	0.9	1.2	0.9	0.9	1.3
1.85 - 2.1	0.3	0.5	0.6	0.7	0.8	0.8	0.5	1.3

* 40 g sample of pods.

** 40 g sample of soils.

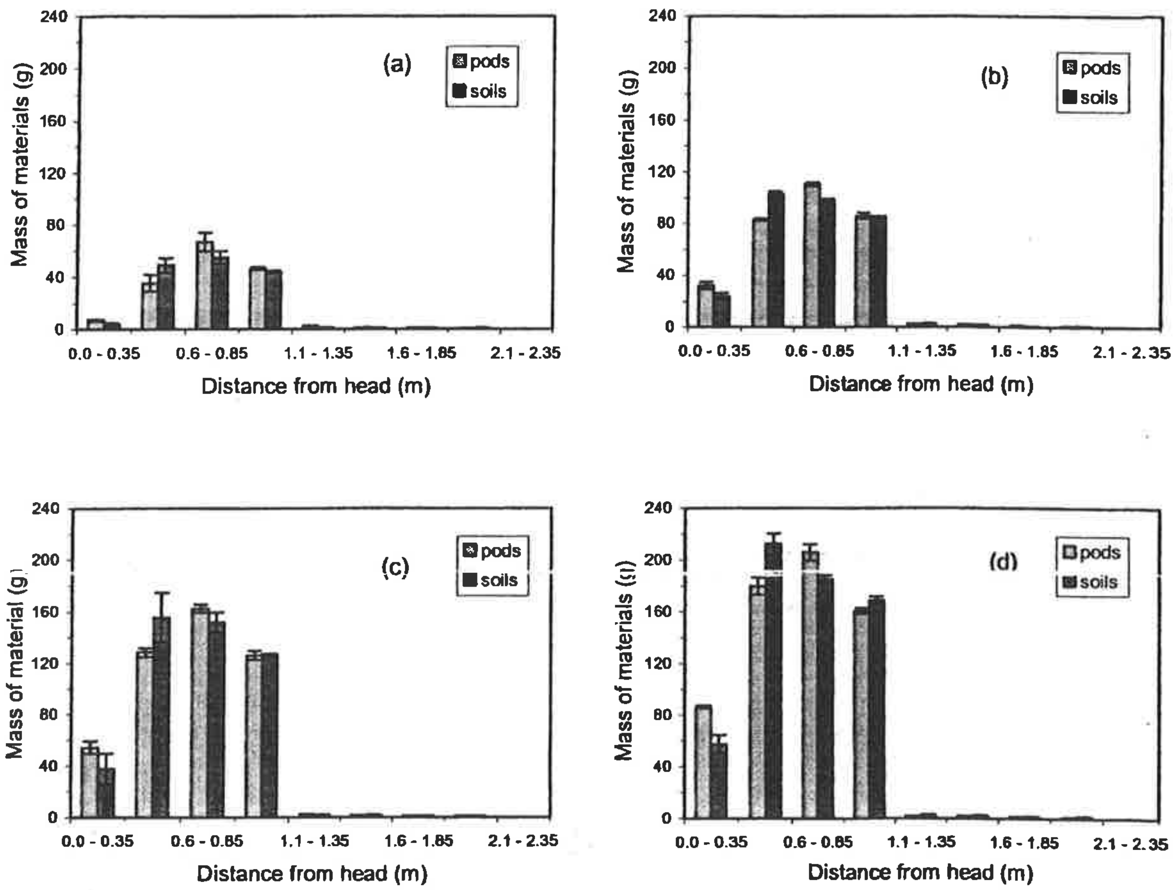


Figure 6.15 Accumulated mass of Paraggio medic pods and soils at different distances from blowing head with face velocity 16.7 m s^{-1}. (a) 40 g, (b) 80 g, (c) 120 g and (d) 160 g of each material.

6.5.2 Pod Displacement

Objective. To determine whether the presence of soil particles has a significant influence on the movement of pods.

Material and Equipment: Experimental equipment and medic pod samples were identical to previous tests.

Experimental Procedure: The procedure for the previous tests was followed to carry out these tests. The tests were performed with 40 g, 80 g and 120 g of pods.

Results and Discussion: The result of this experiment is presented in Table 6.2 and Figure 6.16.

Table 6.2 Accumulated mass of Paraggio medic pods at different distances from the blowing head (D), face velocity 16.7 m s^{-1} , angle 45° and height 100 mm.

	Mass of Paraggio pods (g)		
Dist. (m)	40	80	120
0.0 - 0.35	1.8	14.7	24.2
0.35 - 0.6	11.0	82.0	131.0
0.6 - 0.85	88.8	111.7	175.9
0.85 - 1.1	51.9	101.0	139.0
1.1 - 1.35	3.2	5.2	4.4
1.35 - 1.6	1.3	2.2	1.7
1.6 - 1.85	0.7	1.7	2.0
1.85 - 2.1	0.6	1.0	1.1

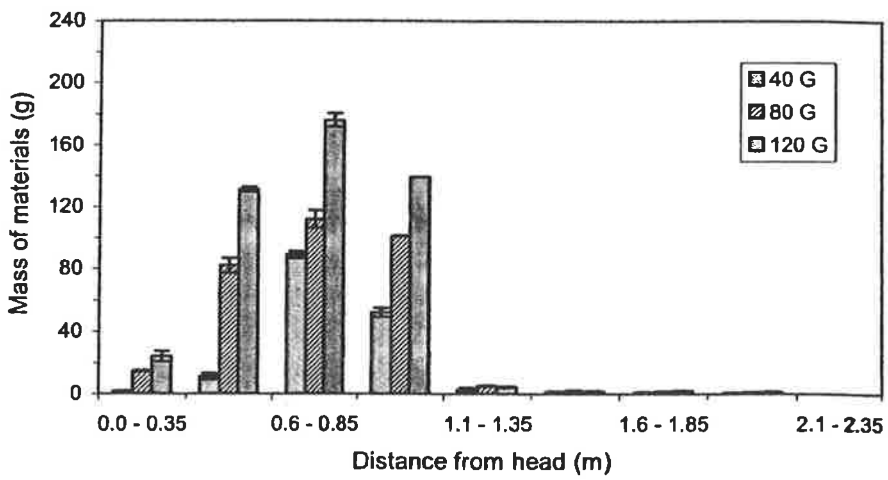


Figure 6.16 Accumulated mass of Paraggio medic pods at different distances from blowing head with face velocity 16.7 m s^{-1} for samples of 40, 80 and 120 g pods.

A comparison of the movement of the 40 g samples of mixture (Table 6.1) and pods alone (Table 6.2) indicates that there is in the latter case a much greater movement from regions 1 and 2, 84% relative to 47%.

For the 120 g samples there is a much smaller difference in the mass of pods being displaced. For the pods only situation, 35% were displaced from regions 1 and 2, whereas in the case of the mixture of pods and soils 24% was displaced.

This is further evidence that the amount of material on the surface influences the velocities that will need to be used in any practical harvester.

6.6 Conclusions

Previous investigation of the terminal velocities of pods and soil particles (Chapter 4) had indicated that velocities for pods existed in a relatively narrow band within the overall range of soil particle velocities and that pod velocities corresponded to those of soil particles of approximately 2-3 mm diameter. Movement in any practical airflow is however complicated by the nature of that airflow and other factors. After carrying out the tests described in this Chapter, it became apparent that the way in which pods and soil particles move along the surface at minimum velocities is a major element for consideration in any design.

Certain test results were more or less as expected, for example the effective distance in blowing flow is much greater than that in suction flow. In blowing flow the ranges of velocities affecting pods and soil particles paralleled those of terminal velocity tests. However in suction flow it appears that pods would have characteristics which are nearer to those of the smallest particle (ie. less than 1.4 mm diameter) rather than those in the 2-3 mm range.

The influence of head height on effective distance is different for blowing and suction flow. In blowing, height does not make a difference, whereas in suction flow, decreasing height reduces the effective distance for all materials.

In blowing flow, as head angle increases, effective distance decreases (as expected); in suction flow effective distance increases. The blowing head angle should be the maximum possible up to the point at which reverse airflow becomes a problem. In suction flow, it is necessary to prevent a high suction velocity from the rear of the head for selective pick-up. It is not possible to suggest an optimum angle at this stage.

Investigating the feasibility of pod and soil separation, for a given face velocity, it appears that in blowing the overall quantity of pods affects their final resting place and that the presence of large soil particles will have a similar effect. Smaller particles (which constitute around 80% of the surface soil) are unlikely to be as big a problem. Possibly the provision of successive pulses of airflow as the harvester advances will progressively reduce surface density of pods (if that density is high).

Chapter 7

FINITE ELEMENT ANALYSIS OF BLOWING FLOW AND IMPLICATIONS FOR HARVESTER DESIGN

7.1 Introduction

The finite element method is now widely used in engineering analysis. Its development since introduction in the 1950's has been made possible by advances in computer technology.

The method is an approximate method of analysis whereby the engineering problem under review (stress analysis, vibration analysis, fluid flow, etc.) is divided up into a finite number of appropriately shaped elements which are presumed to be joined to each other at particular points, called nodes. The equations which govern the behaviour of individual elements are determined and assembled for all elements. Solution is then possible incorporating the boundary conditions which apply to the problem through successive iterations.

Mathematical techniques are utilised to optimise element selection and reduce approximation errors. The method and applications are covered in many texts (eg., Zienkiewice and Taylor 1989 and Zienkiewice and Taylor 1991).

There are many commercial software packages available, increasingly more sophisticated and user-friendly. Nevertheless experienced operators are necessary to generate solutions that can be accepted as offering realistic answers, not only in terms of knowledge of the particular package but also in their knowledge of the values of the variables that must be entered (physical properties, empirical properties, etc).

Software packages usually include a pre-processor for development of the mesh of elements and a post-processor for equation solution.

Fortunately in terms of the analysis to be undertaken, experimental evidence already existed for the behaviour of single blowing heads, so that the first step of model validation was possible before progressing to more complex situations.

The three stages in the analysis were:

- *Free air jet*: Velocity distribution of a rectangular head (D) in free air jet mode.
- *Wall air jet*: Velocity distribution of inclined head (D) impinging on a surface at three different head set-up angle as 20°,40° and 60° from the horizontal surface.
- *Head arrangement*: Combinations of three heads (D) impinging on a surface to optimise medic pod collection.

The computer simulation was undertaken by Mr. Matthew Arbon, final-year honours Mechanical Engineer Degree student. Mr. Arbon has offered the following notes on the software package and the steps involved in obtaining the velocity diagrams (Section 7.2) for the author's interpretation and subsequent discussion (Sections 7.3).

7.2 Details of Finite Element Simulation

A computer simulation of the airflow from head (D) was performed using the package Fluent and it's pre-processor Gambit. The software is the product of Fluent Incorporated, Centerra Resource Park, Lebanon. A full description of the theory and variables involved and programming implementation can be found in the manuals, Fluent 5 User Guide Vol 1-5 (1998) and Fluent 5 Tutorial Guide Vol 1&2 (1998).

Using Gambit, the boundaries of the model were created and the faces patched together to form a volume. The volume is meshed automatically to create a relatively coarse mesh of tetrahedral / hybrid elements. Then the boundary types were specified for each boundary face and the mesh exported to Fluent.

In fluent, the inlet velocity to the system is specified. In this case a velocity of 25 m s^{-1} was specified at a distance of 500 mm in advance of the outlet (ie head) to allow the velocity distribution at the outlet to be fully developed. The head installation and sections used in computer simulation are given in Figure 7.1.

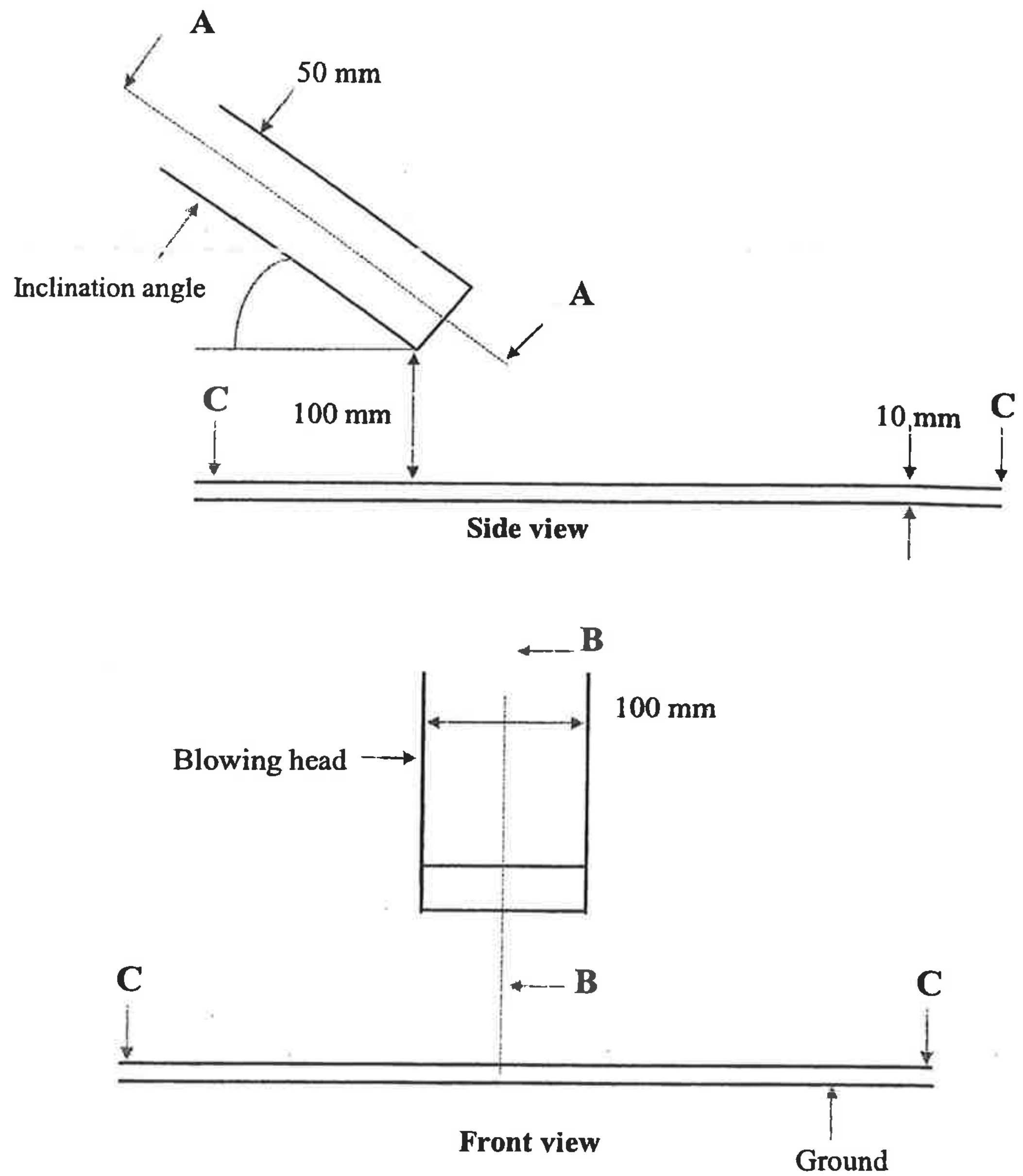


Figure 7.1 A diagram of the head installation and sections used in computer modelling

Discussions with the software consultant led to the selection of the following parameters:

* The standard K-ε, model was used. This is a semi-empirical model based on model transport equations for the turbulent kinetic factor (K) and its dissipation rate (ε). This model assumes the flow to be fully turbulent and the molecular velocity to be negligible.

* An appropriate "friction factor" along the impacting surface could be expected by using a roughness constant of 0.5. The "friction factor" is a complex matter in this type of flow - the roughness constant of 0.5 is equivalent to the surface of a pipe roughened with tightly packed uniform sand grains.

* Air density 1.225 kg m^{-3} and viscosity 1.7894×10^{-5} kg $m^{-1}s^{-1}$.

Once the appropriate parameters are entered the iterations are performed automatically until the residuals of x, y and z velocities as well as K and ε, reach the limit of 10^{-3}. This means that the differences in the values of successive iterations for every element in the mesh is less than 0.1%. At this time the coarse mesh has been solved and it is appropriate to refine the mesh along walls and other areas of large velocity gradient. The finer mesh of elements is based on values of velocity gradient being no more than 10% of the greatest velocity gradient in the model.

The velocity contours produced are examined and if deemed unacceptable another grid mesh adaptation is performed. In most cases this was not required.

The results achieved have been presented in terms of velocity contours (colours joining points of equal velocity), velocity vectors (arrows showing the magnitude and direction of velocity at specified points) and airflow path lines (the paths followed by individual molecules of air).

Velocity contours, vectors and path lines are viewed for the sections as specified in Fig. 7.1.

7.3 Results and Discussion

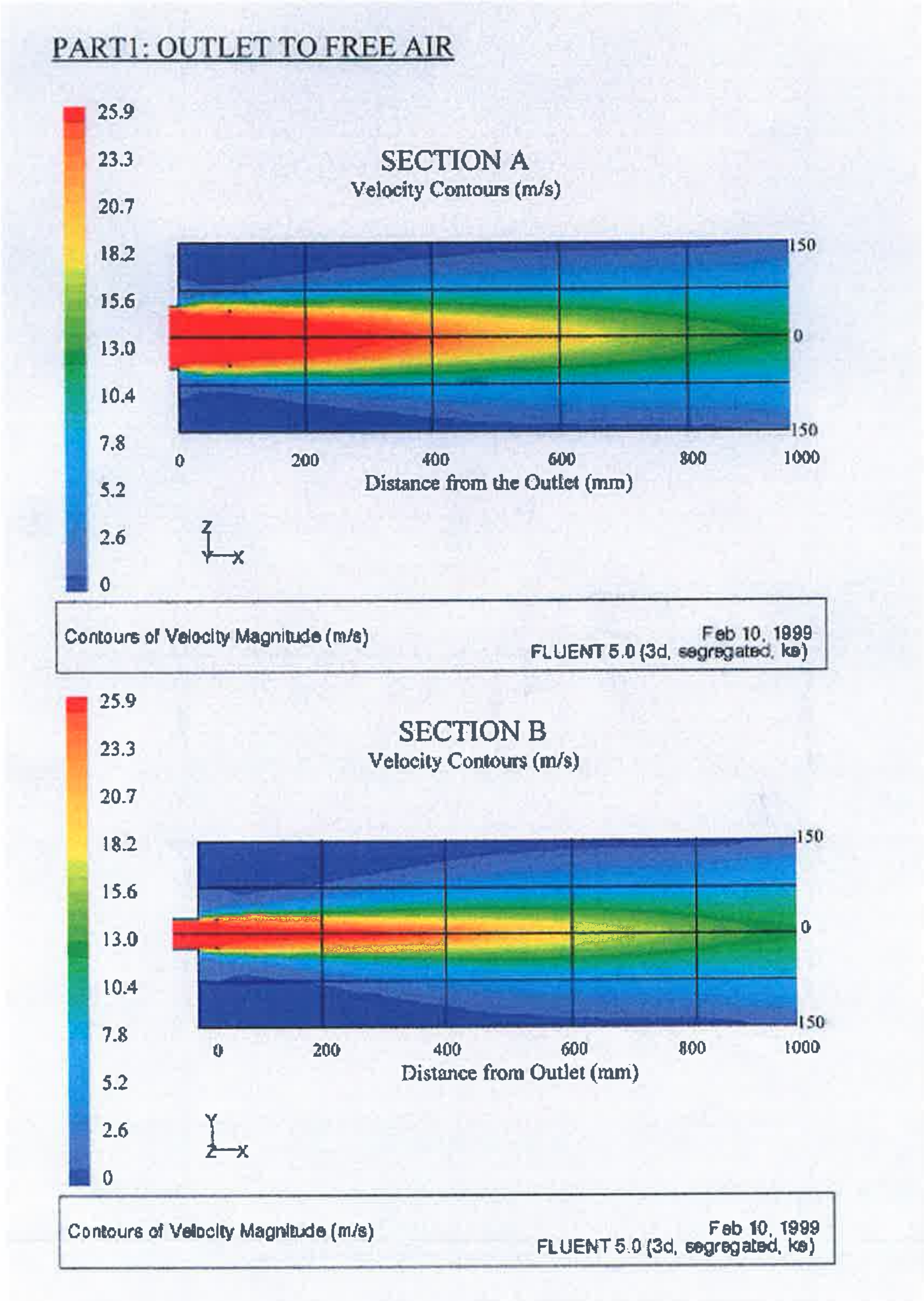


Figure 7.2 Computer simulation of the free air jet delivered from rectangular blowing head (D) in terms of velocity contours, (a) at section A and (b) at section B

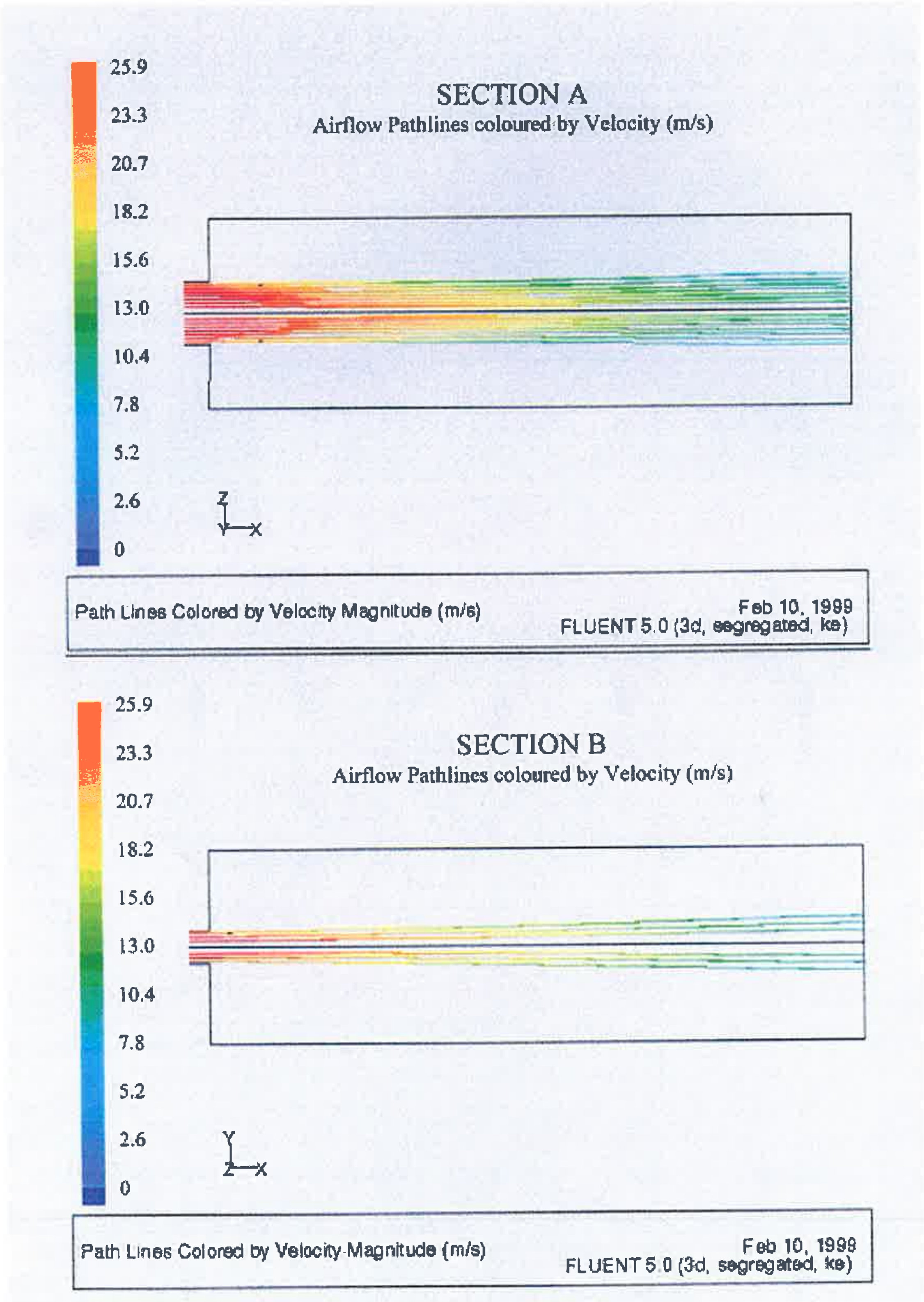
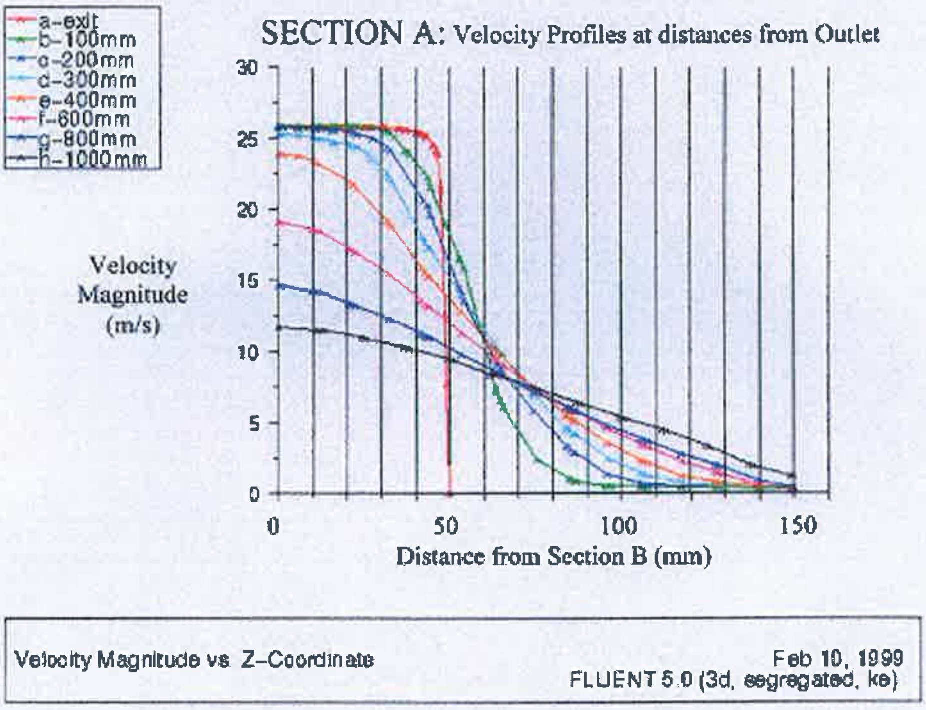


Figure 7.3 Computer simulation of the free air jet delivered from rectangular blowing head (D) in terms of air flow pathlines, (a) at section A and (b) at section B



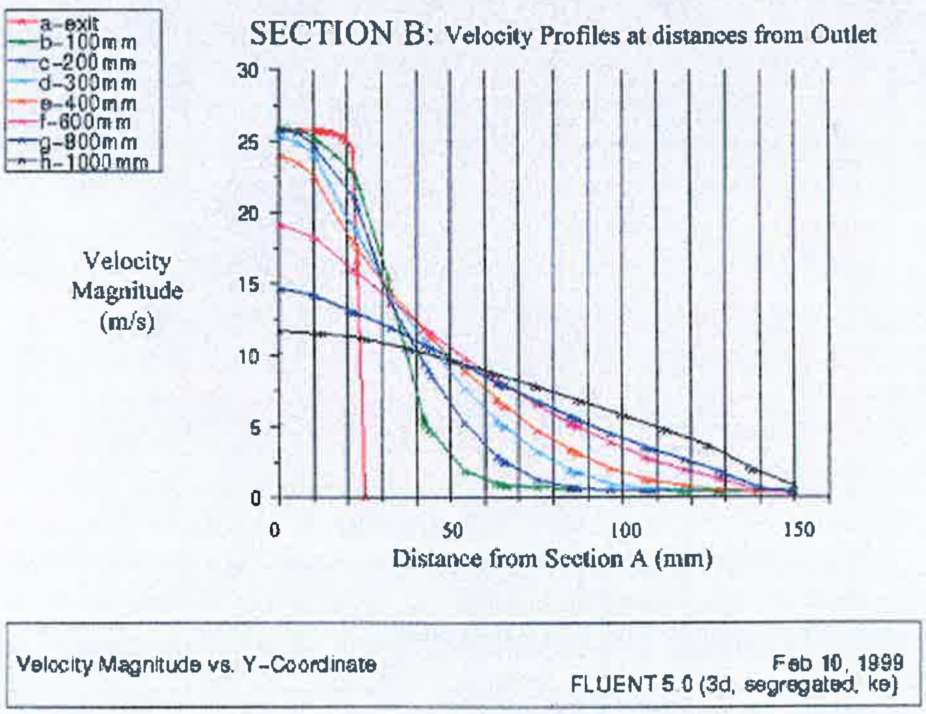


Figure 7.4 Computer simulation of the free air jet delivered from rectangular blowing head (D) in terms of velocity profiles at different distances from head, (a) at section A and (b) at section B

7.3.1 Free Air Jet - Model validation

The result of the simulation of a 100×50 mm rectangular head blowing into free air is presented as velocity contours (Fig. 7.2a and b), airflow path lines of particles leaving the head (Fig. 7.3a and b) and velocity profiles for sections at distances from the outlet up to 1000 mm (Fig. 7.4a and b). These figures can be compared to the experimental data of Figs 5.5 and 5.4. Initial inspection indicates general similarity in the nature of the resultant airstream - the axial decay and widening of the airstream with distance. Relative numerical values obtained for the experimental and simulated tests, comparing axial velocity decay and velocity profile at a distance of 600 mm. from the head are shown in Figs 7.5 and 7.6.

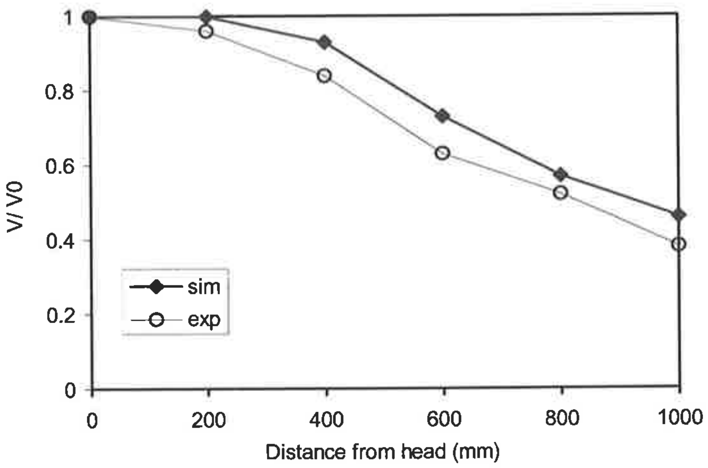


Figure 7.5 Velocity decay relative to head velocity for a free air jet.

In Fig. 7.5 where velocities in both cases are referred to the head velocity, the simulated values are in the order of 10% greater than the experimentally measured quantities.

In Fig. 7.6 it can be seen that the simulated velocity profile is a little flatter than the experimental one, however the half - velocity points are at the same distance from the axis.

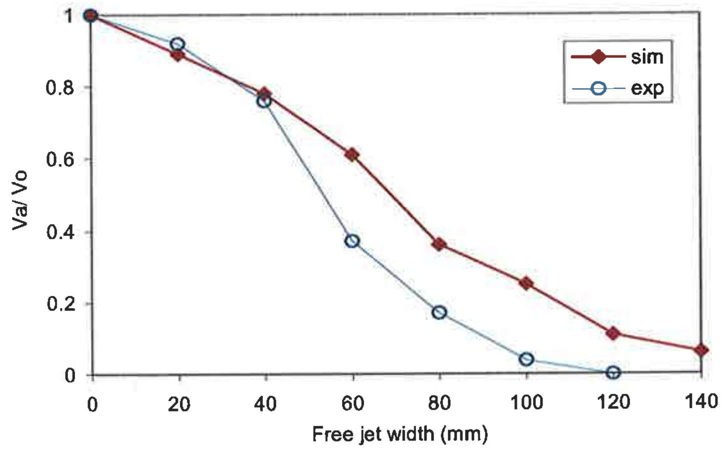


Figure 7.6 Velocity profile for a section 600 mm from head (actual velocity relative to centre line velocity) for a free air jet.

Thus from the first test, the simplest situation, it is clear that velocity magnitudes will differ by up to 10% for the velocity in these regions of practical significance.

The readers attention is drawn to the regions around the main jet which indicate the presence of velocities between the jet produced and the more distant space of zero velocity.

7.3.2 Wall Jet Characteristics - Model validation

Experimental evidence had already indicated that an inclined jet impinging on a surface produced a complex airflow and that small changes in parameters such as head inclination could have a marked impact on velocity magnitudes and directions. Consequently the simulation was carried out for 3 arrangements, at head inclinations of 20°, 40° and 60° at a single head height of 100 mm. (Figs. 7.7 to 7.15), beginning with the 40° case. These values can be compared to experimental values for a head inclined at 33° with height of 120 mm. (Fig. 5.25).

The relative numerical values obtained for centre line velocity decay (Fig. 7.16) indicate similar decay slopes for the experimental and simulated cases. The magnitude of the experimental velocity result however is greater than that which would have been predicted for a 33° inclination, particularly closer to the head. At this point it needs to be remembered that the computer simulation was based on a 10 mm height above the surface. Increasing the height to 15 mm. would have produced greater magnitudes.

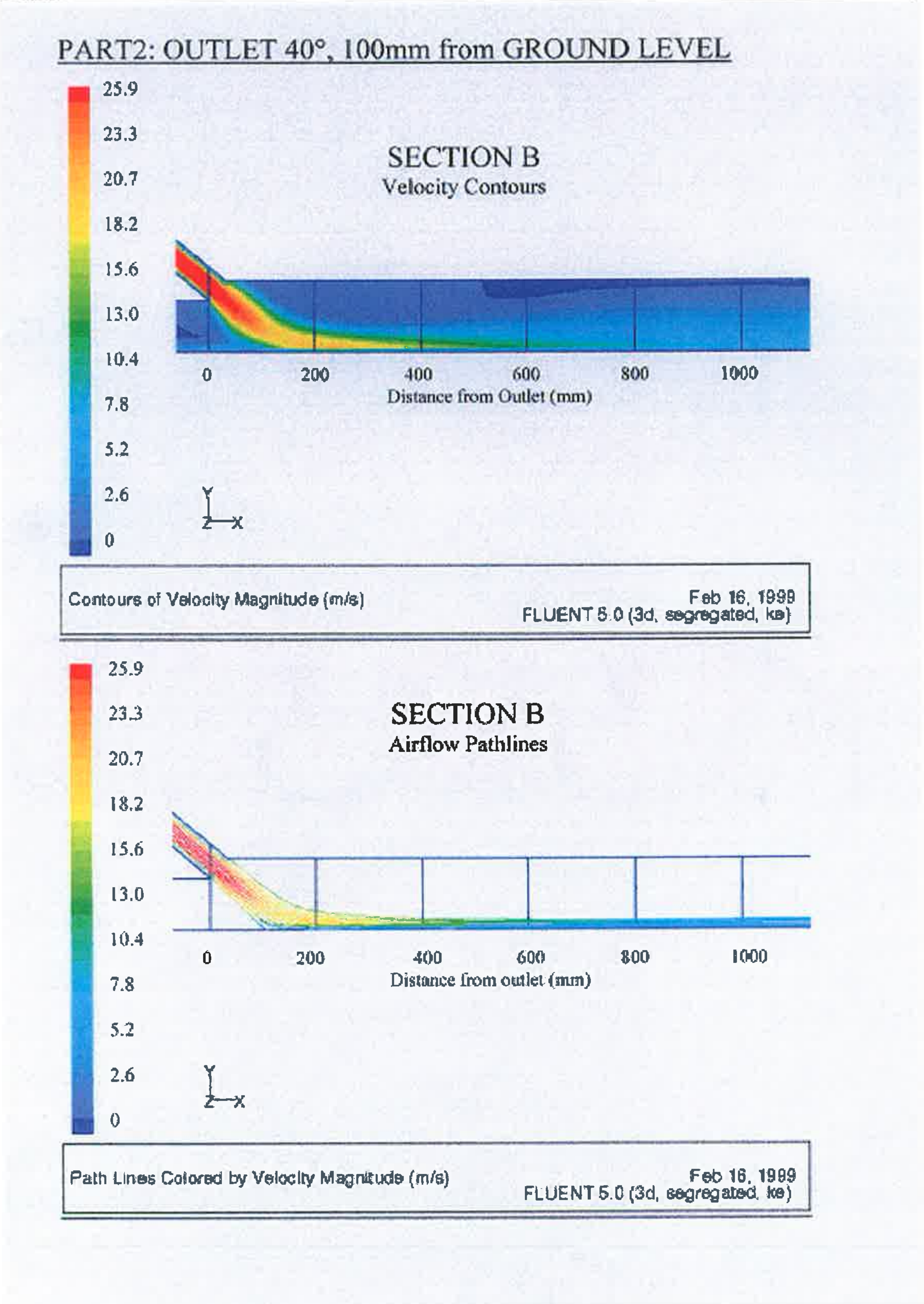


Figure 7.7 Computer simulation of the blowing head (D) with 40° inclination and 100mm height. Section view of (a) velocity contours and (b) airflow pathlines.

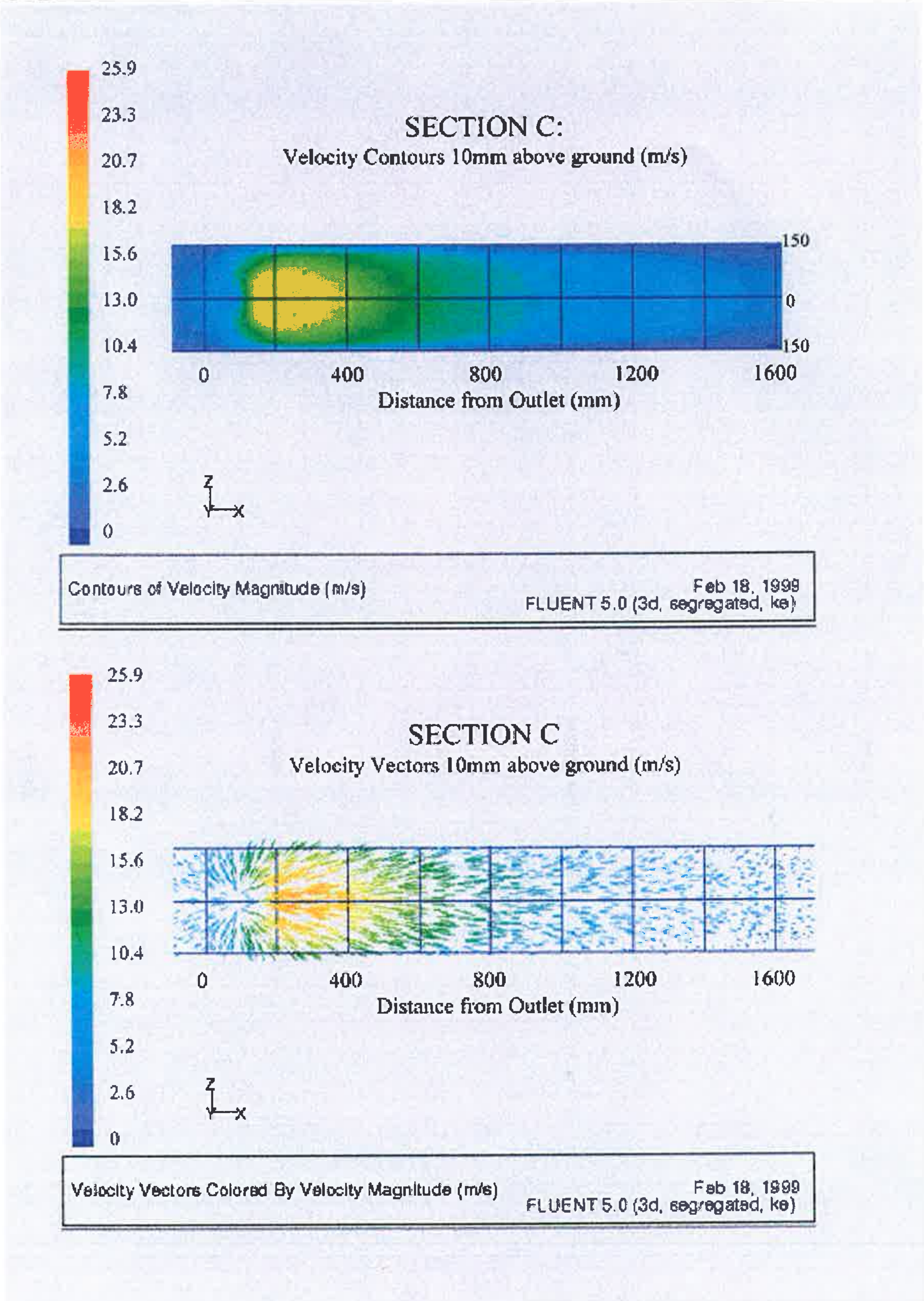


Figure 7.8 **Computer simulation of the blowing head (D) with 40° inclination and 100mm height. Plan view of (a) velocity contours and (b) velocity vectors 10mm above** ground.

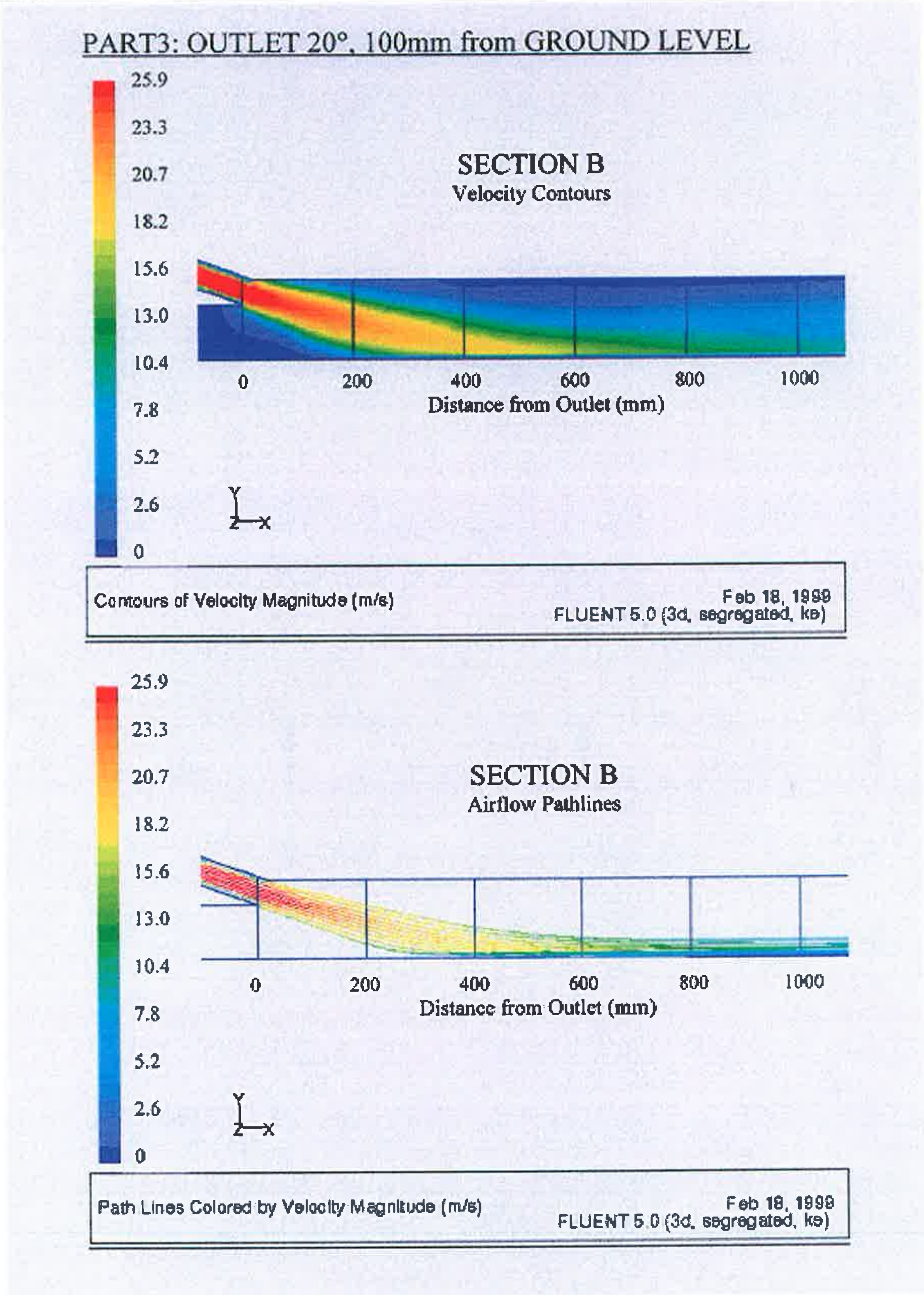
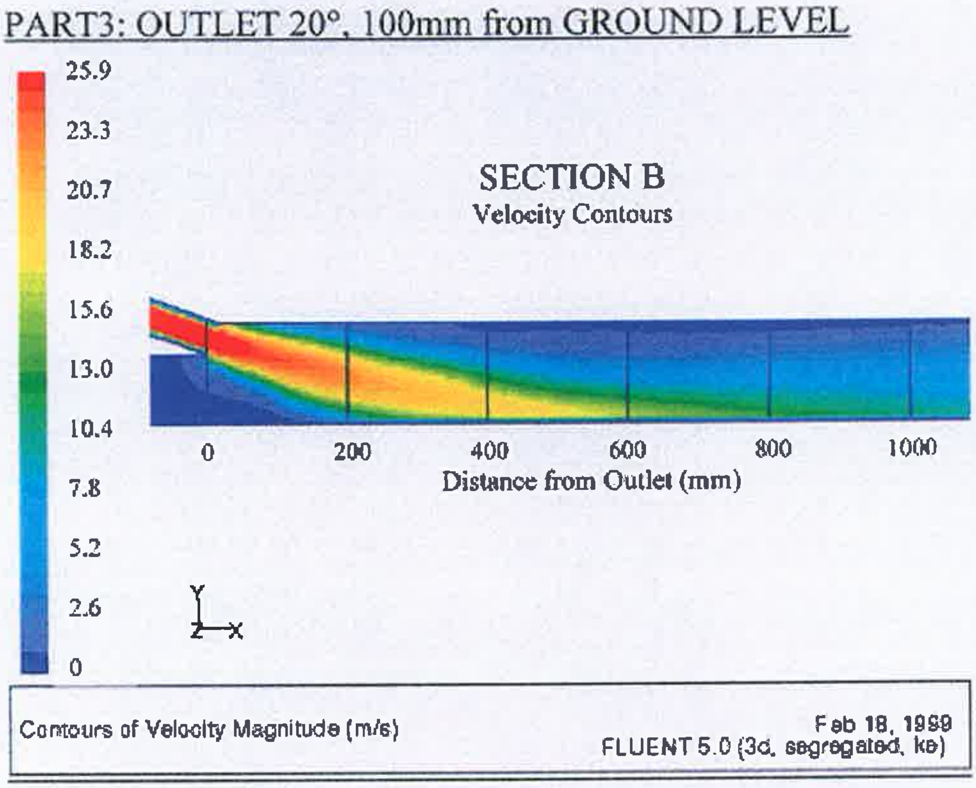


Figure 7.9 Computer simulation of the blowing head (D) with 40° inclination and 100mm height in terms of velocity magnitudes at different distances from head.



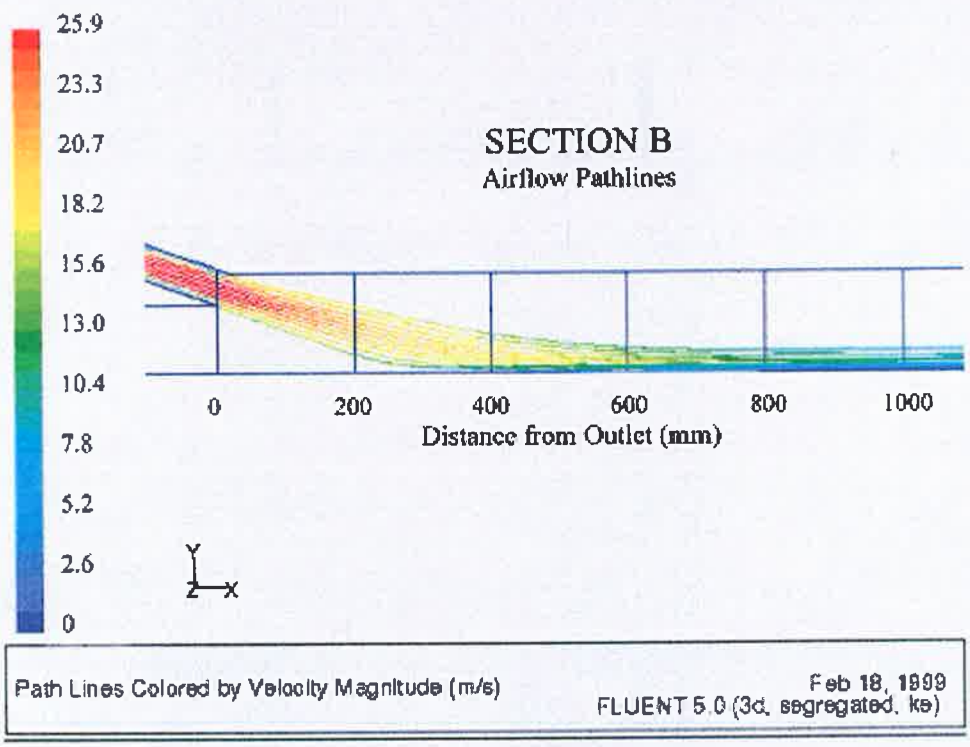
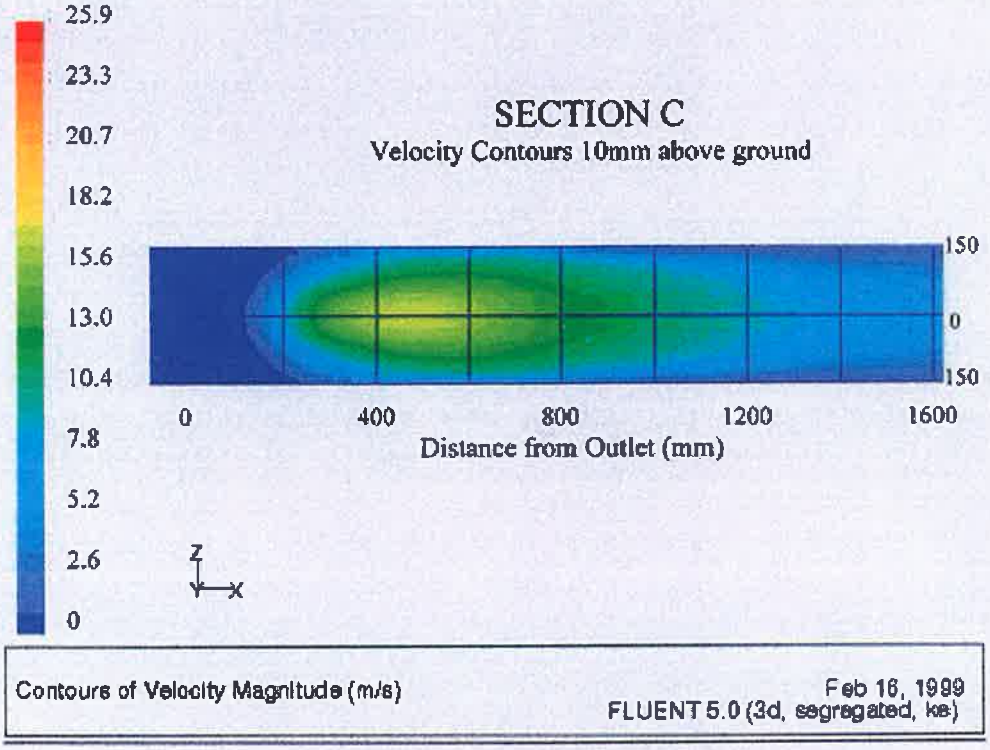


Figure 7.10 Computer simulation of the blowing head (D) with 20° inclination and 100mm height. Section view of (a) velocity contours and (b) airflow pathlines.



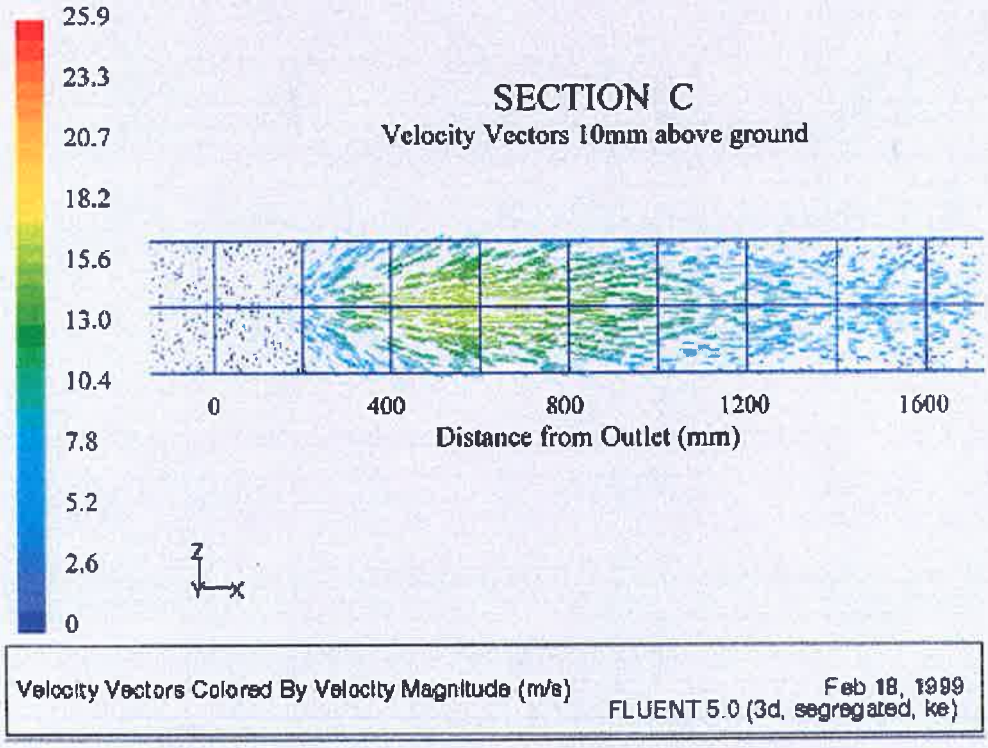


Figure 7.11 Computer simulation of the blowing head (D) with 20° inclination and 100mm height. Plan view of (a) velocity contours and (b) velocity vectors 10mm above ground.

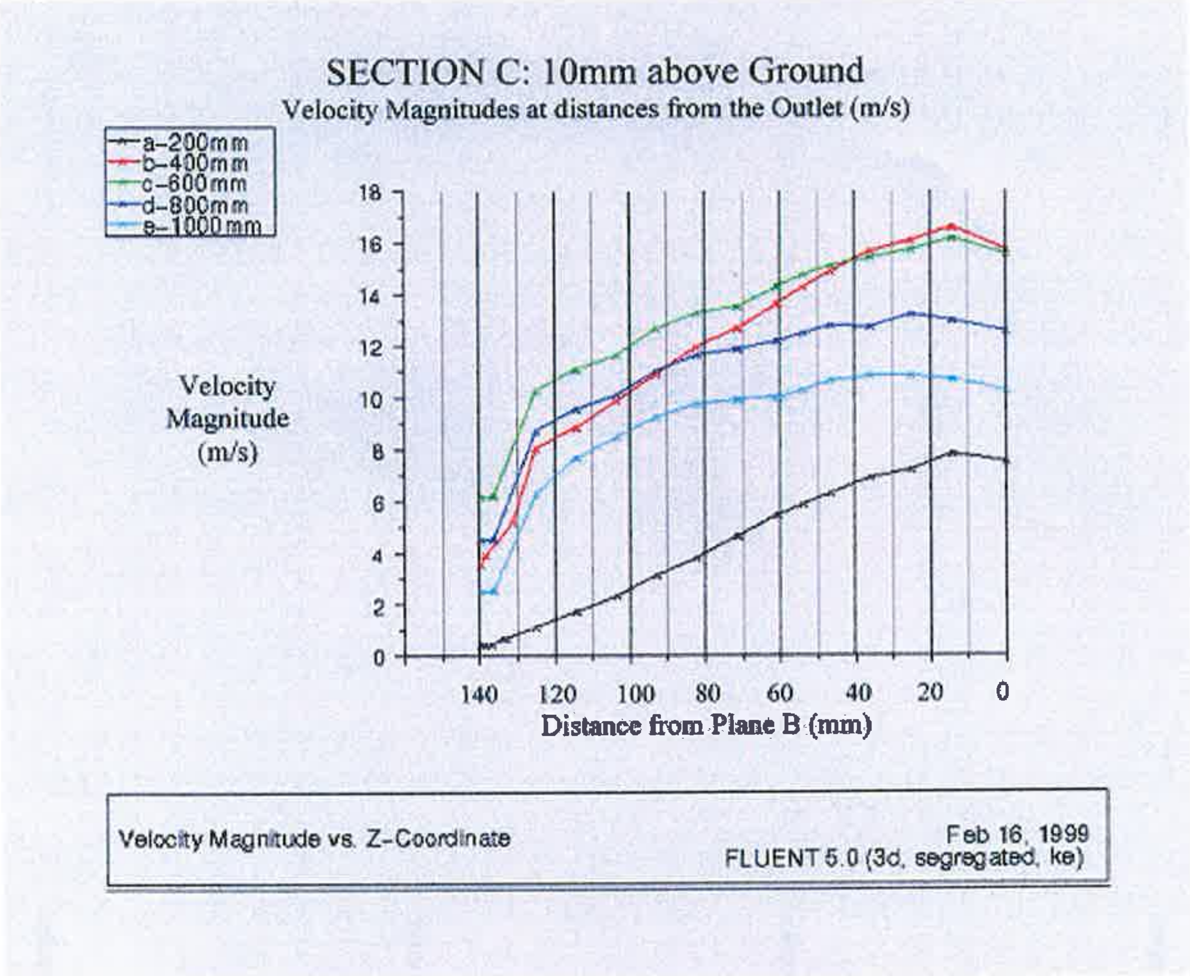


Figure 7.12 Computer simulation of the blowing head (D) with 20° inclination and 100mm height in terms of velocity magnitudes at different distances from head.

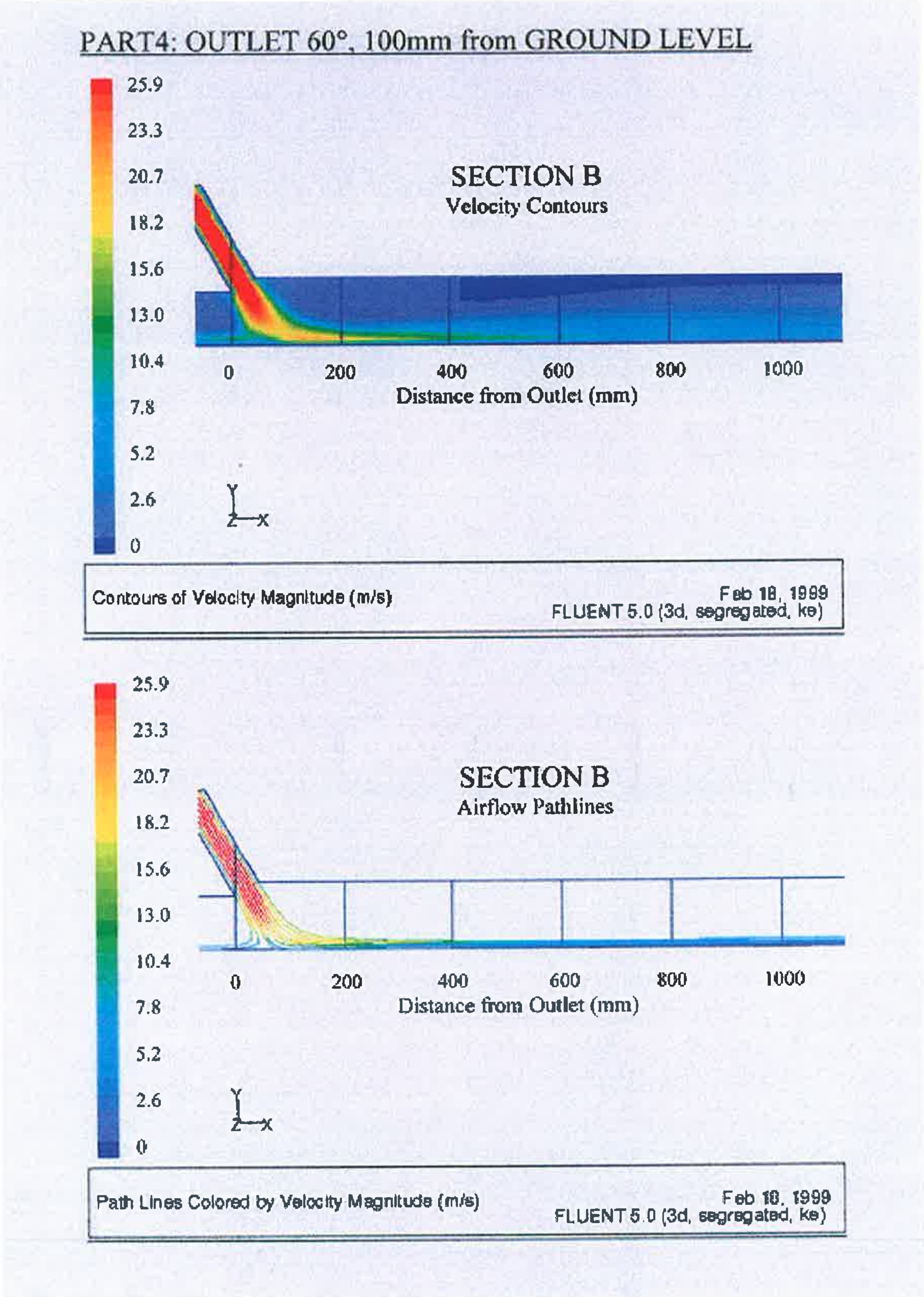


Figure 7.13 Computer simulation of the blowing head (D) with 60° inclination and 100mm height. Section view of (a) velocity contours and (b) airflow pathlines.

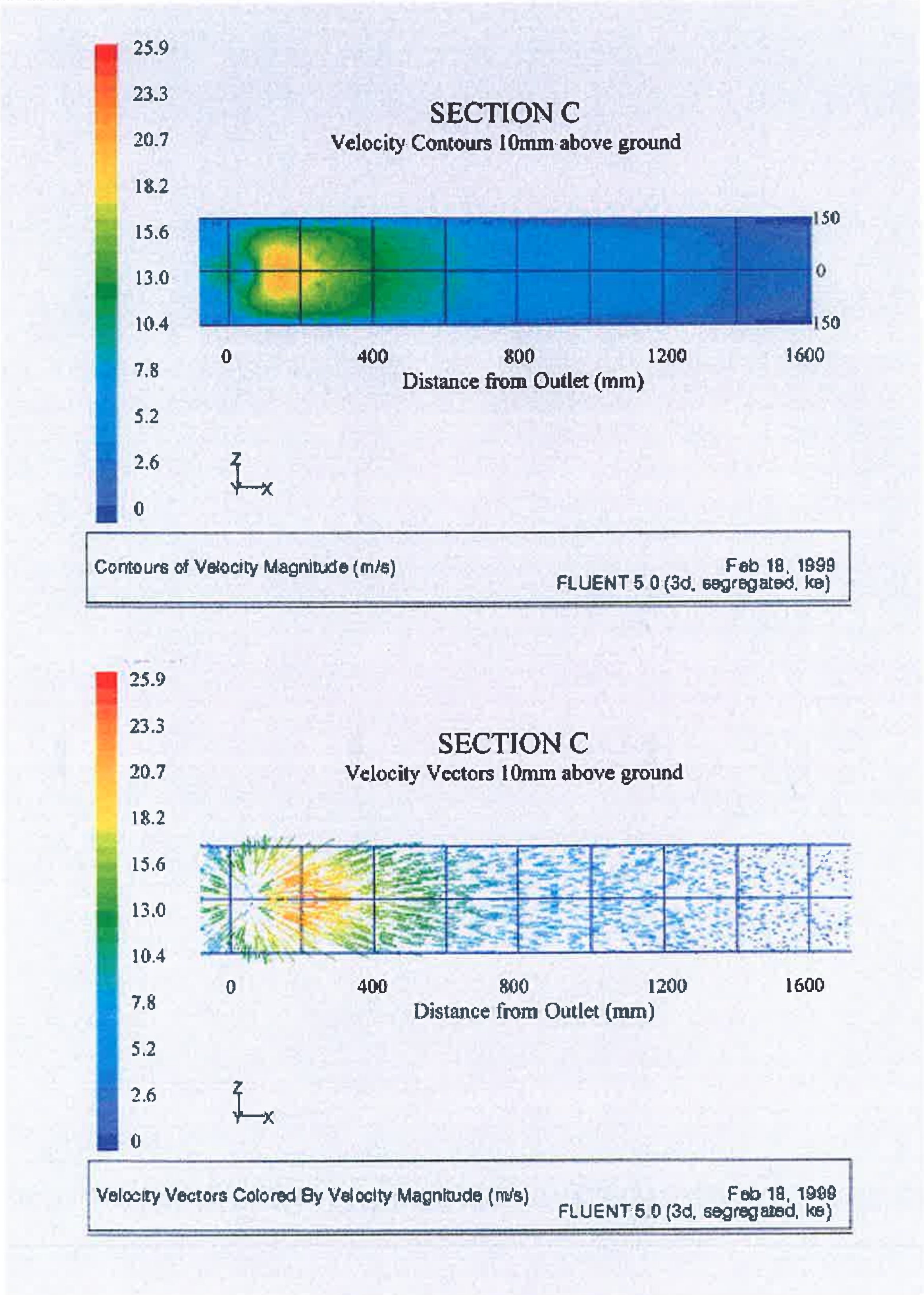


Figure 7.14 Computer simulation of the blowing head (D) with 60° inclination and 100mm height. Plan view of (a) velocity contours and (b) velocity vectors 10mm above ground.

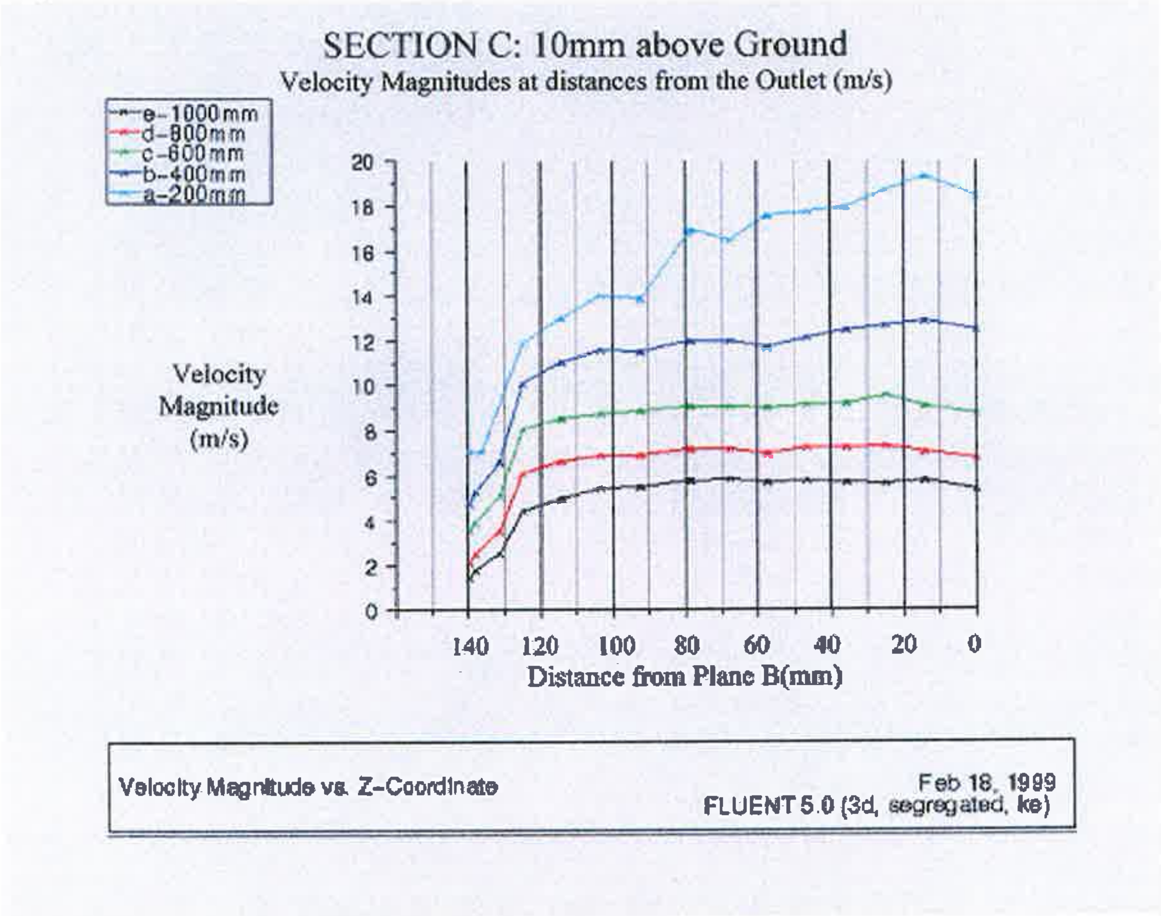


Figure 7.15 Computer simulation of the blowing head (D) with 60° inclination and 100mm height in terms of velocity magnitudes at different distances from head.

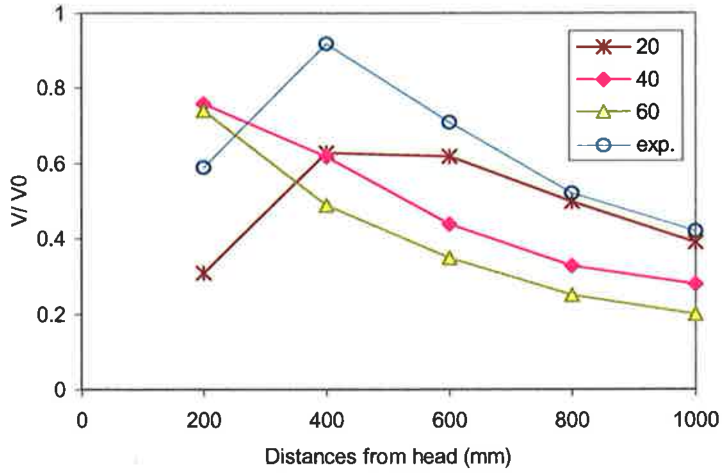


Figure 7.16 Velocity decay comparing simulation values to experimental results.

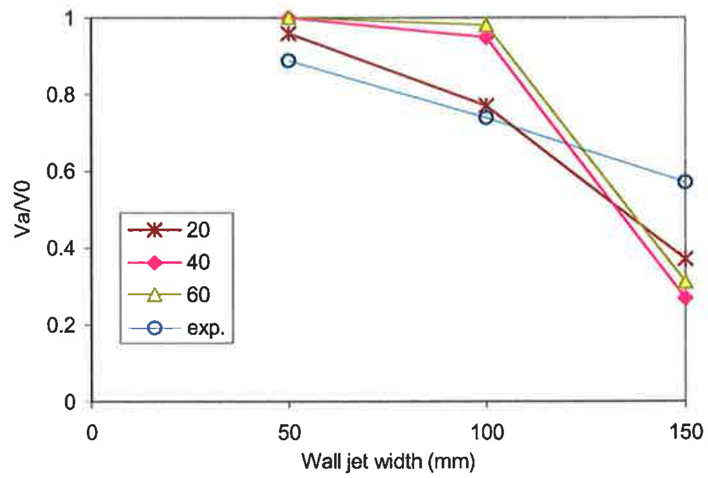


Figure 7.17 Velocity profile comparing simulation value to experimental result.

The lateral profiles at a distance of 600 mm. from the head are given in Fig. 7.17. In this case magnitudes closer to the centre line (up to 120 mm.) are similar, but the experimentally derived results indicate much greater width. Further examination of the simulated output shows an extremely rapid drop off in magnitude beyond the 120 - 140 mm. distance from the centre line suggesting that the lateral distance examined may have been inadequate.

7.3.3 Conclusion of Model Validation

Whilst greater similarity of velocities and velocity profiles would have been preferred, the author is satisfied that the computer simulation reasonably reflects the experimental results and that substantial additional knowledge can be obtained by examining computer simulations of multiple blowing head designs.

7.3.4 Characteristics of the Wall Jet Produced by a Single Head at Different Inclinations

With reference to Figs 7.7 to 7.15:

* the vertical velocity profile changes rapidly from immediately above ground surface from zero to a maximum value.

* a low inclination angle (eg., 20°) means that an air stream will have a higher velocity over a greater horizontal distance.

Inclination in degrees	Distance along centre line of velocity 12 m s^{-1} to 12 m s^{-1}
20	640 mm
40	470 mm
60	340 mm

* the lateral width of the airstream is also affected.

Inclination in degrees	Lateral distance of velocity 12 m s^{-1} to 12 m s^{-1}
20	195 mm
40	255 mm
60	270 mm

* velocity directions can be approximately predicted by identifying a centreline first point of impingement on the surface and radiating outwards (Fig. 7.18).

* A reverse velocity is generated at impingement for steeply inclined heads.

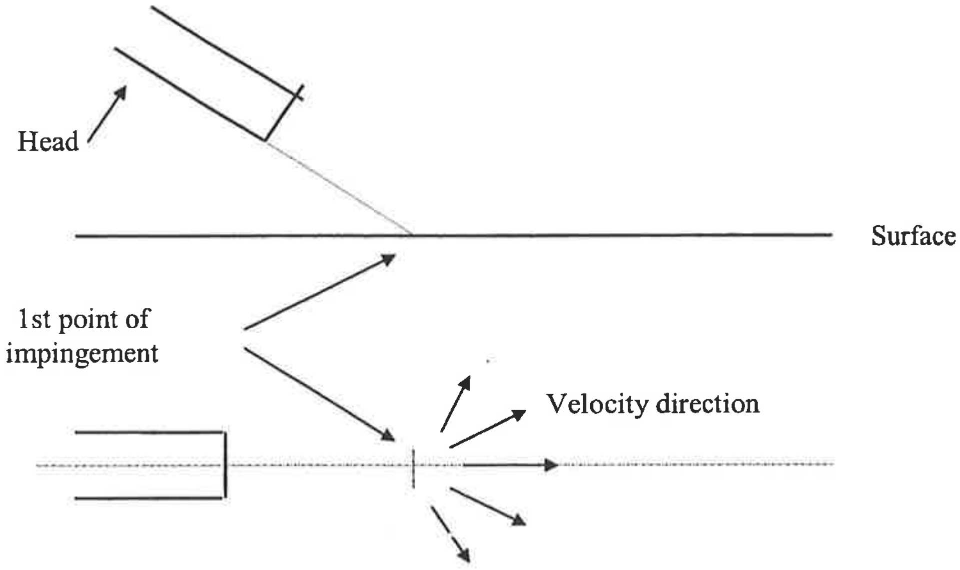


Figure 7.18 Velocity directions related to an impinging jet

7.3.5 Characteristics of the Airstream Formed by Multiple Heads

In combining multiple heads to create a particular airstream, the designer has many variables to consider, for example, head inclination, head height, relative location of heads, input velocities, etc. for the purpose of this section the guiding parameters were:

* The system would create an airstream in which velocities of 8 to 13 m s^{-1} existed at critical locations.

* The airstream formed would operate over a distance that would be useful in a practical harvester, say 1.5 m to 2 m.

Each system chosen involved 3 heads with the separation between heads in the 'x' direction being 500 mm. (Fig. 7.19).

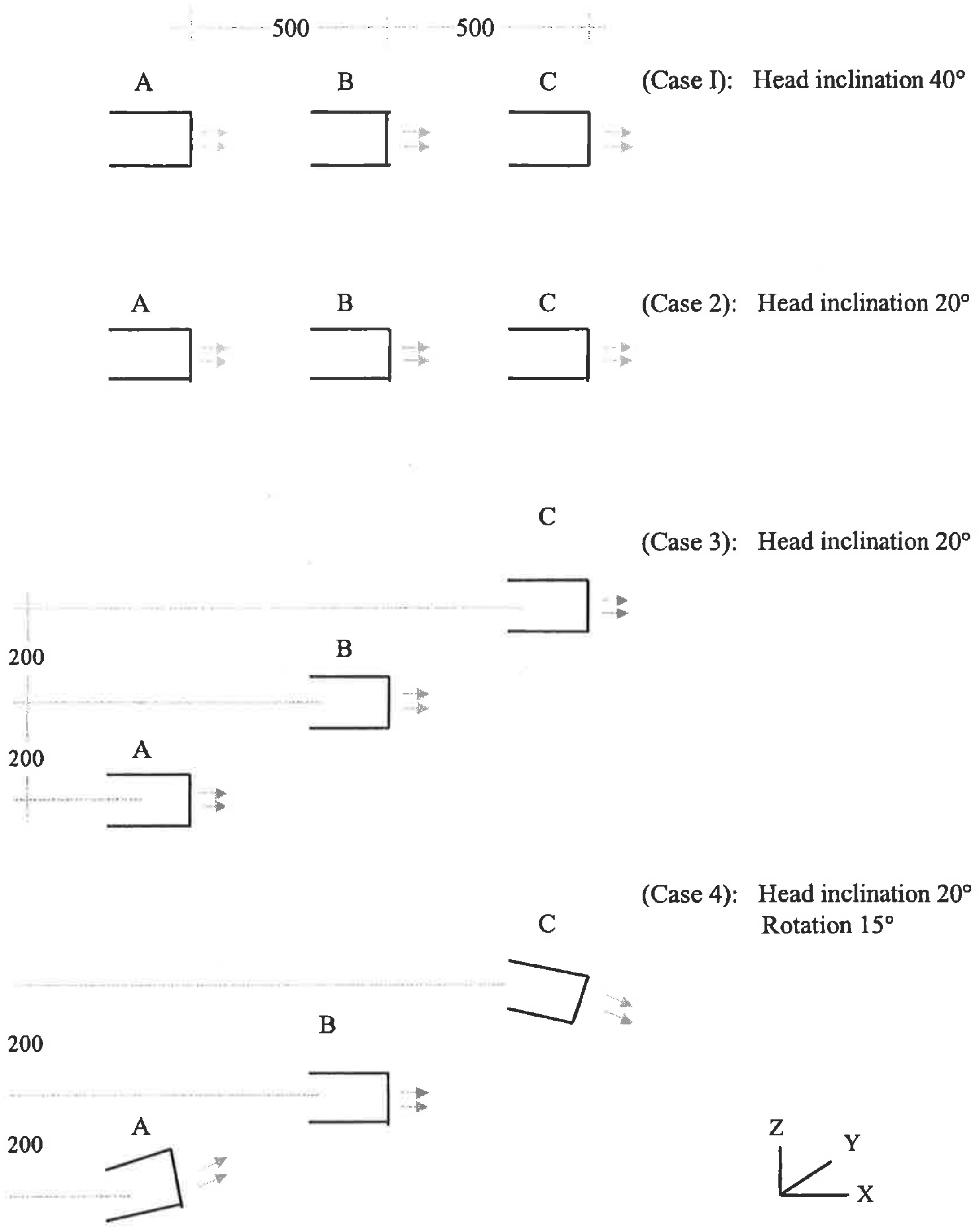


Figure 7.19 Head arrangements used to study the characteristics of multiple head airstreams.

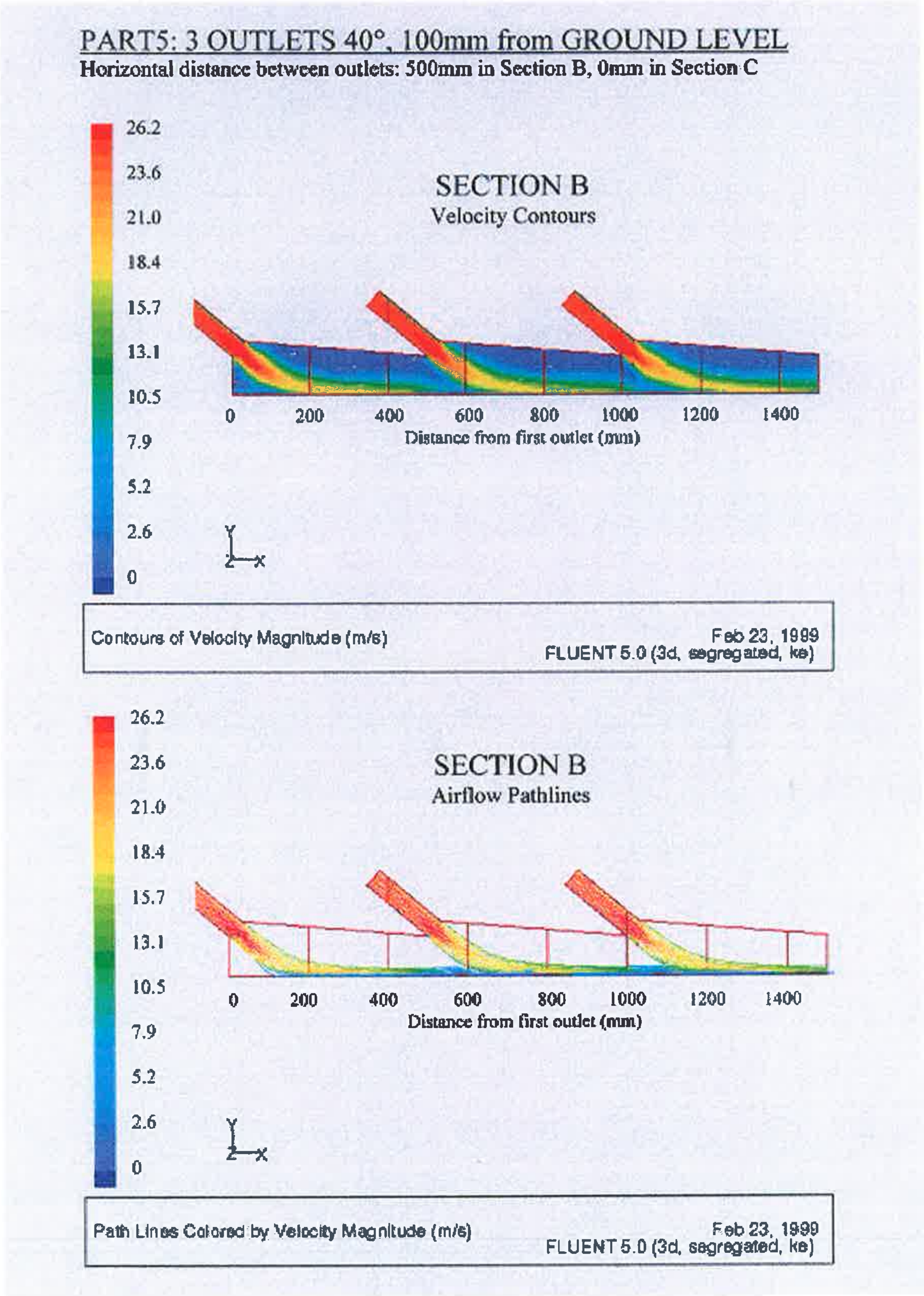


Figure 7.20 Computer simulation of three blowing heads (D) (40° inclination and 100mm height) in a common axial line. Section view of (a) velocity contours and (b) airflow pathlines.

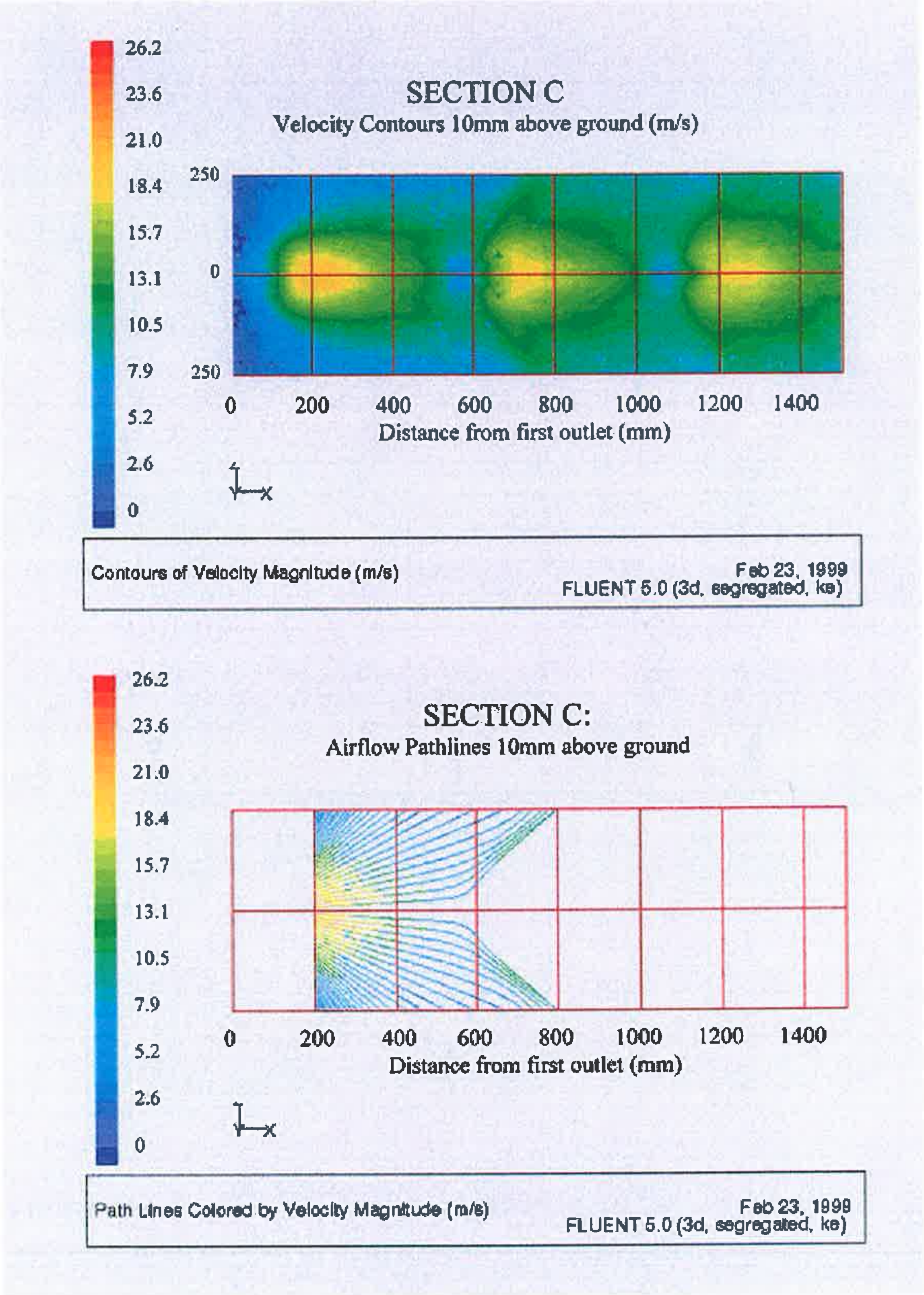


Figure 7.21 Computer simulation of three blowing heads (D) (40° inclination angle and 100mm height) in a common axial line. Plan view of (a) velocity contours and (b) airflow pathlines.

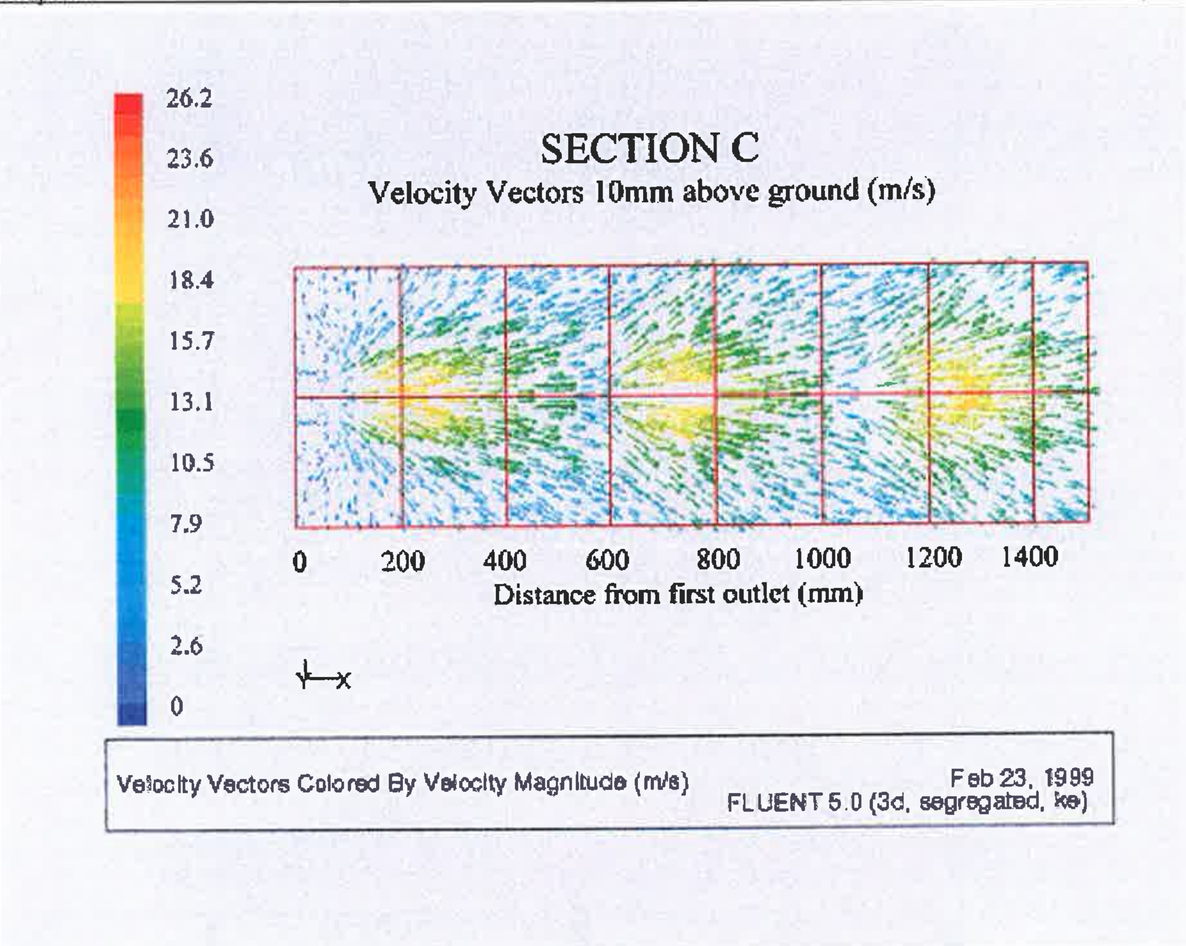


Figure 7.22 Computer simulation of three blowing heads D (40° inclination angle and 100mm height) in a common axial line. Plan view of velocity vectors.

Case 1: The first simulation performed was based on the 3 heads having an inclination of 40° (Figs. 7.20 to 22). It can be clearly appreciated (Fig. 7.22) that this system does not fully satisfy the guiding criteria – axial coverage is of the order of 1.4 m, and more importantly, there are gaps in the velocity distribution where velocities fall below the lower limit. Also of note is the way in which path lines of air particles from head A are diverted around head B increasing the angle away from the centre line.

Case 2: Decreasing head inclination angle to 20° (Fig. 7.23 to 25) overcomes the problems associated with the first case, namely, appropriate velocities exist in a stream that extends some 2 m without substantial gaps.

The airstream produced may have other benefits:

* there are high velocities at vertical distances of 150 to 50 mm. above ground surface with directions that are generally downwards (Fig. 7.23a).

* the velocity at 10 mm. elevation increases with distance from head A (Fig. 7.24a) and occurs over a greater width.

* the velocity directions do not diverge markedly from the centre line and are more predictable (Fig. 7.25).

Case 3: if the heads are now separated in the 'Y' direction by 200 mm. (Fig. 7.26) the result is an airflow which will satisfy the criteria (remembering that the harvester is moving) but is one in which there are no regions of the higher velocities at ground level. Reasonable velocities are present over a greater width in the lateral direction. In addition:

* there are higher velocities up to heights of 100 to 50 mm. (Fig. 7.26a), but no longer in one continuous line.

* velocity directions in useful velocity ranges are in the 'X' direction (parallel to the centre line) (Fig. 7.27).

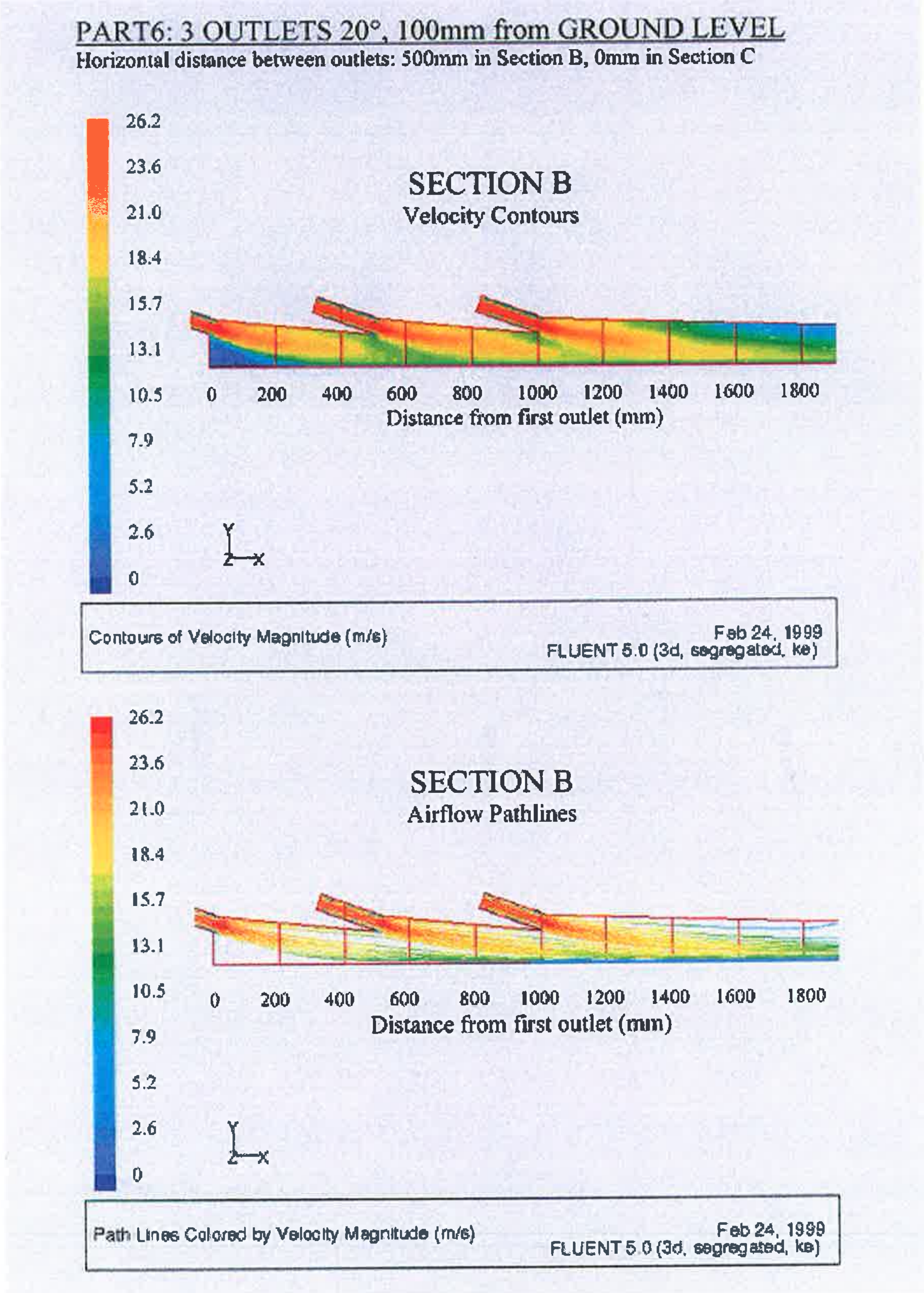


Figure 7.23 Computer simulation of three blowing heads (D) (20° inclination and 100mm height) in a common axial line. Section view of (a) velocity contours and (b) airflow pathlines.

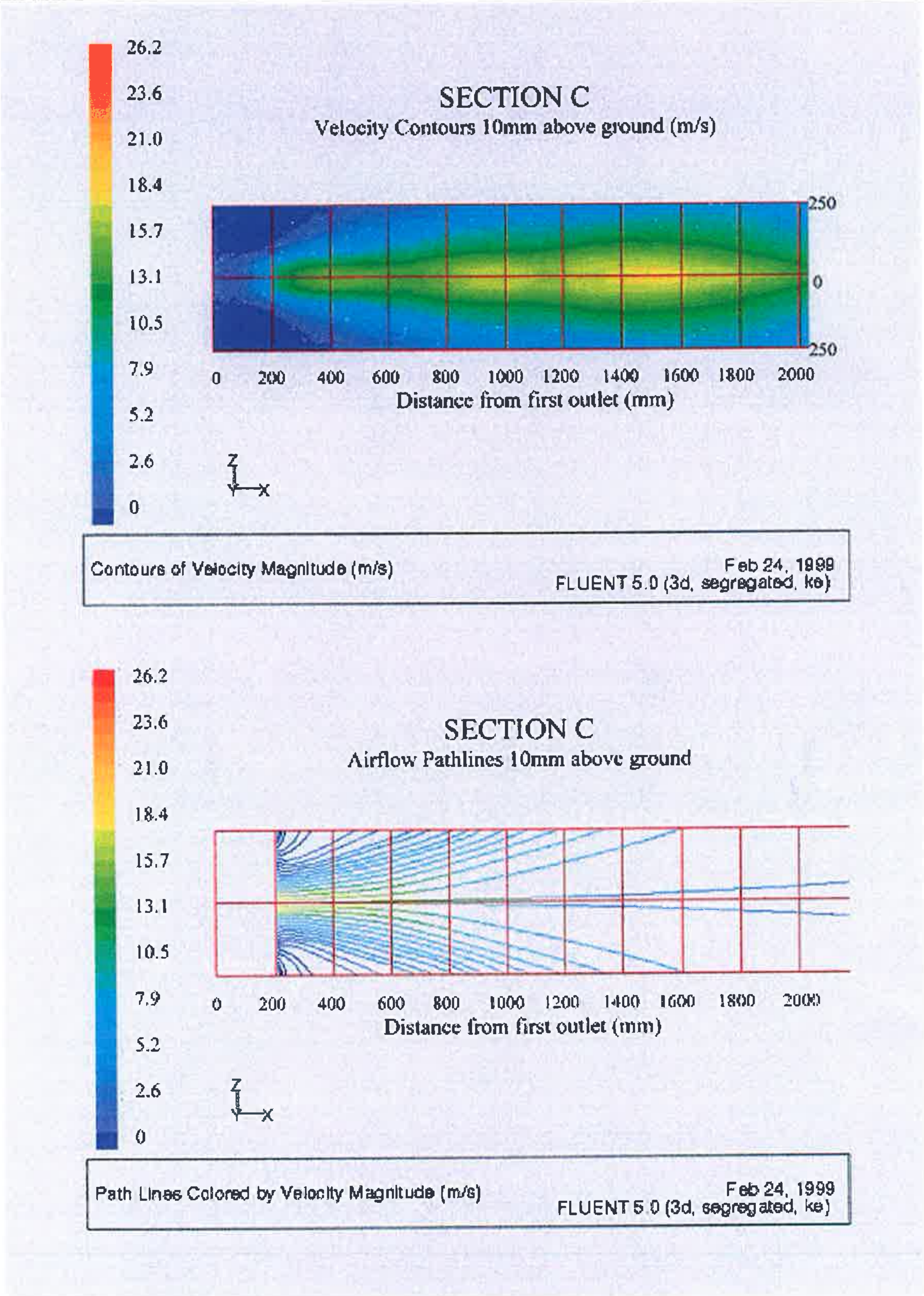


Figure 7.24 Computer simulation of three blowing heads (D) (20° inclination angle and 100mm height) in a common axial line. Plan view of (a) velocity contours and (b) airflow pathlines.

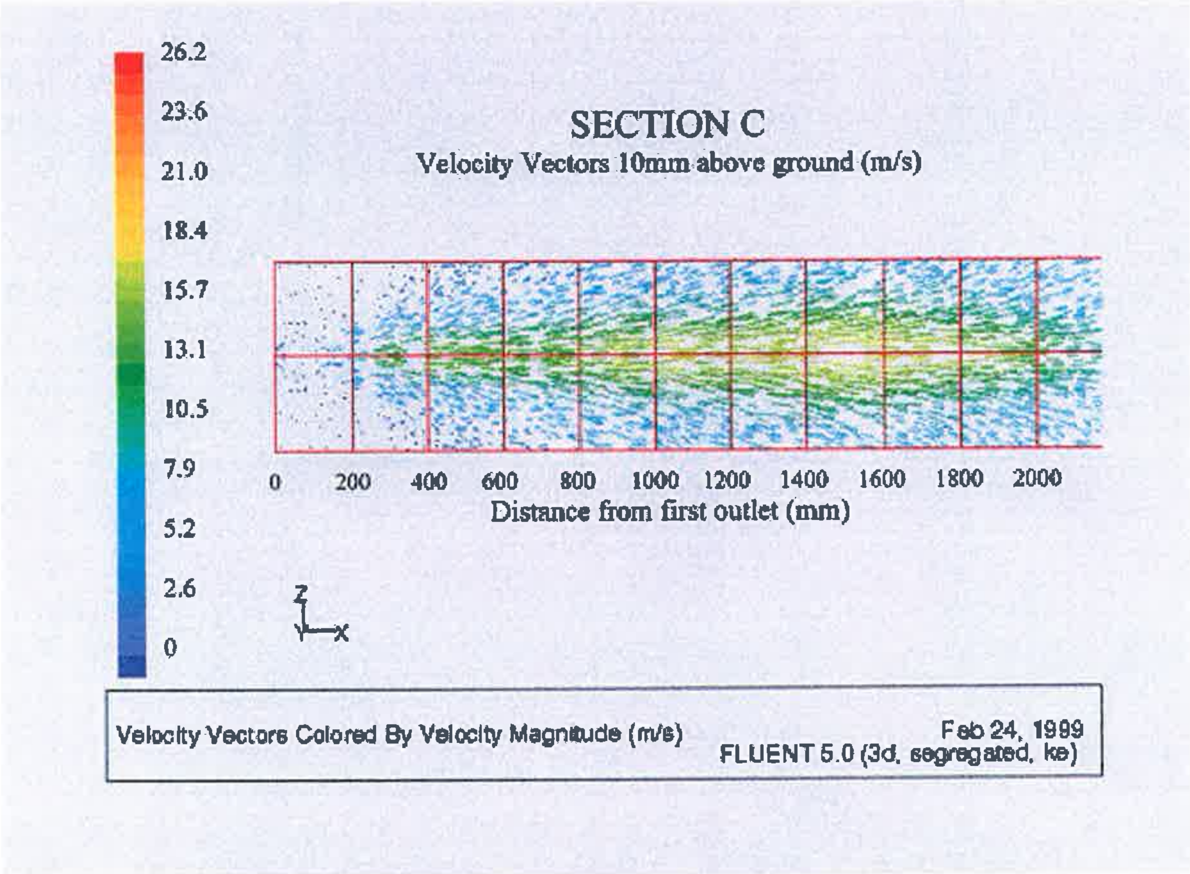


Figure 7.25 Computer simulation of three blowing heads (D) (20° inclination angle and 100mm height) in a common axial line. Plan view of velocity vectors.

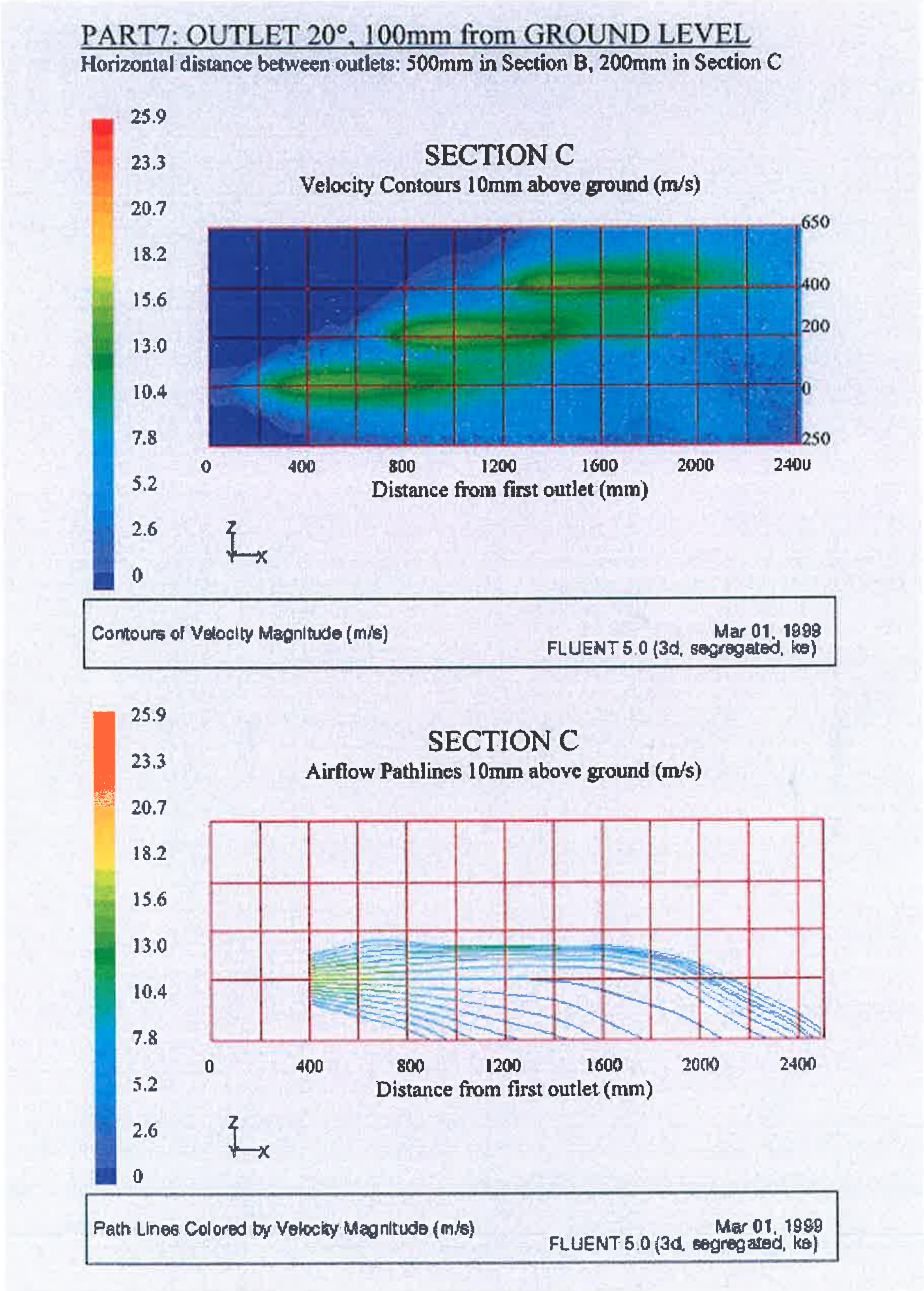


Figure 7.26 Computer simulation of three blowing heads (D) (20° inclination and 100mm height) offset from a common axial line. Plan view of (a) velocity contours and (b) airflow pathlines.

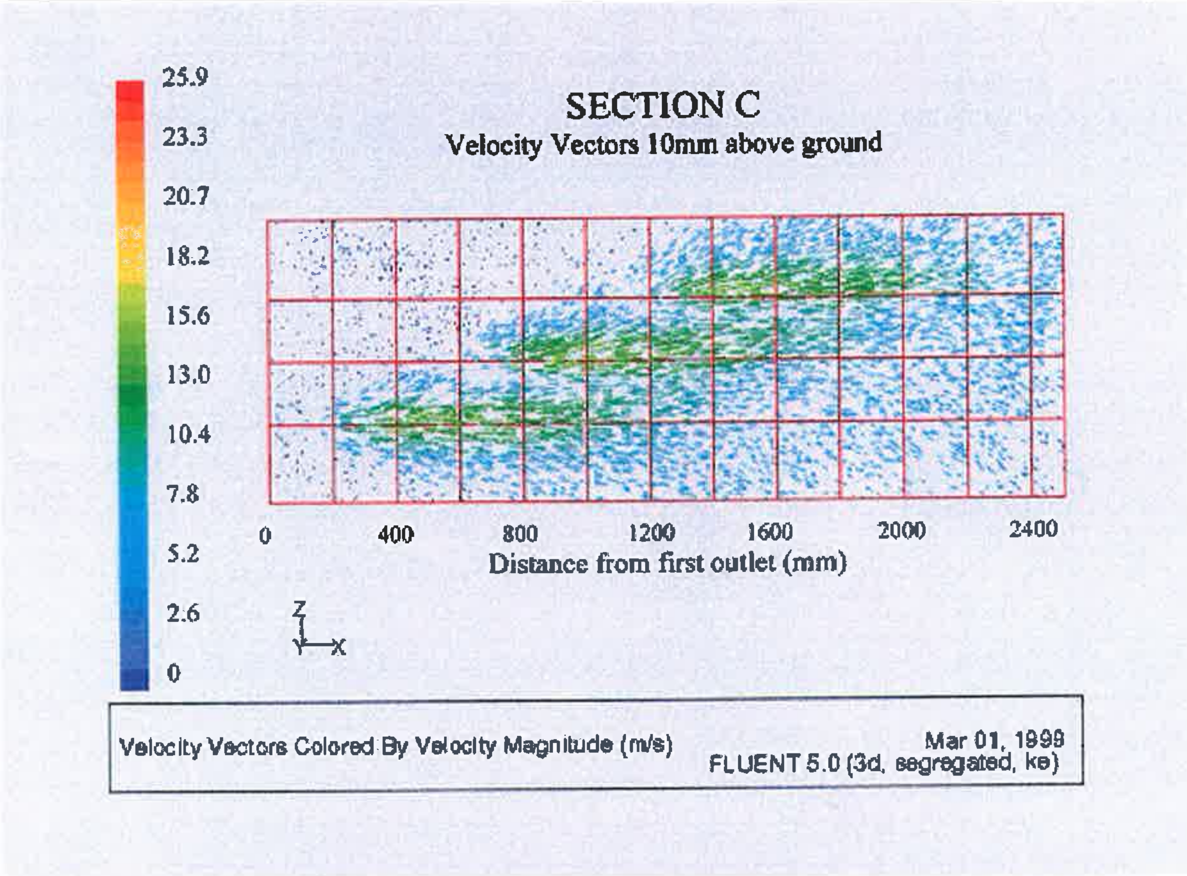


Figure 7.27 Computer simulation of three blowing heads (D) (20° inclination and 100mm height) offset from a common axial line. Plan view of velocity vectors.

Case 4: The final arrangement of heads is one in which head A and head C are rotated by 15° about a vertical axis towards head B (Fig. 7.28 to 29). The effect is generally to pull together the features of the two previous cases. In particular,

* velocities of reasonably high magnitude exist in an arc at near ground level.

* higher velocities at greater heights will be continuous.

* velocity directions are backwards for the initial 1000 mm. then parallel to the 'X' direction for the remaining 1000 mm. (Fig.7.29).

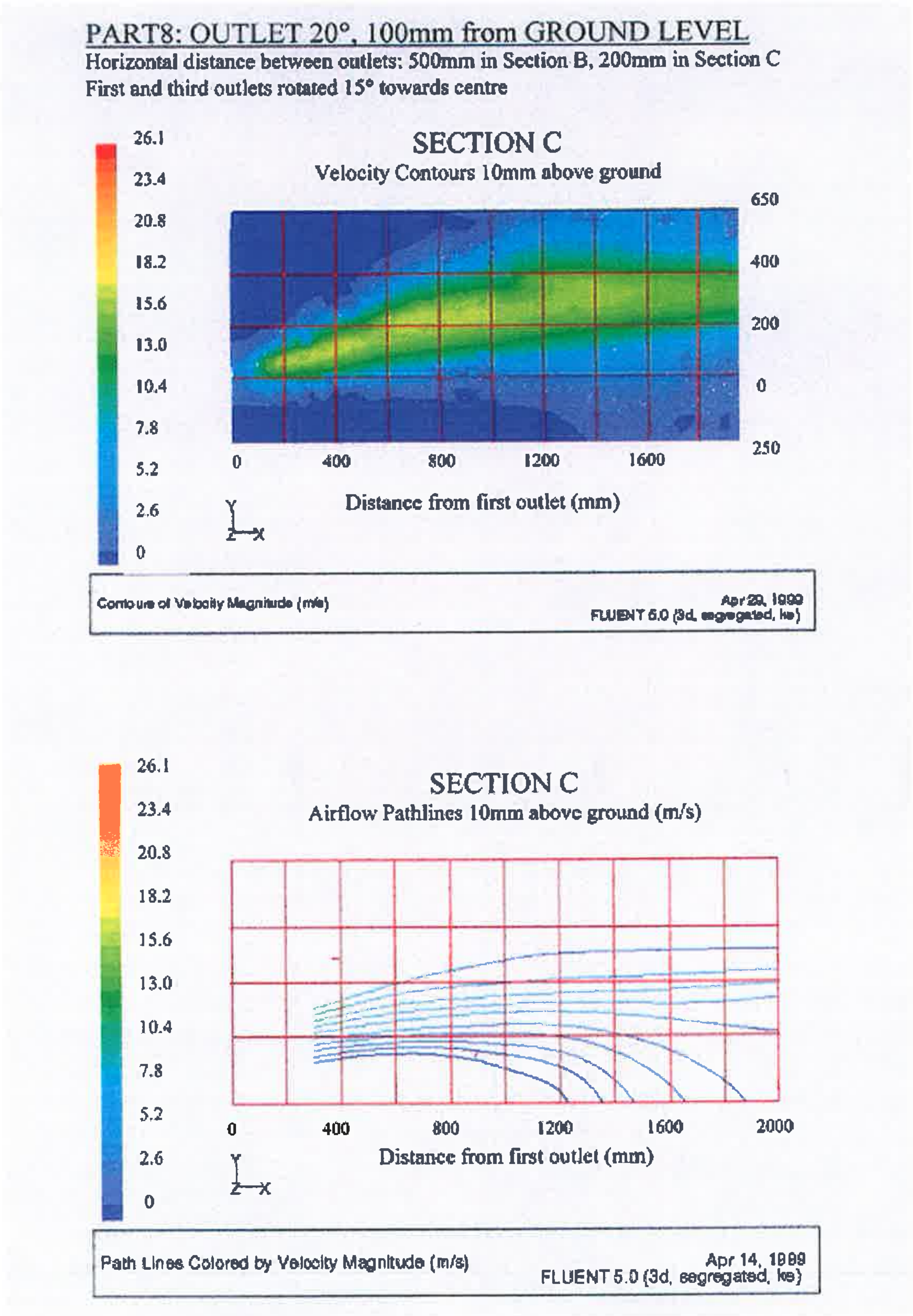


Figure 7.28 Computer simulation of three blowing heads (D) (20° inclination and 100mm height) offset from a common axial line and partly rotated. Plan view of (a) velocity contours and (b) airflow pathlines.

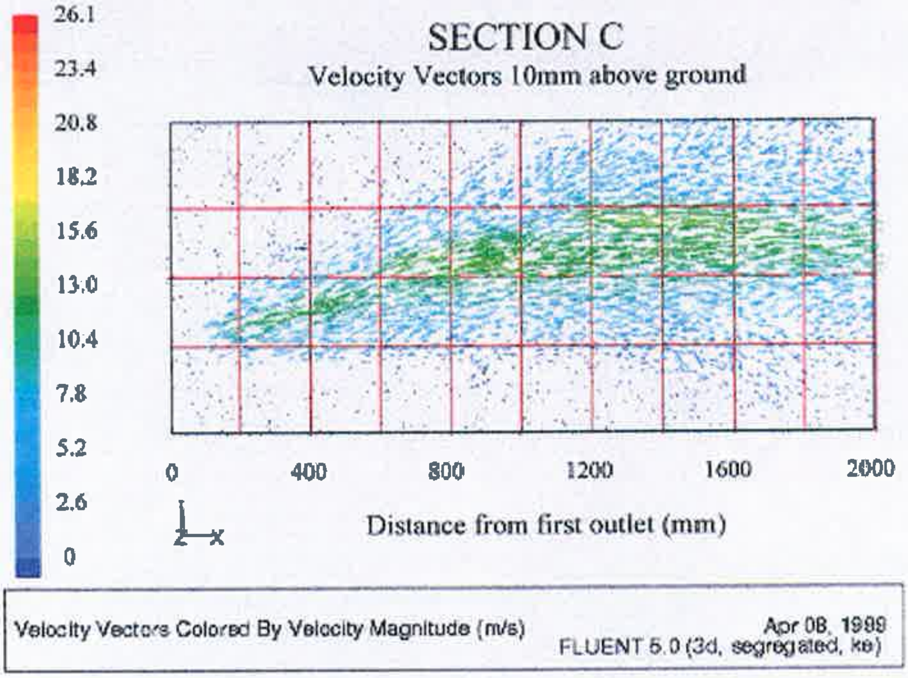


Figure 7.29 Computer simulation of three blowing heads (D) (20° inclination and 100mm height) offset from a common axial line and partly rotated. Plan view of velocity vectors.

7.4 Harvester Design

Field and laboratory physical property testing have shown that in the conditions studied medic pods on the ground surface can have a mass of the order of 3000 kg ha^{-1} (300 g m^{-2}) which, if pods are uniformly spread, corresponds to a spacing of 1 pod each 15 mm. In reality the distribution is totally uneven. Pod sizes range from approximately 4 to 9 mm with 70% in the range 6.25 to 7.93 mm.

The mass of loose soil on the surface can be 2 to 4 times that of the pods. Soil particles generally range in size from less than 1.4 mm to 8.0 mm. 82% of the loose soil is of size less than 2 mm.

Laboratory measurements have provided information on the velocities necessary to initiate pod and particle motion along a surface. It is not possible to categorise the motion of all materials – some pods and particles may become airborne, some roll and others slide, but whatever the mode of motion, it is likely that motion for the individual pod/particle can be continued with a lower velocity than that necessary at initiation. The velocity of moving pods and particles is an unknown - it cannot be assumed that it will be the same as the initiating velocity. Movement begins when the force on the pod/particle due to the airstream velocity exceeds the net force resisting motion; an airstream velocity of 10 ms^{-1} may initiate motion, but most materials are unlikely to reach that velocity.

It is proposed that harvesting of pods is to be carried out with some arrangement consisting of a number of blowing heads leaving pods suitably positioned for collection by a single suction head. The windrow of pods should contain a minimum of soil particles. Understanding how this can be best achieved is simplified by reference to three movement-initiating velocity ranges or zones:

Velocity zone	*Velocity range*	*Pods and/or soil particles initiated into motion*
Low velocity	3 – 8 ms^{-1}	Soil particles up to 2 mm (82% of total)
Medium velocity	8 - 13 ms^{-1}	Pods and soil particles 2 – 4 mm (8% of total)
High velocity	13 – 18 ms^{-1}	Soil particles 4 – 8 mm (10% of total)

There are many factors that will influence the way in which different arrangements of blowing heads effectively contribute to the collection of pods. Fig. 7.30 is an outline of a general arrangement and some of the terminology used.

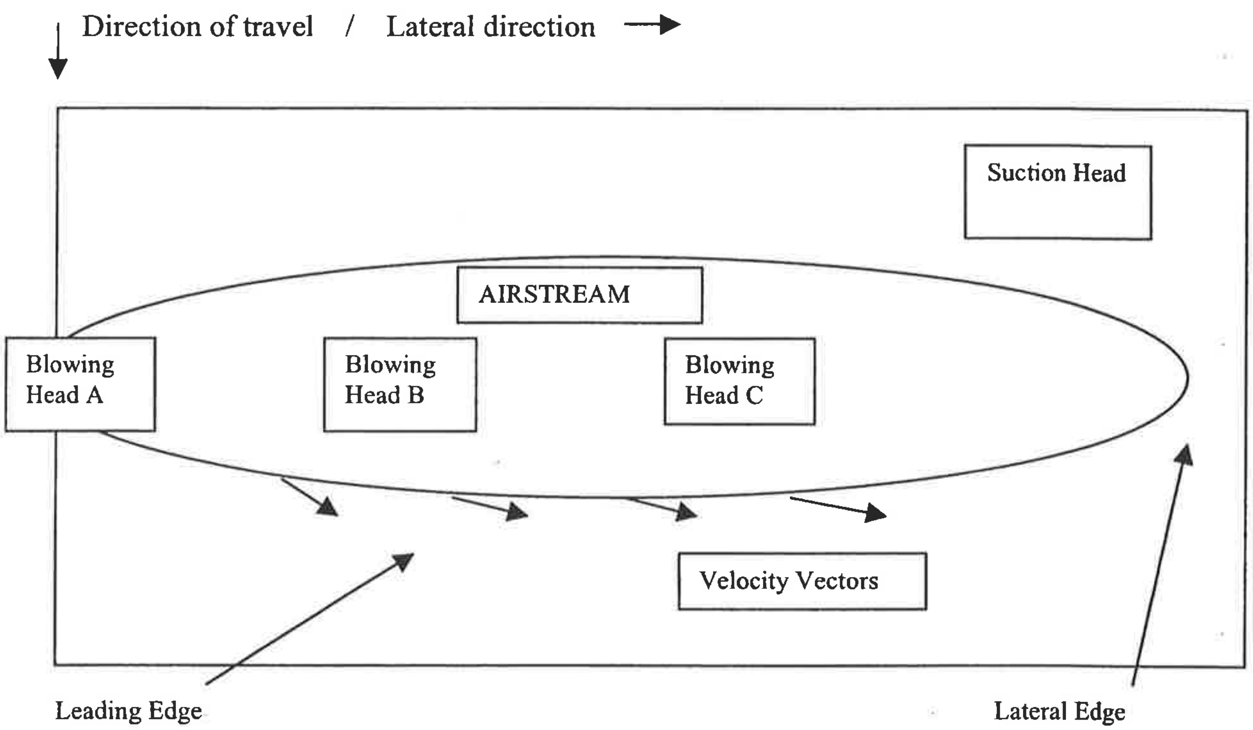


Figure 7.30 A schematic of a three blowing head harvester designed to selectively windrow pods and minimise uptake of soil particles.

These factors include:

1. Composition of the airstream and its orientation relative to the direction of travel.

2. Distribution of pods and soil particles on the surface and the influence this has on moving pods.

3. Harvester travel velocity.

Ideally, after passage of the blowing head arrangement there will be 3 bands of soil particles and pods in the direction of travel:–

- on the far side of the path of the suction head there will be a band of all soil particles of size less than 2mm,

- in the path of the suction head, the pods and a very small amount of soil will be aligned for collection, and

- on the near side of the suction head path the larger soil particles, some, or many of them not having moved.

This will be achieved because the initial lower velocities of the airstream will start the movement of fine soil particles before affecting the remaining material. That movement will cease when airstream velocity is too low or particles are impeded by other material. This latter difficulty, shown in Section 6.5 to be a problem, is largely dependent on the direction of the velocity vector; if the material is driven in the direction of travel as well as the lateral direction, material will begin to accumulate in front of the airstream. It is presumed that the separation process will be most effective when:-

(a) lower velocities have sufficient time to act on the smaller soil particles, and

(b) the path for particles is as close to the lateral direction as possible.

Harvester velocity may adversely affect movement of the smaller particles. Presently, velocities are of the order of 1 ms^{-1}. A change to a forward speed of 2.5 ms^{-1} would be a huge improvement, but this will give velocity vectors at the lower airstream magnitudes a directional shift towards the direction of travel and slow the progress towards the final at-rest position. Fortunately, there is to some degree a self regulating mechanism at work within the airstream – any particle or pod whose progress towards the final resting position is too slow will automatically be reactivated as the higher velocity of the airstream overtakes it.

Perhaps the simplest arrangement would be to have two separate airstreams, the first to activate and move the low velocity particles, the second to move the medium velocity material. If this were to be the case, ideally each velocity airstream would be characterised by:-

(a) velocity magnitudes in the lateral direction which are constant and extend to a lateral edge positioned to leave materials at the correct location. Maximum velocity magnitudes would be selected to be appropriate to either the low or medium velocity range with the low velocity airstream preceding the other in the direction of travel,
(b) velocity directions which are close to parallel to the lateral direction, and
(c) an airstream that is as wide as possible in the direction of travel.

In comparing the airstreams resulting from a single 20^0 head (Figure 7.11) and three 20^0 heads in line (Figure 7.24) it is obvious that a single head cannot satisfy the first of the criteria and could not be used. The three head arrangement is a much better option but could create some problems with velocity directions. It is acknowledged that a six head arrangement is becoming excessively complex.

In summary, it appears that there is a restricted lateral distance over which a single inclined head can be effective for this type of application; increasing air flow through the head may seem to be a solution, but it will create problems with too great a variation in velocity in the airstream. Increasing the depth dimension of the head (see Table 5.3 for definition of depth) would assist in extending the airstream lateral distance, but only marginally. On the other hand, doubling the breadth dimension to 200 mm and halving the depth will smooth out the velocity profile in the direction of travel and not introduce unecessarily high magnitudes. Consequently by using three heads it will be possible to form a single airstream which is capable of fulfilling the function of two separate airstreams.

In the practical harvester it will be a relatively simple matter to locate the blowing heads in a variety of positions to form that single airstream. The particular airstream used will be determined on the basis of ease of soil particle and pod movement; this in turn means, as far as possible, minimal interaction between materials.

Two difficulties which can contribute to an increased interaction between materials are as follows:

1. An accumulation of materials in front of the leading edge, especially towards the suction end (see Figure 7.31). This can be caused by velocity vector direction along the leading edge.
2. Small particles from the Blowing Head A end of the airstream do not have the opportunity to reach their final resting place before pods closer to the suction head begin to move (see Figure 7.32). The relative velocities of the harvester travel and particle movement are important here.

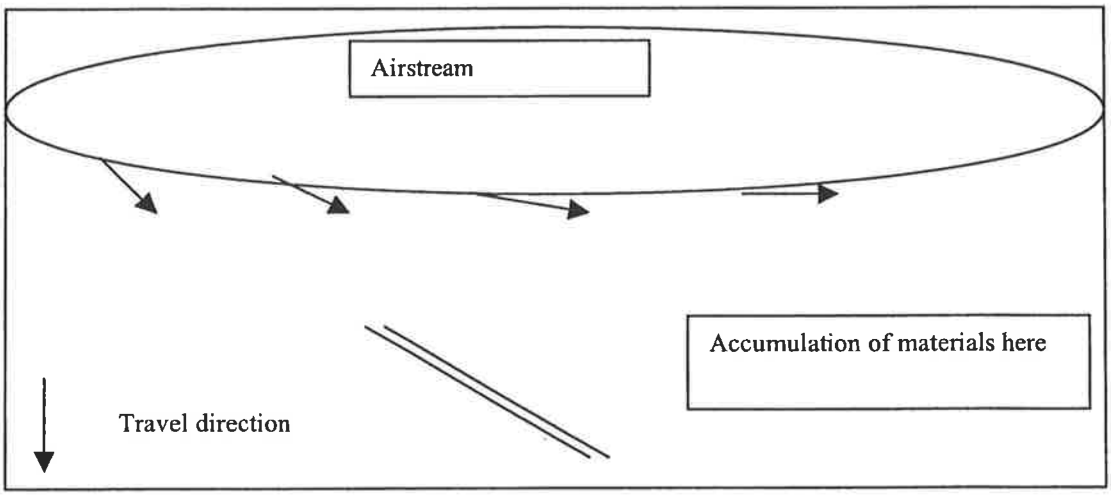


Figure 7.31 Accumulation of materials in front of the leading edge resulting from velocity vector direction.

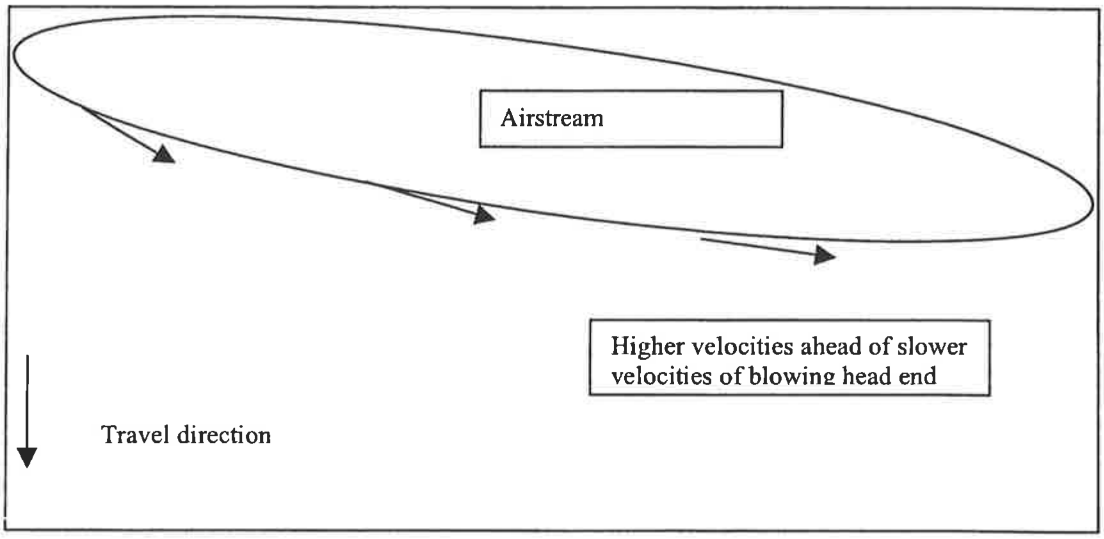


Figure 7.32 Adverse interaction between fine soil particles and pods due to forward inclined airstream.

An airstream inclined backwards relative to the direction of travel (Fig. 7.33) offers the advantage that the velocity vectors will be largely parallel to the lateral direction, even taking account of the forward movement of the harvester, thus minimising the distance materials need to move before coming to rest.

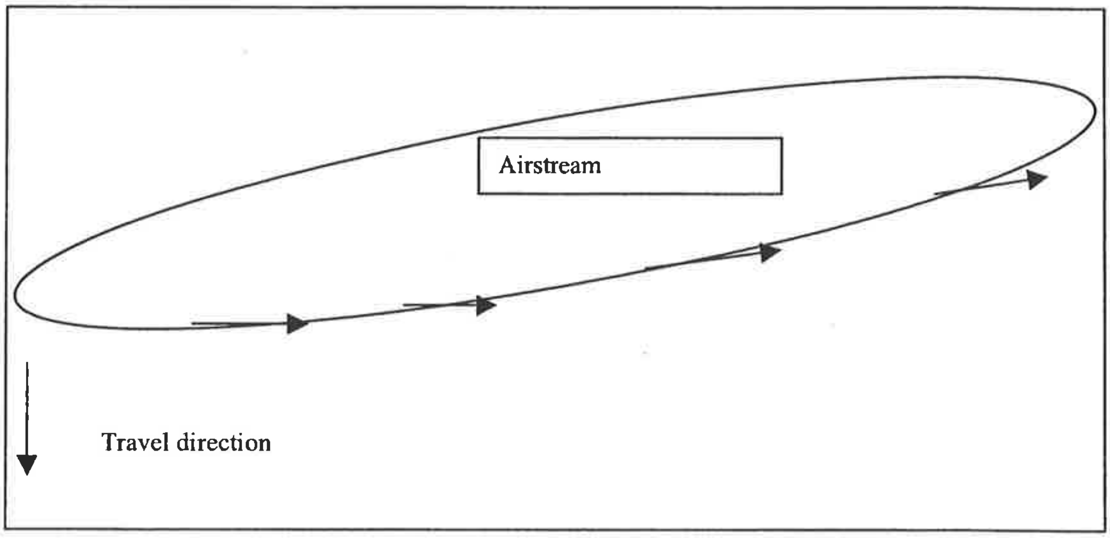


Figure 7.33 Velocity vector directions associated with backward inclined airstream.

In the simulation of blowing head arrangements, two other cases were considered, one in which the heads were offset in the direction of travel (Fig. 7.26), the other in which individual heads were rotated relative to each other (Fig. 7.28). There seems to be no advantage to the first layout, but being able to rotate the heads does offer the possibility of making fine adjustment to the air flow.

As a consequence of the above factors, it is suggested that in the harvester three heads should be positioned in line on an arm which can be given a backward inclination and that each head have the capacity for some limited rotation about its own axis (Fig 7.34).

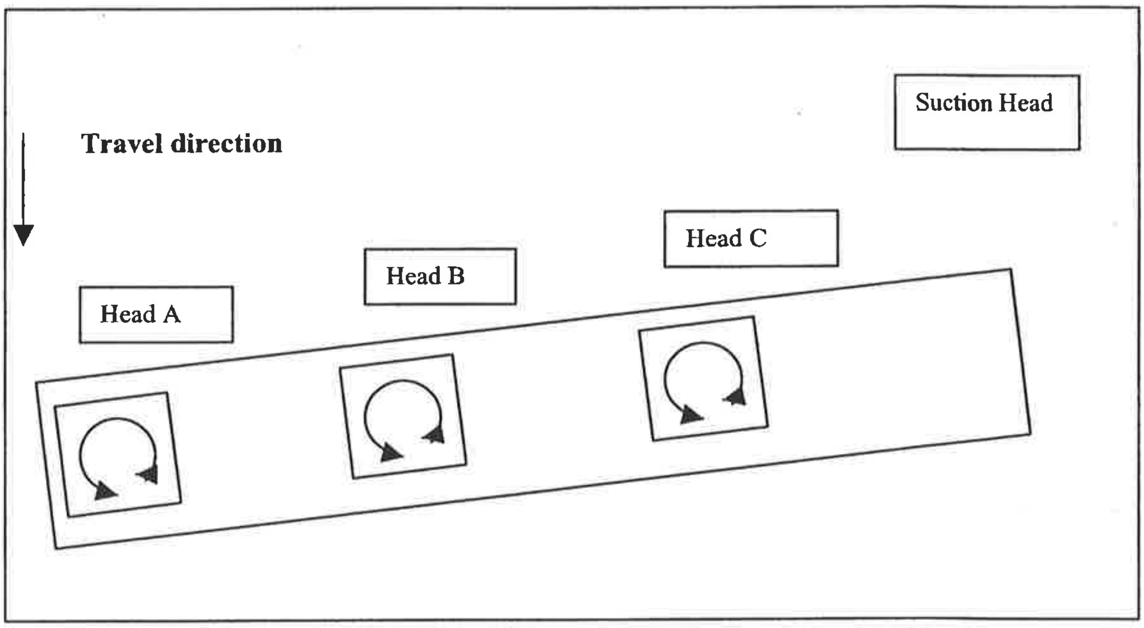


Figure 7.34 Proposal for the arrangement of blowing and suction heads in a harvester.

As to the suction head, the selection of location, dimensions and height will depend on the blowing airstream and the way in which pods have aggregated on the surface.

7.5 Conclusions

The results of the computer simulation of airflow using single blowing heads have been compared to those obtained in the laboratory. The two sets of results have been similar, perhaps not as close as originally expected, but it is necessary to review the individual sets of circumstances; laboratory measurements are subject to errors, especially due to measurement equipment; computer simulation is based on mathematical equations invariably requiring inclusion of certain real and sometimes arbitrary factors. The other element in this situation is the nature of the problem – we are attempting to determine airflow characteristics very close to a surface. This is a region where velocity changes very rapidly and may be subject to a multitude of circumstances. The finite element simulation, however, has proved itself to be a magnificent design tool that enhances the understanding of a problem as well as allowing rapid adjustments to the variables to make changes to the problem under study, in this case, airflow characteristics.

The technique proposed for the harvesting of medic pods requires an airstream that will react appropriately with pods and suface soil; it is not anticipated that the simulation could be extended to study the whole process. This is because there are too many unknowns. Included would be the nature of movement of individual pods and particles, the complexity of collisions between materials, and the effect on the airflow of the materials it is moving.

Chapter 8

GENERAL CONCLUSIONS

The annual species of *Medicago* are an important component of the ley farming system and as a grazed pasture plant in Australia and in other regions with a Mediterranean climate. There are many other countries, such as Iran, where widespread distribution of local genotypes on uncultivated lands indicates the potential to establish medic pastures. The benefits of annual medic pastures include nitrogen fixation, feed production, soil structure improvement, controlling wind erosion and root disease control in cereal crop zones.

Seed production has been important in Australia, especially in West and South Australia, for local use and for export, but production cost is high and harvesting is responsible for a large proportion of that cost. The harvesting process is expensive, in particular because it is so time consuming. There is also a fear that harvesting leads to a loss of top soil.

The seeds of *Medicago* species are encased in a wooden capsule (pod), the shape and size depending on the particular species and cultivar. The work in this research project has focussed on *Medicago truncatula*, mainly the cultivar Paraggio, which has a barrel-shaped pod, with a long dimension of 4 to 8 mm. The results of this research mostly apply to this species (*M. truncatula*), but the principles developed should have wide application.

Over the years there have been various attempts to develop efficient medic seed harvesters. These include adhesion to a membrane (specifically sheep skin), sweeping with various brushes and pneumatic collection, or a combination of the last two methods. The Horwood Bagshaw Vacuum Seed Harvester has been designed and manufactured commercially in South Australia. It is used to harvest medic and subterranean clover seed throughout Australia and overseas. Activity in the agricultural sector in recent years has been very depressed and there has been little financial incentive to investigate modifications or alternative approaches.

This study undertook to examine the present effectiveness of harvesting and ways in which performance might be enhanced. Field tests were carried out on three current harvesters, two commercially available, the third developed by a local farmer (Chapter 3). A statistical analysis of the results indicated that pod losses of the three units was not significantly different, being in the range 25% to 19%, which is greater than the more usual 9% average gathering loss with a standard grain harvester in bean harvesting. Figures recorded for pneumatic harvesters of other crops such as, jojoba seed, pecan, almond etc, are of the order of 20%.

The amount of surface soil displaced by the three machines was not considered to be significantly different, being in the range of 4814 to 5296 kg ha^{-1} of loose surface soil. The ratio of pods collected to soil collected over several tests varied between 0.26 to 0.52, although the ratio of 0.26 is felt to be the most representative. Tests verified the slow speed of harvesting of the commercial machines, 2.8 km h^{-1} to 3.4 km h^{-1} and locally-built machine, 4.8 km h^{-1} .

A further series of tests based on varying the two harvesting settings, forward speed and suction head height, indicated that the optimum settings were as recommended by the manufacturer. Of particular significance in these tests was the measurement of soil particle sizes affected by harvesting, in particular, that 80-85% of soil particles are of the 2 mm and smaller size. Further tests proved that this size range was a particular problem in machines ingestion and that any change in pre-harvest procedure to reduce generation of small soil particle sizes would be highly beneficial.

The Horwood Bagshaw Vacuum Seed Harvesters operate on a pneumatic suction principle, ie. they vacuum material from the field surface. The material ingested will depend on airstream velocity and aerodynamic response. The alternatives may include blowing and sweeping, or a combination of all these techniques.

Soil particles pulled into the harvester create problems for pod collection, soil displacement and harvester operation (power required and maintenance). The particular thrust of this work has been to minimise the amount of soil material taken on board ie. to take whatever steps are necessary to increase the selectiveness of the harvester. *Suction alone and sweeping were not seen as allowing this level of selectivity.*

Physical and aerodynamic properties of pods and soil particles had been examined (Chapter 4). Pods are mostly much larger than soil particles; but their densities are much lower. Pods have sizes from approximately 4.0 mm to 9.0 mm, the majority being of larger size; soil particles range up to 8.0 mm but with some 82% in that range up to 2.0 mm. As to aerodynamic properties, terminal velocity tests indicate that pods have velocities (5.2 to 6.4 m s^{-1}) which fall within a region of the soil particle terminal velocities (4.0 to 8.9 m s^{-1}). Fortunately the terminal velocities of the smaller soil particles were found to lie beneath those of the smaller pods. Of course the test conditions for measurement of terminal velocity do not replicate the harvesting condition of pods and other materials lying on a surface.

The design of an airflow for velocity magnitude, distribution and direction, whether in blowing or suction, necessitates a detailed knowledge of the influence of head parameters (size, shape, etc.). In the case of blowing flow, because of the need to create an airstream along a surface, the effect of varying the angle between the head and the surface is very important. These aspects were examined experimentally in Chapter 5. Wherever a blowing airstream impinges on a surface it generates a wall jet which is a jet that adheres to the surface with only a restricted thickness above that surface and as such material can be pushed along a surface. The airstream associated with a suction head in proximity to a surface cannot be described in the same simple way because of the nature of a suction head ie. it takes air in from all space around the head, not only the surface.

Experimental measurements indicated that the wall jet created by an inclined blowing head was wider than the free jet issuing from the same head. It had been anticipated that the airstream would take on the form of a wall jet having characteristics in nature between that created by a free jet aligned parallel to the. surface and one impinging at 90° to the surface. In the latter case the flow radiates out symmetrically from the area of impingement.

A finite element analysis using the software package Fluent has permitted a detailed study of the airstreams created by an inclined blowing heads (Chapter 7). Inclinations of 20°, 40°, and 60° relative to the surface were studied. In each case the resultant airstream can be assumed to radiate from the area of impingent; the main beam has substantially higher magnitudes in the axial and near-axial directions for the 20° inclination, but is more evenly distributed as the angle increases. The more dominant central beam achieved with the smaller angle of inclination has a slower velocity decrease in the axial direction. In each case the main beam had useful characteristics over twice the lateral distance of that of the free jet. In each case the height of the airstream was restricted. The finite element analysis proved conclusively that very useful airstreams can be generated by appropriately inclined blowing heads.

Suction heads produce velocity characteristics which change very rapidly and have little effect at small distances from the head. Head height is important, and the head should be close to the surface for maximum velocity. Angle seems to be relatively unimportant.

The harvesting process is a dynamic one. Within that environment there is a mixture of pods and soil particles of all sizes spread over the surface. An airstream moving into this mass will vary in velocity magnitude and direction from location to location. The final series of experimental tests (Chapter 6) was designed to examine the behaviour of surface materials to an airflow, firstly individually as a mass of pods or soil, and then together as a mixture.

In blowing flow, tests indicated that the velocities at which movement began for pods existed within the more extensive range of soil particle velocities, as expected from terminal velocity measurements. In summary:

Pods and/or soil particles initiated into motion	*Velocity range*
Soil particles up to 2 mm (82% of total)	3 – 8 ms^{-1}
Pods and soil particles 2 – 4 mm (8% of total)	8 - 13 ms^{-1}
Soil particles 4 – 8 mm (10% of total)	13 – 18 ms^{-1}

Suction flow tests indicate that the velocities required to move pods are lower than blowing velocities and are less than those of soil particles (at least down to 1.4 mm).

These tests highlighted the different nature of movement along a surface under a low velocity airstream. In blowing, pods roll and slide along the surface until displacement is impeded by pods and soil particles ahead of the moving material. In the case of suction flow, there is no similar impediment.

Therefore, to be effective in moving pods the airflow must constantly push them with a velocity just sufficient to cause continuous movement. In doing this, small soil particles ($p<2$ mm) will also be moved, but because they respond to a lower velocity, they will be pushed beyond the pods. This aspect of differential movement of pods and small soil particles proved to be the case where surface density of material was not too high (Section 6.5). Soil particles in the 2 – 4 mm range will be displaced along with pods, but larger material will not be affected. The technique of using velocities that will maintain pod movement to some predetermined location is the basis of the windrowing action proposed.

Effective design of an airstream to windrow pods for collection by a suction head needs to satisfy two criteria - appropriate velocities must be created to move materials over the operating width of the harvester and accumulation of material ahead of the approaching airstream must be avoided. Single blowing heads lack the characteristics to satisfy the first requirement.

Further finite element analysis, this time of a system employing three blowing heads to be used with a single suction head (Section 7.3.5), has shown conclusively that airstreams can be designed to have different characteristics. Incorporating multiple heads in a system allows consideration of many variables, head location, inclination, rotation, velocity, etc. The design selected incorporates three heads at 20° inclination mounted on a single arm which is capable of some backward rotation. This system provides reasonably constant velocity over an operational width approaching 2m and rapid deployment of surface material to its final stationery location.

Summary

Whilst pods and most soil particles can be separated on the basis of size and / or weight, the optimum solution to the problem of medic seed harvesting is to reduce the soil particle intake by selectively collecting pods. Tests indicate that it would be possible to achieve this aim by blowing pods and soils at minimum velocities to largely separate pods into a windrow and then with a suitably located head operating at minimum velocity, suck the pods into the harvester. The blowing action can be achieved by combining the flow of three heads. Such a harvester would not need to handle the aerodynamic load that the present harvesters are required to service and should therefore be able to proceed at a faster speed and need less maintenance. Field surface soils would also be subjected to much less disturbance and be more able to withstand the deleterious climatic conditions that exist at that time of the year.

Recommendations for future work

It is suggested that further work to optimise design variables would include investigation into:

- the movement of pods and soil particles ahead of an advancing airstream, especially in terms of separation. This could be carried out in a laboratory by having surface material on a belt or other structure moving past a stationary airstream,
- the ability of a suction head to collect a heaped windrow of pods,
- overcoming any problems associated with high densities of pods and soil particles, for example whether increased velocities should be used, whether some pulsing of the airstream is appropriate, etc,
- the field performance of a prototype harvester.

APPENDICES

Appendix A

Table A.1 Head losses and entry coefficients for circular and rectangular heads with different divergence angles.

Head	Circular heads		Rectangular heads	
Divergence angle	Entry coeff.	Loss in % of head face vel.	Entry coeff.	Loss in % of head face vel.
0	0.72	0.93	0.72	0.93
20	0.94	0.13	0.91	0.21
40	0.96	0.08	0.93	0.16
50	0.96	0.08	0.96	0.16
60	0.95	0.11	0.92	0.18
80	0.94	0.18	0.91	0.21
100	0.91	0.21	0.88	0.29
120	0.89	0.26	0.86	0.35
150	0.85	0.38	0.83	0.45
180	0.82	0.49	0.80	0.56

Appendix B Dimensionless velocity profile for free jets produced by circular head (A) and rectangular head (D).

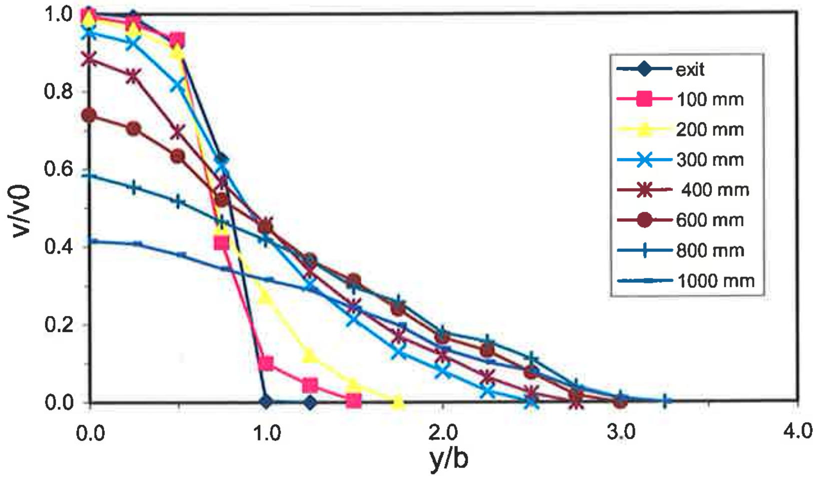


Figure B.1 Half velocity profile of the jet delivered from circular head (A)

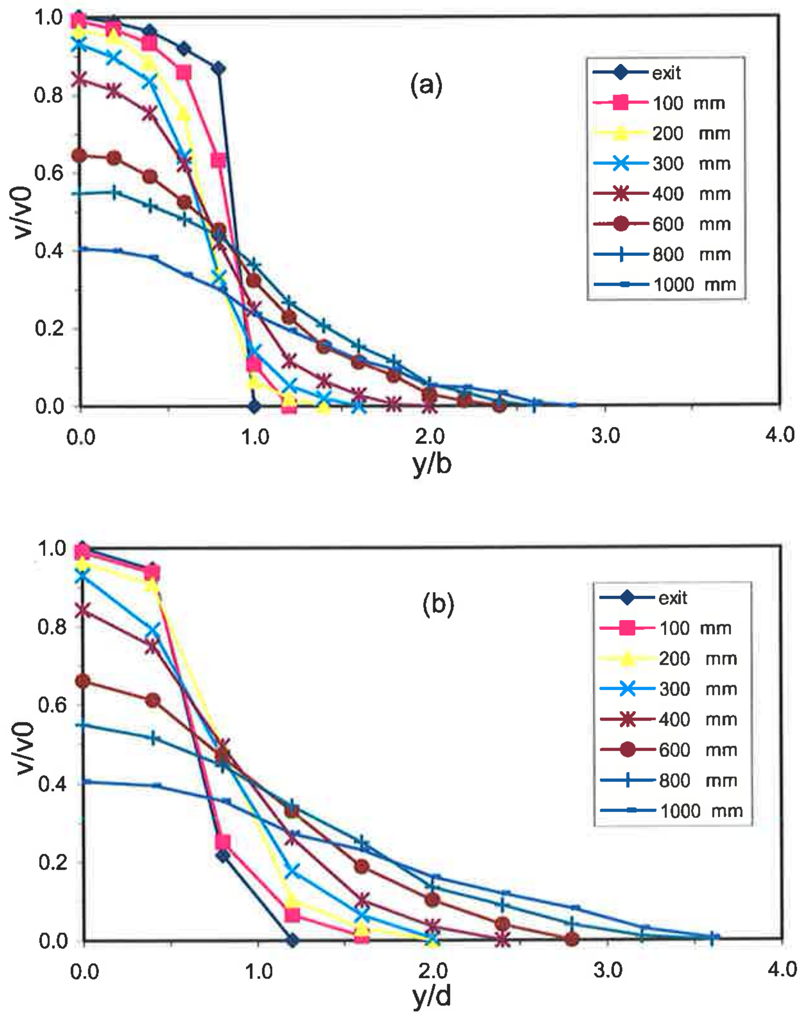


Figure B.2 Half velocity profile at different sections of the jet discharged from rectangular head (D) (a) perpendicular to the breadth, (b) parallel to the breadth

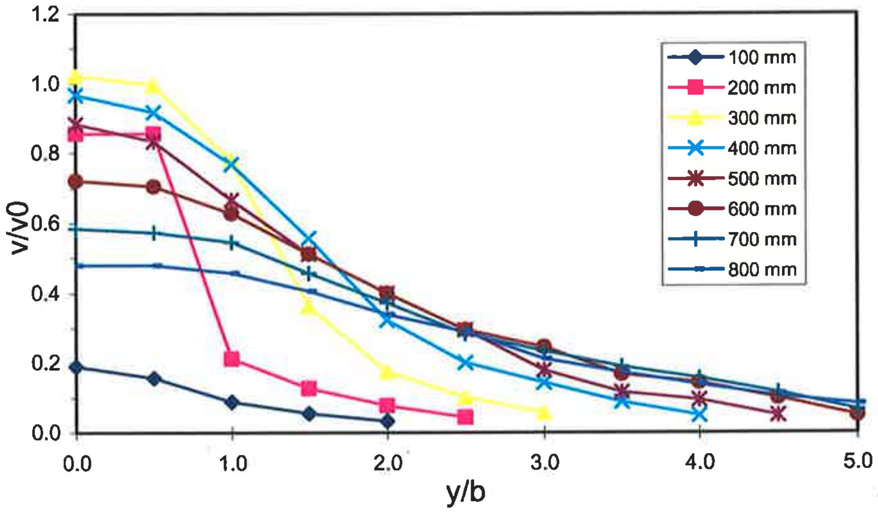


Figure B.3 Half velocity profile at different sections of the wall jet generated by the inclined rectangular head (d) parallel to the width.

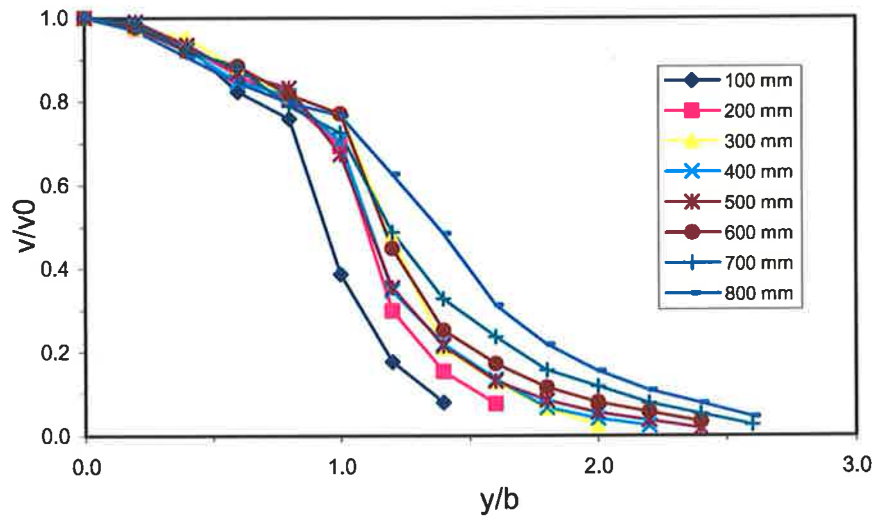


Figure B.4 Half velocity profile at different sections of the wall jet generated by the inclined rectangular head (E) parallel to the width.

Appendix C Air velocity required to move medic pods on a surface

Table C.1 Air velocities required to move pods in a blowing airstream.

Face vel.(m/s)	Effect. vel. (m/s)	Displaced pods (g)	Displaced pods (%)
6.2	5.8	0.0	0.0
7.3	6.9	0.5	1.2
7.6	7.3	0.8	2.0
8.9	8.5	1.4	3.5
10.7	10.5	3.5	8.7
12.2	11.9	10.7	26.7
12.6	12.3	27.4	68.5
13.3	13.0	39.5	98.7
13.5	13.2	40.0	100.0

Table C.2 Air velocities required to move medic pods in a suction airstream.

Face vel.(m/s)	Effect. vel. (m/s)	Displaced pods (g)	Displaced pods (%)
7.1	4.4	0.2	0.5
9.2	5.3	1.7	4.2
12.9	6.4	4.8	12.0
13.1	6.8	5.0	12.5
15.1	8.4	7.7	19.2
19.4	10.2	8.7	21.7
29.4	14.2	10.6	26.5
32.4	15.5	15.9	39.7
37.9	17.5	16.5	41.2
40.8	19.1	17.5	43.7
46.4	21.4	17.9	44.7
*	22.3	18.9	47.2

* The air velocity meter was not able to read this velocity, because of restriction on capacity.

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