AN INVESTIGATION OF WATER JET THREAD PROPULSION

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

By

Barry Strauss

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Textiles

Georgia Institute of Technology

March, 1976

AN INVESTIGATION OF WATER JET THREAD PROPULSION

Approved:

Amad Tayebi, Chairman

W. Denney Freeston, Jr.

Winston C. Boteler

Date approved by Chairman: Feb. 27, 1976

Dedication

I gratefully dedicate this thesis
to my parents, Mr. and Mrs. William H. Strauss,
for their love and encouragement.

ACKNOWLEDGMENTS

I am greatly indebted to Dr. Amad Tayebi, for whose guidance, counsel, and encouragement as advisor and friend made this thesis possible.

I wish to express my appreciation to Dr. W. Denny Freeston, Jr., for serving on the Reading Committee and for awarding me a financial assistantship. I also wish to thank Professor Winston Boteler for serving on the reading committee.

I am grateful to Matt Sikorski, F. D. Smith and Frank Ko, for their assistance and advice on setting up the testing apparatus. I wish to thank Mr. R. M. Stacks for his time and effort in taking photographs.

I also want to express my thanks to the management of Scottdale Mills for providing employment during the latter stage of my thesis work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

A testing device was developed to measure the initial drag force on a weft yarn when entrained in a water-jet. The drag force was measured as a function of loom settings and weft yarn parameters, to determine optimum running conditions without the use of fluid additives or the redesigning of existing picking components.

Results indicate that the drag force at the leading end of the weft is significantly increased by increasing the pump spring constant, and the initial water pressure.

It has also been determined that by keeping the yarn guide within the constant diameter zone of the nozzle body, the drag force will be optimized.

Results obtained by testing different monofilament and multifilament yarns indicate that the initial drag force is found to be a function of such yarn parameters as total yarn surface area, unit of fiber surface area, and fiber surface area per unit volume.

CHAPTER I

INTRODUCTION

In conventional weaving it is necessary to use a shuttle weighing 500 gms or more to insert a length of weft yarn weighing a few milligrams. The shuttle is accelerated to a speed of about 13-15 meters/sec. from complete rest only to be abruptly decelerated and brought to a complete rest again. This cycle is repeated as many as 300 times per minute.

This system from a mechanical and economical viewpoint is highly inefficient. The mass of the shuttle being accelerated and decelerated takes a toll on many loom parts. Also the power required to insert the weft on a conventional fly shuttle loom is relatively high when comparing it to the different types of shuttleless looms commercially available today.

Another disadvantage of conventional looms is that the supply of weft yarn is small and has to be replenished more often. This requires auxillary winding machinery which again creates additional energy requirements and more often than not additional mill floor space.

A third disadvantage of the conventional loom is that the weft supply package (often referred to as bobbin, quill or pirn), is that the yarn tension varies as the amount of yarn on the pirn decreases. This tension variation may cause irregular cloth construction.

Finally, due to inherent mechanical limitations (i.e. torsional vibrations, mass of the system, noise control), the optimum loom speed (that at which a loom can run so that the weaving costs per square meter are least) is relatively low.

It is due to these limitations that new weft insertion systems have been developed. These new concepts do not make use of a heavy reciprocating object such as the shuttle. Instead a large yarn package is placed on one side of the loom and weft insertion is accomplished from one side only.

In order to accomplish this, a few basic principles were utilized. Among those principles, which will be discussed in the next chapter, is the water jet picking system which accelerates the weft from one side of the loom to the other by means of the fluid drag of a fluid stream acting on the yarn.

It is the objective of this thesis to study the interaction between the yarn and the accelerating fluid (water) and to investigate the effects of machine settings and certain yarn parameters on the resulting drag force. Ultimately a better understanding of this interaction will lead to either higher rates of weft insertion and/or wider weaving widths.

CHAPTER II

REVIEW OF LITERATURE ON SHUTTLELESS WEFT INSERTION SYSTEMS

In a shuttleless loom an alternative to the shuttle is used. Three main categories of shuttleless weft insertion systems have been developed.

1. solid weft insertion systems
2. inertia weft insertion systems
3. fluid weft insertion systems

All three share basically these advantages over the conventional fly shuttle loom.

1. higher rates of weft insertion
2. lower energy consumption of the picking elements
3. elimination of the need for weft winding
4. less noise.

Figure 1 schematically illustrates the principles (1) of the three systems mentioned.

2.1 Solid Weft Insertion Systems

In solid filling insertion systems the weft is conveyed through the shed by means of a solid object generally having a mass a fraction of that of a shuttle. Examples of this system are:

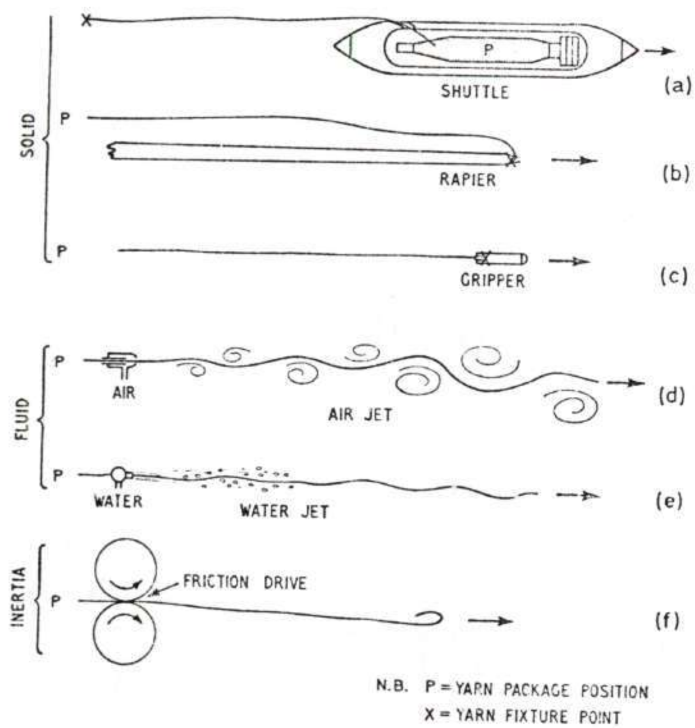


Figure 1. Comparisons of Available Weft Insertion Mechanisms (Ref. 1).

1. gripper or projectile looms
2. rapier looms
   a. rigid rapier
   b. flexible rapier
3. multiphase looms

2.1.1 Gripper or Projectile Looms

The basic theory of this system is that the weft is presented to a gripper weighing approximately 40 gms. The gripper is then propelled into the warp shed by means of a mechanical propulsion system. The most common propulsion system is a torsion bar (e.g. the Sulzer loom). The torsion bar is subjected to a shear strain. The shear strain energy is stored until picking takes place. When picking occurs the energy stored in the torsion ban is released which in turn sends the gripper "flying" through the shed, carrying the weft with it. Picking occurs from one side of the loom.

A series of grippers are used each having the weft attached to it. After checking a conveyor returns the empty gripper to the picking unit and the process is repeated.

2.1.2 Rapier Looms

The most widely used solid weft insertion system of weft insertion is the rapier system. There are two main types: the rigid rapier and the flexible rapier systems.

The rigid rapier system incorporates two types of weft insertion systems. There are the single rigid rapier and double rigid rapier. Both systems offer higher weft insertion rates than that of a fly shuttle loom; however, looms their speed is relatively low compared to other types of shuttleless looms.

The single rigid rapier loom uses one long rapier to insert the weft yarn through the shed. The rapier control is located outside the loom frame and requires considerable floor space. As the rigid rapier is extended, a small gripper mechanism grips the weft yarn from a supply package located on one side of the loom. Both the rapier and weft traverse the width of the loom. When the rapier gets to the other side of the loom it releases the weft and then traverses back to its control stand.

Loom production is rather slow, due to the fact that shedding time for actual weft insertion is effectively utilized for only one half the time. The other half is needed to remove the rapier from the shed. The main advantage of this loom is the gentle action of weft insertion. The weft is not subjected to high acceleration and deceleration forces. Therefore very fine yarns can be woven at a much faster rate than if they were woven with fly shuttle loom or some of the other shuttleless systems. The Iwer loom is the most widely used Single Rigid rapier loom.

The Double Rigid rapier system uses two rigid rapiers for weft insertion, one on each side of the loom. Production rates are higher with this system than with a single rigid rapier. One rapier called the "giver" receives the weft yarn from the supply package and traverses into the shed. At the same time the "giver" rapier begins its movement the "taker" rapier begins its travel into the shed from the opposite side of the loom. At center shed the "giver" transfers the weft "mini" shuttle) at all times. Each yarn carrier contains a pre-measured length of weft, which is prepared and inserted by a special rotating device. The reed which is unlike any other, is now segmented and pushes the yarn carriers through its shed. The individual yarn heddles also open and close simultaneously with the movement of the yarn carriers. Beat-up is performed by the segmented reeds, which are operated by a screw shaft.

Although the rate of weft insertion of each individual carrier is slower than that of a conventional shuttle, the total production rate can well exceed 1,000 ppm due to the multiplicity of sheds and "shuttles."

Three manufacturers displayed multiphase looms as ITMA '75.' Iwer (OWA), Elitex (Contis and Ruti)("TWR"). The fact remains that due to the complexity of the machine, the range cloth constructions yarn sizes and cloth density that can be produced is limited.

The future for these machines looks very promising. The manufacturers of the multiphase looms will undoubtedly broaden the range of fabrics that can be produced.

2.2 Inertia System of Weft Insertion

This concept reduces the number of moving elements in the shed to a minimum: the length of weft itself. This is accomplished by imparting to the weft direct frictional contact caused by either feeding the weft through high speed rollers (i.e. Vincent system) or through cones (Hodgkinson system (2). The rollers or cones grip the yarn and accelerate the weft to a velocity equal to that of the rollers themselves; the yarn then traverses through the shed under its own momentum.

The disadvantage of this system is that after traveling a small distance past the initial point of acceleration (i.e. past the nip of the rollers) the front end (or leading end) of the yarn begins to slow down due to air resistance. Meanwhile the rear end (or trailing end) of the yarn is moving at a speed close to that of the propelling rollers. Thus yarn buckling occurs. As the yarn length increases so does the extend of buckling thereby necessitating small weaving widths systems to be discussed in the next section. At present, there are no commercially available inertia system looms on the market.

2.3 Fluid Systems of Weft Insertion

With a fluid weft insertion system the weft is transferred across the loom by means of the drag force of the fluid on the yarn. Like the inertia system, no solid parts are required to carry the yarn across the shed. The principal fluids used are air and water. Both air and water jet looms are commercially available and are in operation throughout the world.

The fluid system of weft insertion shares the same basic problem associated with the inertia system; that being the difficulty in controlling weft buckling. Once the weft yarns is no longer being accelerated by the fluid it must reach the other side of the loom under its own momentum if the velocity of the leading end decreases because of the opposing drag caused by air resistance, the weft yarn will buckle.

Yarn buckling becomes the major factor which determines maximum weaving widths, for the further the yarn moves away from the nozzle the greater the more likelihood buckling will take place. To date,narrow weaving widths is still the major disadvantage of the fluid systems. The air jet being more restricted by this problem than the water jet.

To achieve control of weft buckling it is essential that the drag force created by the fluid jet be effective along the weft length for as long as possible. Using air as the accelerating medium presents more difficulty in achieving such a goal. Since air is a low viscosity fluid, having a low mass and density a large amount of energy is needed to create the velocity necessary to entrain the weft yarn and carry it any reasonable distance. Hence weaving widths in air jet looms have remained narrow since the looms conception in 1914 (3). Other problems arose due to the low mass of air. It is greatly affected by turbulence associated with sley oscillation. The ambient air surrounding the air jet tends to reduce the jet's kinetic energy rather sharply after a short distance from the jet nozzle tip (Figure 2).

Once the air mass is slowed it grows or disperses into a larger but slower mass. Once this occurs the leading end will travel slower than the trailing end and the yarn will no longer remain straight.

Recent developments reduced somewhat air jet dispersion and weft buckling. Attempts to find a more effective fluid system led to the idea of using water as the weft insertion carrier.

2.3.1 Water Jet Development

The invention of the waterjet loom is credited to V. Svaty (4) who

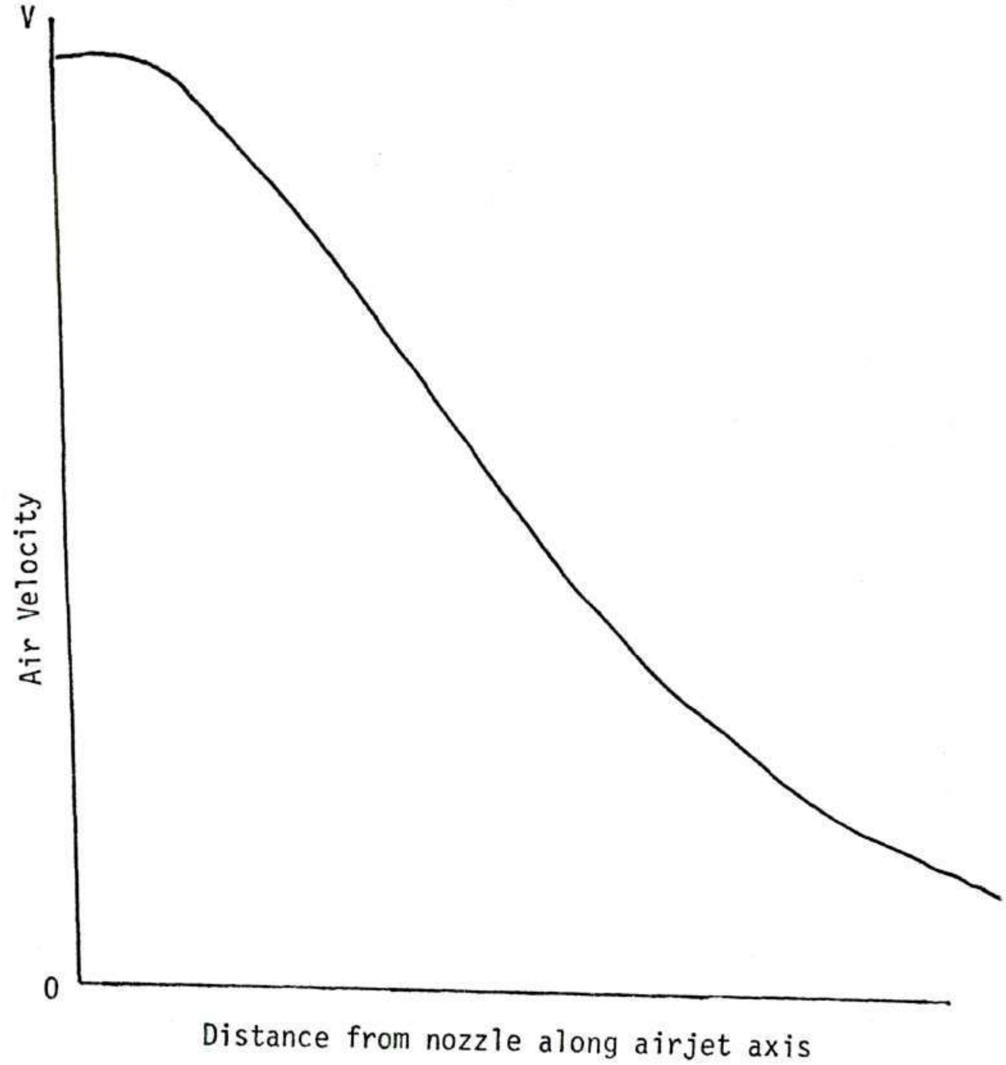


Figure 2. Relationship of Air Velocity as a Function of Distance from the Airjet Nozzle. (Ref. 1)

at the time was a pioneer in air jet weaving. Discouraged with the limited range of weft insertion by the air jet, Svaty developed a means for inserting the weft with a jet of water. Water is more viscous than air. It also has a greater mass and a density than air. Hence the drag force excerted by the water jet on the yarn is greater, and the water jet is less susceptible to the dispersal problems mentioned in the discussion of the air jet loom.

Due to the fact that water has a higher density than air, and that water is an incompressible fluid, the velocity of the water need not be excessively high in order to entrain the weft yarn across the loom. Thus the energy requirements for picking are lower than those for air. In fact, the water jet loom requires the least amount of energy of any commercially available picking system (Table 1) (5). Other advantages of the water jet loom and that it is extremely quiet in operation (around 70 db) it can weave a wide range of yarns and fabrics at widths between 100-165 cm. It appears that water-jet weaving might be the weaving method of the future.

Table 1. Comparison of Energy Consumption for Various Weft Insertion Mechanisms (Ref. 5)

Picking element	Speed of weft insertion m/sec	Speed of picking element m/sec	Kinetic energy of picking element kg·m.
Shuttle	7-13.5	7-13.5	1-3.7
Air-jet	20-30	300	1.1-2.3
Water-jet	30-50	40-60	0.02-0.18

Although the problem of weft buckling is not as pronounced in water jet weaving as it is in the case of air jet looms it still exists and prevents the loom from weaving double and triple width cloths (cloths whose widths are greater than 210-250 cm. wide). A second major disadvantage of the water jet loom is that there is a limitation of the yarn and fiber type that can be woven.

These limitations are due primarily to the inability to keep jet cohesion for a longer distance. Jet cohesion is analogous to the air mass dispersion problem found in the air jet system. It seems that the water jet begins to break up into small droplets soon after leaving the nozzle tip. This decreases the effectiveness of the drag force created; thus the velocities of the leading and trailing ends will differ therefore weft buckling will result.

Figure 3 illustrates how the fluid systems are at a disadvantage to other systems of weaving when comparing maximum weaving widths.

It is believed that by increasing the initial drag force, many of the disadvantages might be overcome with little added expense. By measuring the initial drag force created by the water acting on the yarn a better understanding might be obtained of how certain machine and yarn variables affect the drag force. This may lead to the possibility of increasing weaving widths, increasing weft insertion rates, and widening ranges of fiber types that can be woven.

2.4 Review of Literature of Water-Jet Weft Insertion

So far little has appeared in the open literature concerning the study of the drag force created between the water jet and the yarn.

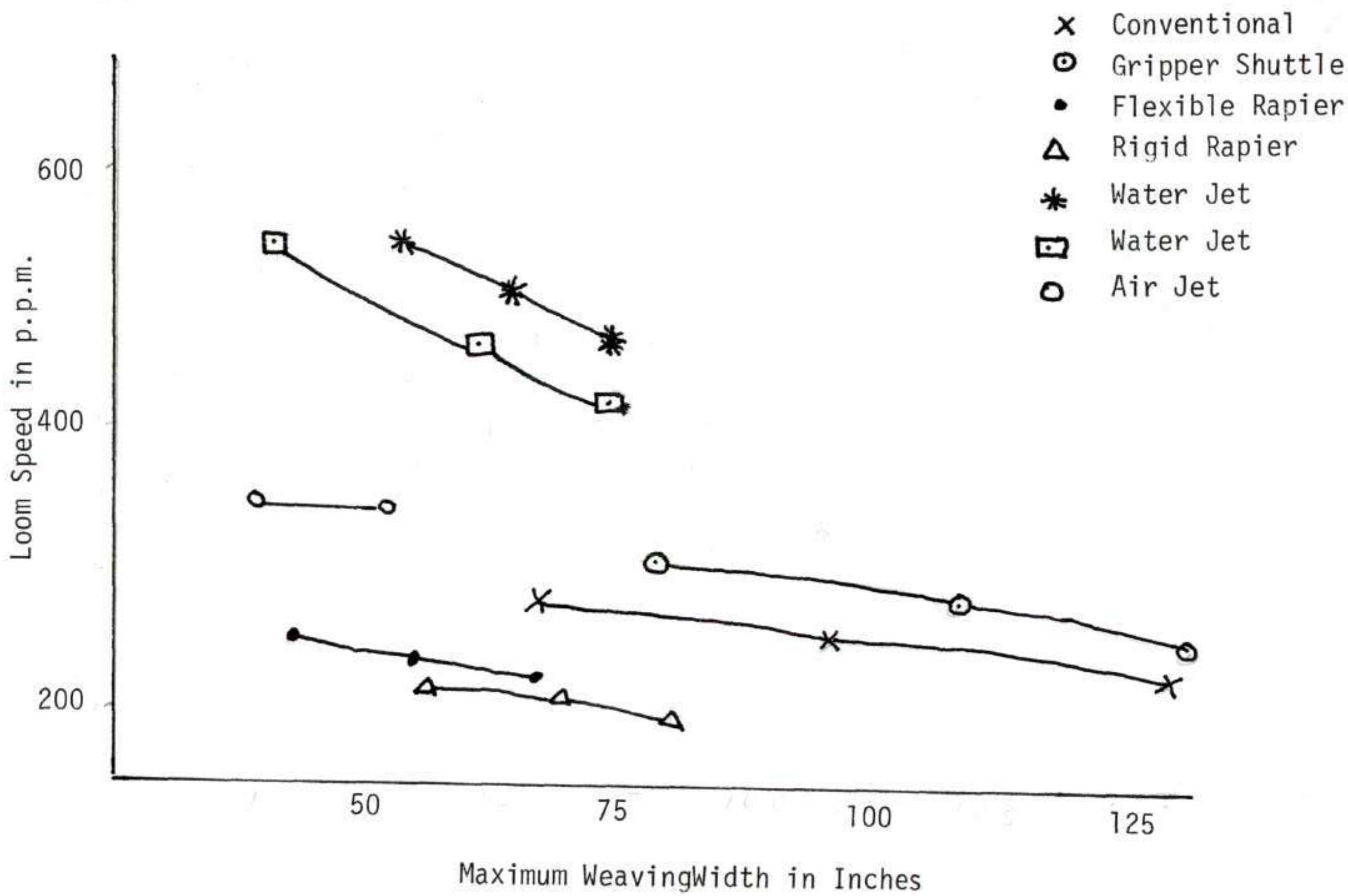


Figure 3. Comparison of Maximum Weaving Widths of the Various Weft Insertion Systems (Ref. 2).

In his original work Svaty developed some data on the drag created between the water jet and two types of yarns (5); cotton and nylon. The scope of his work was limited since he was interested in observing the effect of yarn wettability as a function of the yarn's ability to be propelled across the loom. His conclusion where that cotton developed a greater drag force than nylon because the cotton yarn is wetted to a greater degree than nylon.

Cheung (2) studied the coherence of the water jet as a function of the viscosity and surface tension of the water. He assumed that if the turbulence of the jet is decreased and if jet cohesion is maintained for a longer distance, both jet and weft velocity will increase, resulting in higher rates of weft insertion, and wider weaving widths.

He found that increasing the viscosity of the water would result in greater jet cohesion. Whereas a decrease in surface tension would have no beneficial effect. His study was based solely on the fluid jet system without introducing the interaction of a yarn.

The most recent and thorough in depth published study of the water jet system of weft insertion was carried out by R. Dawson, et al. (6). Dawson's work was published in four separate articles. Each will be reviewed individually.

In his first paper (6) Dawson investigated the weft and jet velocities by photographic means. Through his observations Dawson discovered that the velocity of the front of the jet increases as it gets further away from the nozzle until it reaches a maximum value, then levels off, and finally decreases due to air drag. He attributed the increase in jet velocity to an increase in efflux velocity at the nozzle, meaning that the leading edge of the jet could be overtaken by elements of the jet that left the nozzle earlier in the cycle.

In Part Two (7) Dawson again studies jet behavior. This time he observed radial jet dispersion in which his work closely parallels that of Cheuny (2). By building a fluid collecting device Dawson was able to measure the amount of radial dispersion (jet break-up) as a function of distance traveled from the nozzle tip. His results led to the conclusion that as the jet increased its distance from the nozzle, its radius increased, meaning that less of the fluid was staying at or near the jet axis. This would result in a decrease in drag force on the weft, for it is the fluid at the jet axis that interacts with the yarn

The third article in the series leads to a model for studying jet motion. The model looks at the water jet after it reaches its maximum velocity, for it is at this point that the elements of the jet at the leading end remain constant.

It is concluded that the maximum efflux velocity is reached 3° of crank revolution after the jet emerges from the nozzle. Also that along the length of weft different jet elements have varying velocities. This causes a net effect on weft motion to be a function of an intermediate velocity closely approximating the velocity of the leading end of the jet.

In the fourth and final paper (9) Dawson investigates weft motion as a function of weft velocity relative to the jet velocity. In this study two assumptions were used to help explain weft motion. Firstly, jet velocity is treated as a constant throughout the weft length, and secondly, the drag force inserting the weft is assumed to be proportional to the square of the weft velocity relative to the jet velocity.

Studying the weft and jet trajectories under varying values of initial weft velocities, Dawson found that if the weft velocity is made to deviate from its normal value then the resulting change in drag will tend to restore the weft velocity to its normal value, and the corresponding deviation of the weft location is only slight when compared to its normal value.

Dawson explains this behavior as being a function of an inherent automatic control of the weft velocity and that the water jet insertion mechanism has a significant degree of control over the velocity and location of the weft.

The preceding section has dealt with what has previously been studied on the water jet insertion mechanism. Even though a considerable amount of information has been generated from these studies the effect of varying loom conditions and yarn parameters on the initial drag force has been neglected.

It is the objective of this thesis to develop a better understanding of factors influencing the drag force created between the weft yarn and propelling jet. A total of eight different conditions were studied. These parameters involved changing certain loom settings and yarn parameters and measuring the resulting drag force.

CHAPTER III

EXPERIMENTAL WORK

3.1 Scope of Experimental Work

A total of eight parameters involving 45 different test conditions were studied to determine the effect of the water jet/weft interaction on yarn picking force. Table 2 outlines the eight parameters and Appendix A lists all tests with corresponding initial conditions.

Table 2. Investigated Parameters

Parameter No.	Description
One	Effect of length of weft yarn protruding from nozzle
Two	Effect of yarn diameter
Three	Effect of Water pump pressure
Four	Effect of water volume/pick
Five	Effect yarn guide-nozzle relative location
Six	Effect of yarn guide diameter
Seven	Effect of weft yarn variables
Eight	Effect of pump spring modulus

Table 3 shows the number of different test conditions used for investigation of the above mentioned parameters, and Table 4 shows the different yarns used.

Table 3. Number of Test Conditions Used for Investigation of Effects of Various Parameters

Parameter Number	Number of Test Conditions
One	Nine protruding lengths
Two	Four monofilament diameters
Three	Four levels of water pump pressure
Four	Five values of water volume per pick
Five	Five relative posistions of yarn guide end into nozzle body
Six	Three different yarn guide end diameters
Seven	Seven different multifilament yarns
Eight	Two springs with different constants

In carrying out tests for determination of the effect of certain parameter, other parameters were kept unchanged (whenever possible) so that comparisons of the results could be made with some degree of reliability. The main procedure was to determine the maximum initial drag force for a given parameter, and then use the conditions that gave the maximum results as the initial settings for the following parameters. Unless otherwise indicated, this was the procedure followed.

Table 4. Yarns Used for Experimental Work

Yarn No.	Fiber Type	No. of Filaments	Linear Density of yarn (or Diameter)	Linear Density of Fiber (or Diameter)
1	Nylon	One	Diameter=.0126"	.0126"
2	Nylon	One	Diameter=.015"	.015"
3	Nylon	One	Diameter=.018"	.018"
4	Nylon	One	Diameter=.021"	.021"
5	Polyester	34	70 Denier	2.06 Denier
6	Polyester	34	100 Denier	2.94 Denier
7	Polyester	50	220 Denier	4.4 Denier
8	Polyester	100	440 Denier	4.4 Denier
9	Nylon	26	100 Denier	3.85 Denier
10	Nylon	34	100 Denier	2.94 Denier
11	Nylon	50	100 Denier	2.00 Denier
12	Nylon	100	440 Denier	4.40 Denier

3.2 Equipment for Experimental Work

3.2.1 Water Nozzle Assembly

All experiments were carried out on the Nissan water-jet Loom. A detailed description of the picking mechanism is given in this section.

Figure 4 shows a detailed illustration of the Nissan water-jet loom weft insertion mechanisms. Since this thesis deals with the study of the jet/weft systems, mechanisms not directly related to picking will not be discussed.

For the purpose of this study it is adequate to omit the explanation of pick insertion stages as they apply to normal weaving conditions,

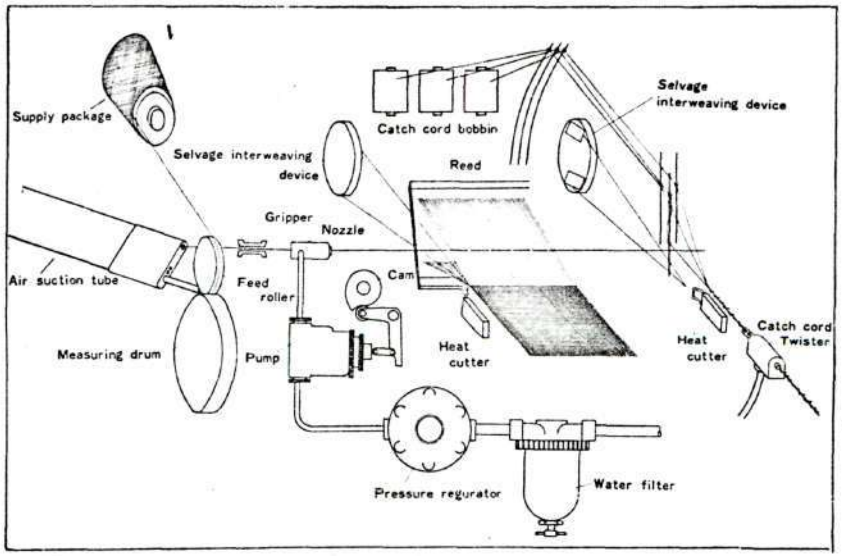


Figure 4. Principal Weft Insertion Mechanisms of the Nissan Water Jet Loom. (Ref. 10)

and just explain the picking procedure as it applies to the experimental set-up. In this case the two main elements utilized are the jet nozzle and the pump-cam assemblies. Figures 5 and 6 show (10) a more detailed illustration of these two assemblies.

The water from the supply tank is sucked in the body of the pump (Figure 5) by means of the plunger (3). The plunger movement is controlled by the pump cam (1) when the pump cam toe is resting on the follower (2), the plunger has completed its intake stroke and the spring (5) is fully compressed. Upon the rotation of the cam past this point, the spring is allowed to expand, thus pushing the plunger back into the cylinder of the pump. The return stroke of the plunger forces the water out of the pump and into the nozzle where it entrains the weft yarn.

By adjusting the distance "K" between the spring cap (6) and the locknut (7) the initial compression of the spring is altered. This will either increase or decrease the pressure within the pump. Increasing the "K" value decreases the pressure and as the "K" value decreases the pressure will increase.

The pressurized water enters the nozzle assembly (Figure 6-A) through six holes evenly spaced around the circumference of the nozzle body as indicated by arrow (1). The water then flows through the annular space (2) created between the inner wall of the nozzle body (8) and the tapered outer diameter of the yarn guide (6). The initial flow characteristics of the fluid jet are determined by the clearance (2) created between the yarn guide and the wall of the nozzle.

As the water emerges from the annulus it comes into contact with

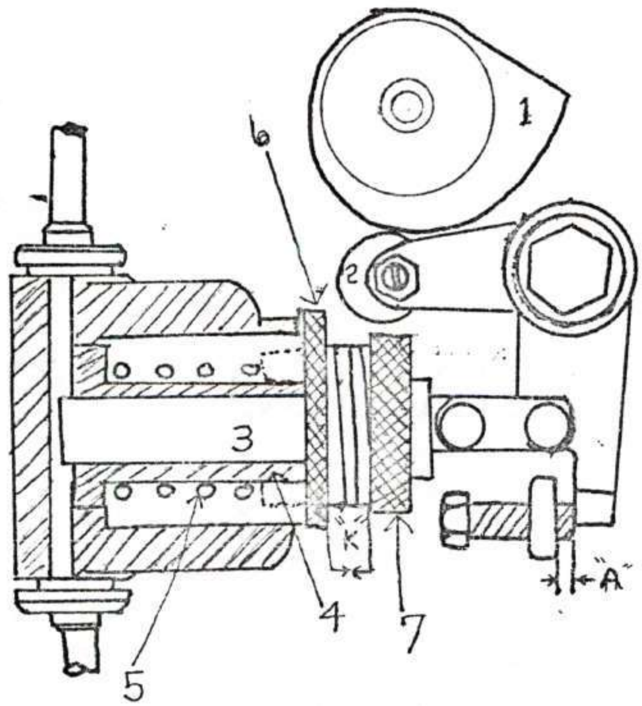
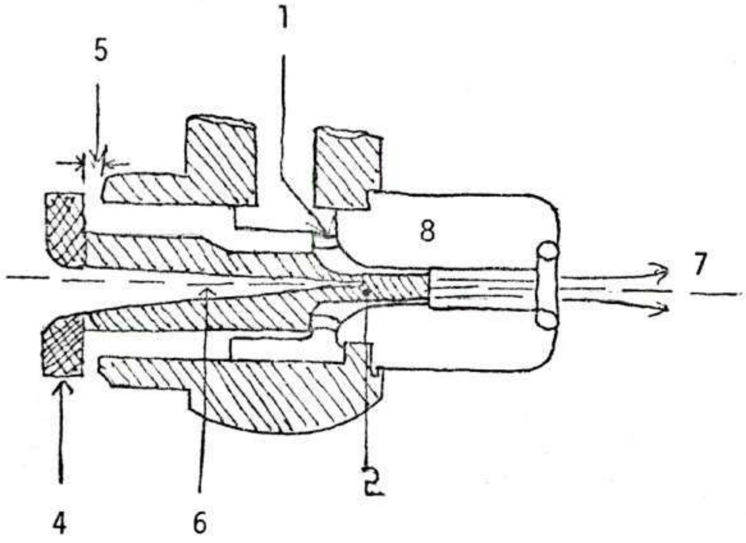
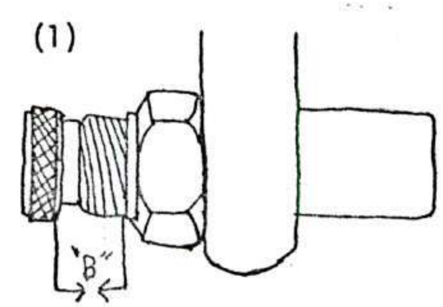


Figure 5. Pump-Cam Assembly. (Ref. 10)



(a)



(b)

Figure 6. Yarn Guide Nozzle Assembly.
(Ref. 10)

the weft yarn (7) and at this point a shear stress or drag accelerating force acting on the yarn surface is developed to propel the weft yarn through the open shed of the warp.

The clearance can be changed by either increasing or decreasing the gap (5) or by inserting larger or smaller diameter yarn guides while keeping the same size nozzle body. Figure 6(b) shows the external adjustment needed to alter the gap (5) in Figure 6(a). By screwing the yarn guide head (1) farther into the nozzle body or by unscrewing the yarn guide farther out of the nozzle body, this will alter the distance "B" as the "B" value decreases the clearance is decreased, causing a decrease in the annular area between yarn guide and nozzle.

The water volume per pick can also be altered. Referring to Figure 5, by increasing the "A" distance the effective intake and discharge strokes of the plunger are reduced resulting in a lower water volume/pick. In addition, the pump pressure and the yarn guide-nozzle clearance will affect the water volume per pick. In this study, the water volume per pick ranged between 1.1 to 2.5 cc's/pick.

3.2.2 Apparatus Used for Measuring Drag Force

The water jet nozzle is mounted on the loom so that yarn and water jet are ejected in a horizontal plane. To mount a force measuring device in this posistion is extremely difficult, therefore the nozzle was mounted so that the water jet was ejected vertically downward. This is more desirable for two reasons: ease of adapting a force measuring device and collineating the gravitional force with the yarn path.

The nozzle was then securely mounted and a transducer was mounted above the nozzle so that the force acting on the yarn going through the nozzle could be measured. A 1,000 ml. graduated cylinder was placed under the nozzle, to measure the water volume during picking. Thus a means of measuring water volume per pick was established. Figure 7 slows a schematic diagram of the final experimental set-up.

The Instron "A" load cell was used for measuring the drag force exerted on the yarn. The "A" load cell has a maximum load measuring capacity of 100 gms. The natural frequency of the load cell is 100 Hz. Since the picking speed used was 300 picks/min (5 picks/sec), interference caused by load cell natural vibration frequency should not cause random variations in the measured load.

When in operation the emerging water-jet on the yarn creates a drag force on the length of yarn it entrains. Since one end of the yarn is directly attached to the Instron load cell (Figure 8), this force will correspond to a voltage change by varying the resistance of the wheatstone bridge within the Instron load cell. The voltage signal corresponding to the drag force is very weak (5-50 millivolts). To convert the voltage signal to a more recordable form a Stratham model UR 5 Universal Transducer Readout amplifier was used to amplify the voltage signal, and to supply the excitation needed to operate the load cell.

The amplified signal was displayed on a Tektronix 5103 N Oscilloscope. The force/time curve was permanently recorded by using the accompanying polaroid oscilloscope camera. Figure 8 shows a schematic diagram of the recording apparatus and Figure 9 shows a typical oscillograph.

1. Instron load cell (A)
2. Frame supporting load cell & graduated cylinder
3. Support bracket for nozzle assembly
4. Nozzle Assembly
5. Jaw connecting yarn to Instron load cell
6. Water line from pump
7. Pump
8. Graduated cylinder
9. Mounting bracket to connect nozzle assembly to support bracket (3)

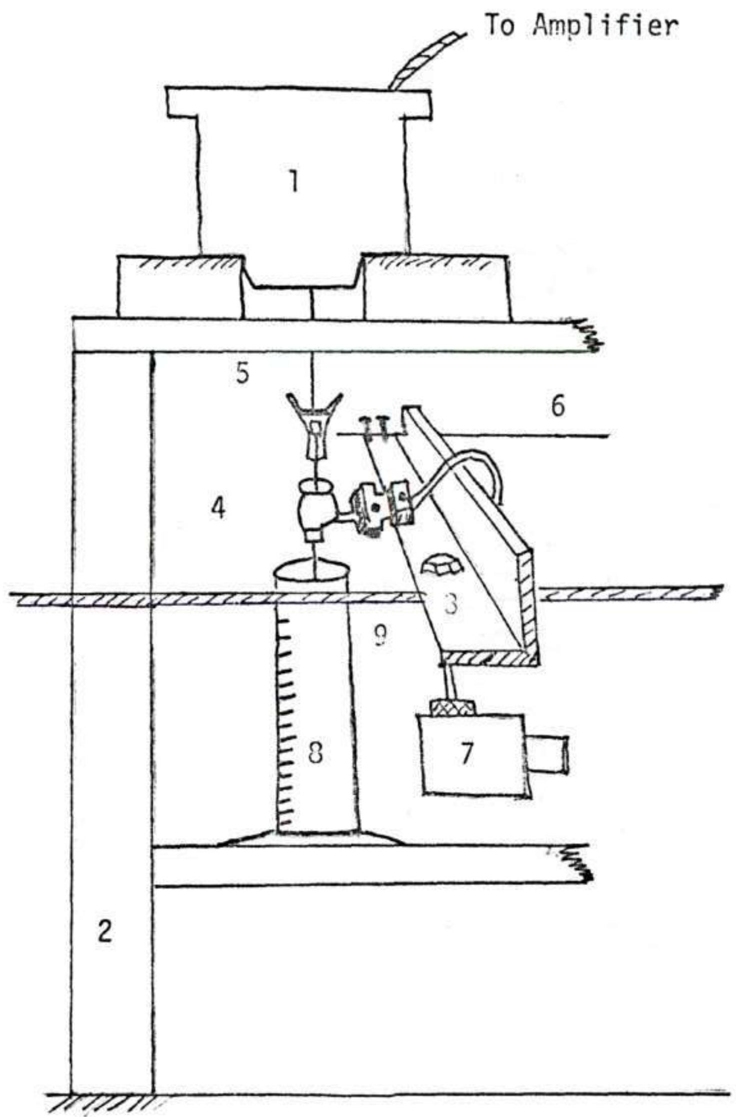
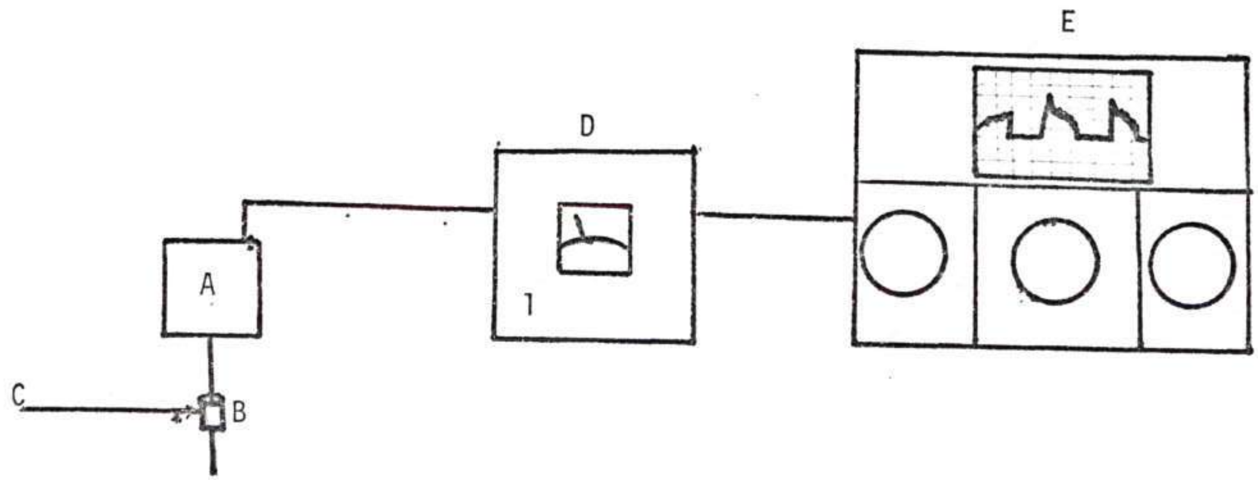


Figure 7. Experimental Set-Up.



A: Instron load cell A

B: Nozzle

C: Water line from pump

D: Model UR5 carrier amplifier

E: Tektronix 5103N oscilloscope system

Figure 8. Schematic Diagram of Force Measuring and Recording Equipment.

3.3 Experimental Procedure

The main objective in experimentation is to measure the initial drag force, which is represented by the first peak of the force-time curve in Figure 9. The initial drag force is considered because it determines such factors as initial weft acceleration, velocity, and the maximum potential straight distance the weft yarn can travel.

After the leading end of the weft has experienced the initial drag force and is out of the nozzle and into the shed, there is no further means for accelerating that portion of the weft, thus its motion is governed by the opposing air drag and gravity. It is for this reason that this investigation has concentrated on the initial drag force.

To carry out a test a selected yarn length is clamped to the Instron load cell jaw and threaded through the nozzle (Figure 7). The graduated cylinder is emptied before each test begins. The oscilloscope camera is placed into posistion and the necessary adjustments for recording the display are made. The loom is then started and picking takes place. The oscilloscope beam sweeps the screen once and a photograph of the force versus time is recorded on film. The sweep rate of the oscilloscope in all tests was .50 ms/division. Since there are 10 divisions on the screen the total time span in any picture is 1/2 second. With the loom operating at 5 picks/second a total of 2 1/2 picks are recorded on each photograph. When the test is completed the procedure is repeated in order to obtain at least four measurements per test condition.

3.3.1 Analysis of Test Results

In connecting the voltage signal of the transducer into a measurable force a calibration process is required. Calibration was accomplished

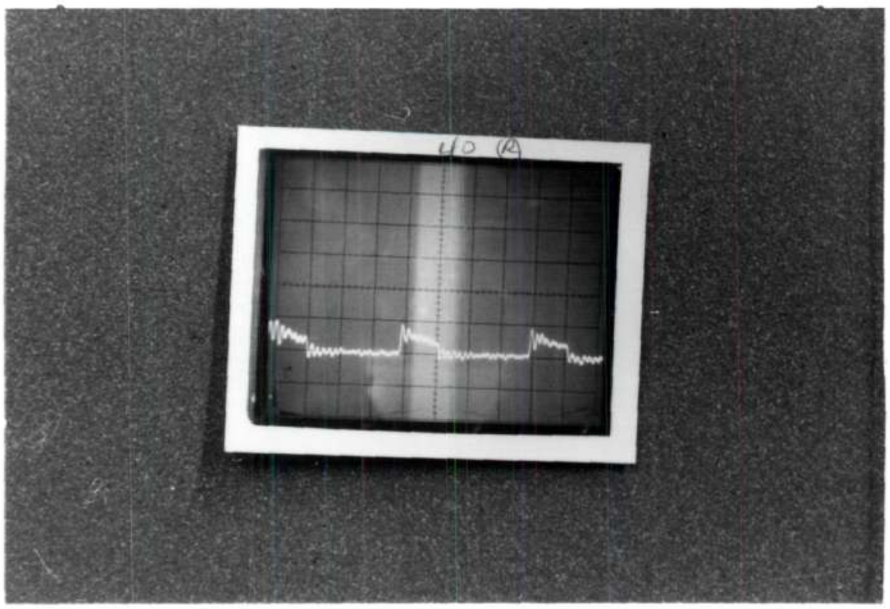


Figure 9. Typical Oscillograph.

by the dead weight technique. Referring to Figure 9 the oscilloscope screen is divided into 10 major horizontal and vertical divisions.

A 20 gram weight was hung from the Instron jaw. This caused the beam to be displaced seven-tenths of one vertical division. The force scale was established using equation (1).

$$\text{Drag force (in gms)} = \left(\frac{20}{0.7}\right)\left(\begin{array}{c}\text{number of vertical}\\ \text{divisions of beam}\\ \text{displacement}\end{array}\right) \tag{1}$$

i.e. one vertical division of beam displacement corresponds to a drag force of 28.57 grams.

The data discussed in Chapter IV were obtained by averaging the results of the four picks representing each test condition. The actual conversion of the beam displacement into force and the subsequent values for each pick are found in Appendix II.

CHAPTER IV

RESULTS AND DISCUSSION

Results of the average measured drag force are shown in Table 5. Figure 10 illustrates how the measured drag force varies with length of yarn protruding from nozzle. From Figure 10 it can be observed that the drag force rises to a maximum value when the protruding yarn length is about 3 inches (7 1/2 cm).

This can be attributed to the increase in surface area of the yarn with sufficient jet cohesion. Equation (2) shows this relationship

$$\text{Drag} \quad (V_j - V_w)^2 \times \text{density} \times \text{surface area} \qquad (2)$$

(Ref. 11)

where

V_j = velocity of the fluid

V_w = velocity of the weft yarn = 0

area = $\pi \times d \times \ell$

where d = diameter of weft yarn

ℓ = length of the weft yarn.

It is reinforcing to note that Dawson (7) observed a rapid increase in jet dispersion somewhere between 5-10 cm away from the nozzle, which closely corresponds to the yarn protruding length at which the maximum drag force was found.

A protruding length of one inch (2.54 cm) was used as the standard

Table 5. Measured Drag Force Results for Each Test (Average of at least four picks)

Test #	Drag Force
One	5.7 gms
Two	22.8 gms
Three	28.0 gms
Four	28.92 gms
Five	41.4 gms
Six	41.4 gms
Seven	40.0 gms
Eight	37.5 gms
Nine	36.7 gms
Ten	16.1 gms
11	22.8 gms
12	24.3 gms
13	26.8 gms
14	26.7 gms
15	23.92 gms
16	15.36 gms
17	8.57 gms
18	27.4 gms
19	27.8 gms
20	27.5 gms
21	27.8 gms
22	25.0 gms
23	21.8 gms
24	9.3 gms
25	17.85 gms
26	20.7 gms
27	23.4 gms
28	25.0 gms
29	16.4 gms
30	19.3 gms
31	23.25 gms
32	26.78 gms
33	8.57 gms
34	11.4 gms
35	10.35 gms
36	16.1 gms
37	42.14 gms
38	38.9 gms
39	36.8 gms
40	38.9 gms
41	34.3 gms
42	97.5 gms
43	54.6 gms
44	23.51 gms

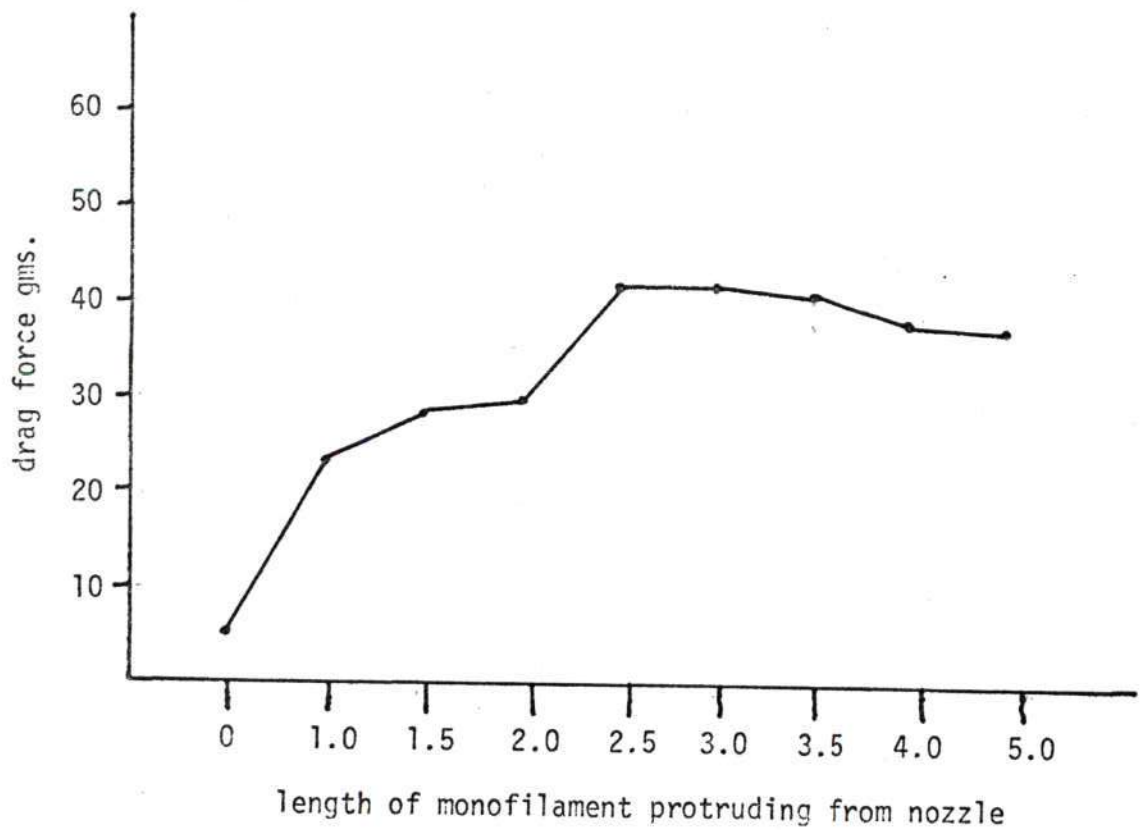


Figure 10. Drag Force vs. Length of Monofilament Protruding from Nozzle.

length for the remaining tests; even though it did not correspond to the maximum observed drag force. It is certain that in this case the yarn exposed to the fluid drag will be subjected to a coherent fluid jet. [note: Total yarn length is 1.5" (3.81 cm) since 1/2" (1.27 cm) of yarn length is entrained by the jet inside the nozzle body].

Figure 11 illustrates the effect of increasing yarn diameter on the measured drag force. From equation (2), the observed increase in drag force can be attributed to an increase in surface area of the yarn.

It is worth noting that the ratio of drag force to filament diameter is almost the same for all four monofilaments tested. This indicates that the drag force/unit area of fiber surface is unchanged provided the relative velocity of fluid remains unchanged.

Figure 12 shows the effect of pump pressure at the start of picking on drag force. Though pump pressure is not directly measured, the initial compressive deformation of the spring (indicated by the "K" value shown in Figure 5), is used for calculation of water pressure as explained in Appendix F.

An increase in water pressure at the start of picking should result in an increase in average velocity of fluid passing through the nozzle. This in turn will result in a higher shear strain rate at the fiber-fluid interface, thus developing a greater drag force, as shown in Figure 12.

Using a water pressure at the start of picking of 248.1 psi and a yarn length of 1" protruding out of the nozzle the effect of changing water vol./pick on the resulting drag force was then studied. Figure 5

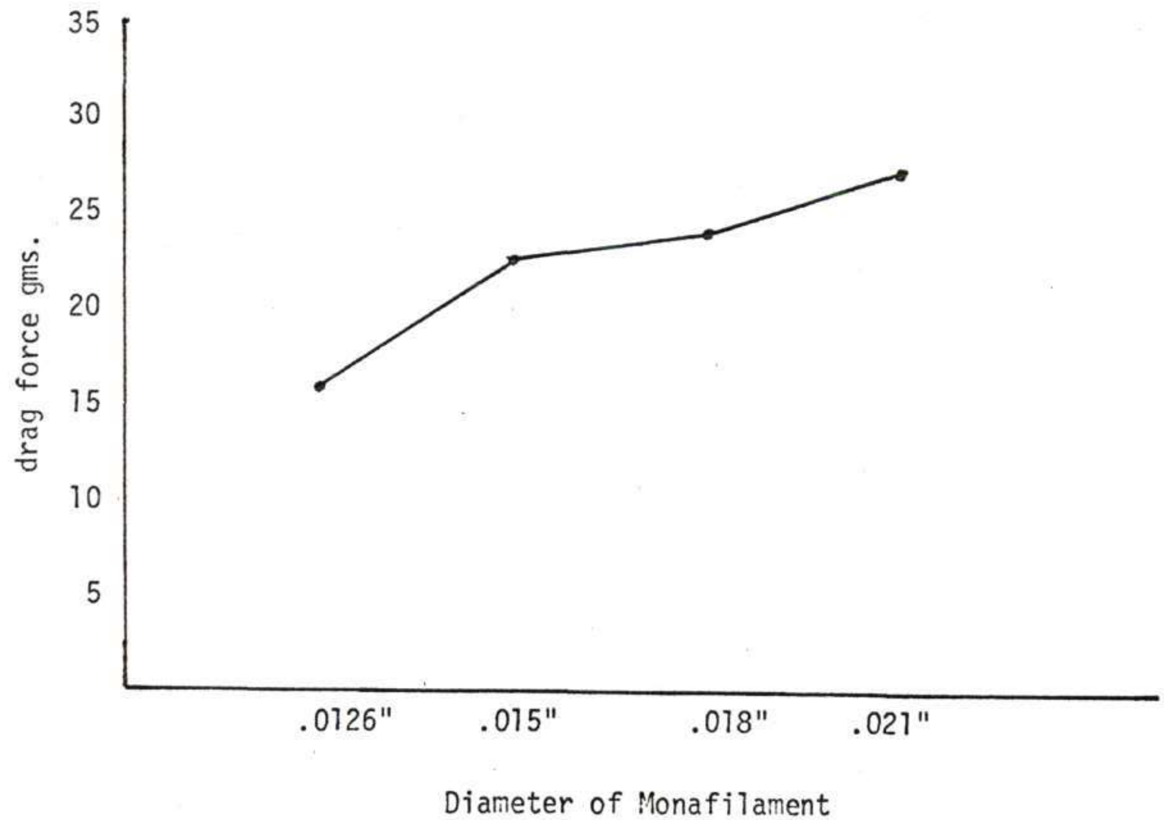


Figure 11. Drag Force vs. Diameter of Monofilament.

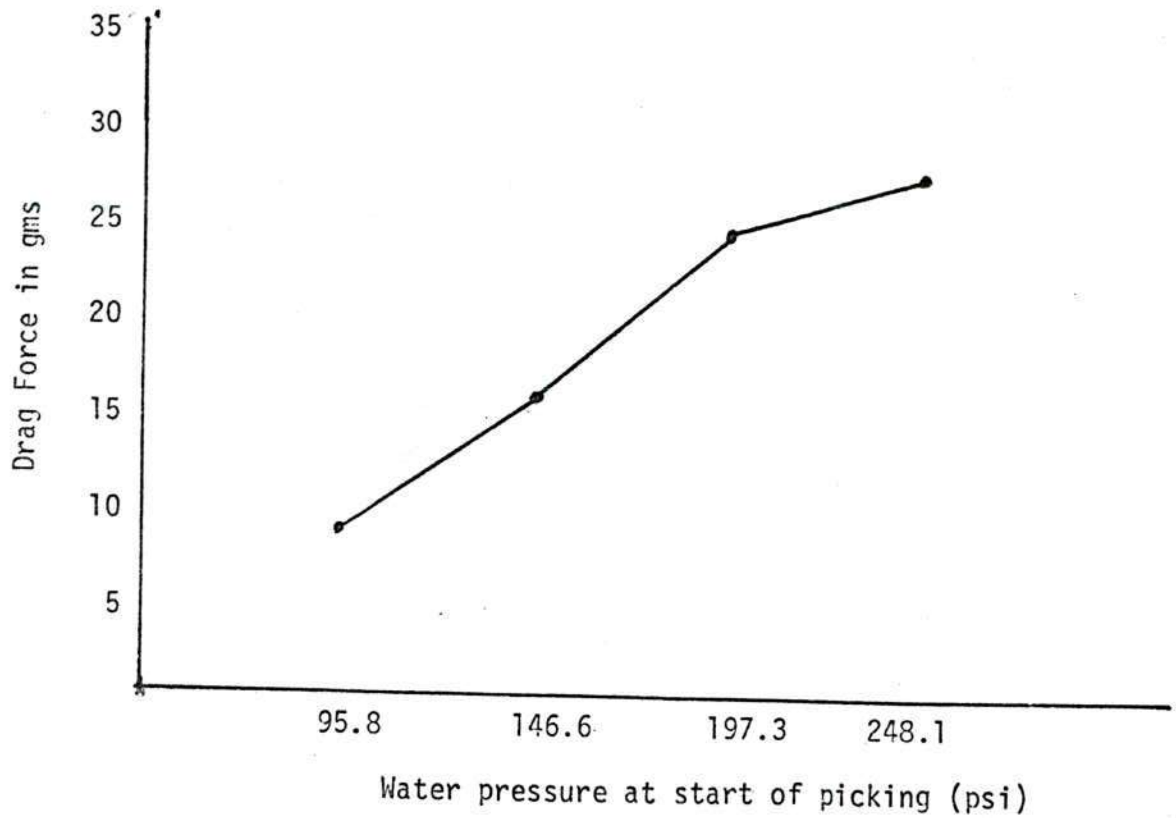


Figure 12. Drag Force vs. Water Pressure.

shows where the necessary adjustment was made. The "A" value is the measure of effective pump stroke. When the "A" value is large the effective pump stroke is reduced, thus less water is ejected from the cylinder during picking.

Measurements of the drag force were taken at two extreme values of effective pump stroke corresponding to an "A" value of 12 mm. for maximum effective pump stroke and an "A" value of 20 mm representing the minimum effective pump stroke.

The resulting values for the initial drag force were the same for both the maximum and minimum effective pump strokes (see Table 6). This indicates that as long as the water pressure at the start of picking remains unchanged the amount of water volume/pick will not affect the velocity gradient of the fluid at the filament - fluid interface.

Table 6. Initial Drag Force as a Function of Water Volume/Pick

"A" Value	Water vol/pick (cc's)	Drag Force (gms)
12 mm	2.24 cc's/pick	27.4 gms
20 mm	1.40 cc's/pick	27.8 gms

Observations of the force-time curves revealed that the time during which water was in contact with the yarn (i.e. duration of picking) was twice as long when using the maximum effective pump stroke length as to when the minimum effective pump stroke length was used. Thus it may be concluded that the amount of water volume used per pick can be reduced without losing desired picking performance. It may even be more desirable to use a shorter duration of picking in order to minimize the possibility of weft yarn buckling in air which is caused by continued acceleration of the weft trailing end. Thus, the use of a greater water pressure and a smaller water volume per pick can insure the insertion of a straight weft yarn through a shed over a longer distance. By increasing the working width of the loom an increase in the production rate (sq. yrd/hr) will also be obtained.

Figure 13 shows five different relative positions of the yarn guide end inside the nozzle body and Table 7 gives the maximum yarn drag forces recorded for each of these positions. In positions (1) and (2) in Figure 13 the yarn guide end is located inside the constant diameter zone (C in Figure 13) of the nozzle body and the drag forces recorded are approximately the same in both cases. When the yarn guide end is located in the fluid expansion zone (B in Figure 14) as shown in position (3) in Figure 13, some loss in drag force is recorded. This loss can be attributed to the expansion turbulence in zone B and when the yarn guide

Table 7. Effect of Yarn Guide End Location in Nozzle

Position Number (See Figure 14)	Drag Force (gms)
(1)	27.5
(2)	27.8
(3)	25.0
(4)	21.8
(5)	9.3

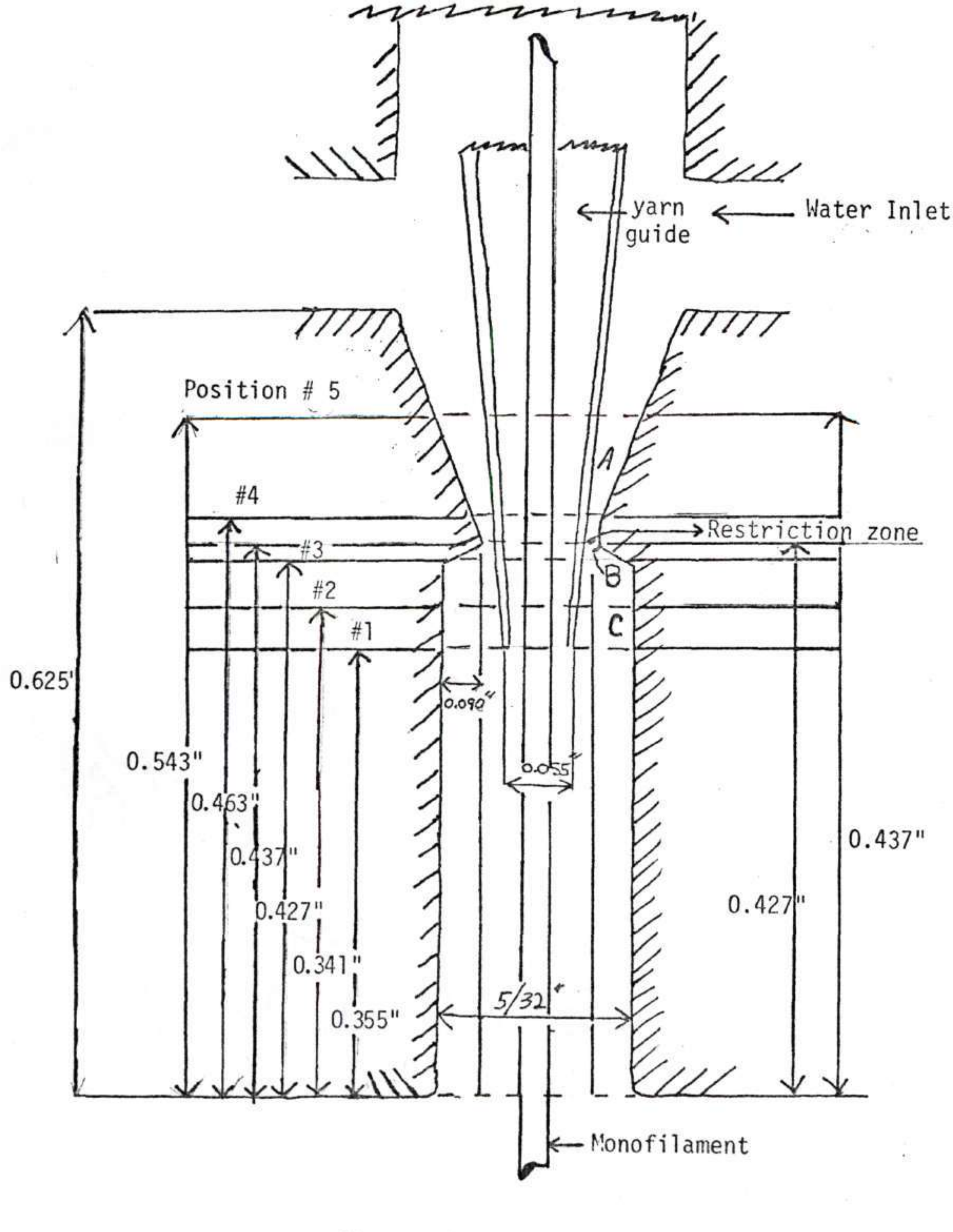


Figure 13. Nozzle Body Geometry.

end is moved further into the contraction zone (A in Figure 13) the excessive turbulence caused by entering water flow direction change and contraction results in very significant losses in drag force as evidenced by the data given in Table 7 for the case where the yarn guide end is located either in position (4) or (5).

Comparing the drag forces recorded in positions (4) and (5) it may be concluded that the closer the yarn guide end is to the water inlet, the greater the loss in drag force, since the effect of fluid direction change on the drag force nearer the water inlet increases.

In order to investigate the effect of the minimum clearance zone, (restriction zone in Figure 13),on drag force, three different yarn guides with ends of diameters of 1.0, 1.4, 1.6 mm have been used with the same nozzle body and in the same position (position (1) shown in Figure 13). The data shown in Table 8 indicate that when the radial width of the restriction zone is excessively small, (i.e., in case 3, Table 8) the yarn drag force will be significantly reduced. This should be expected since an excessively small restriction zone offers a greater

Table 8. Effect of Reduced Restriction Zone on the Drag Force and Water Flow Rate (cc's/pick)

				Drag Force (gms)	
Case No.	Diameter of yarn Guide end	Radial Width of restriction zone	Water Volume* per pick (cc's/pick)	Monofilament .0126"	Diameter .015"
1	1.0 mm	.016"	2.58	17.85	20.7
2	1.4 mm	.008"	2.24	16.4	19.3
3	1.6 mm	.004"	1.38	8.57	11.4

*Actual value obtained from Appendix C.

resistance to fluid flow, thus reducing the rate of flow and the average fluid velocity in the constant diameter zone of the nozzle.

This was further confirmed by measurement of water volume per pick as indicated by the data shown in Table 8.

In Table 9, drag forces for nylon and polyester multifilament yarns are given. As shown therein, the drag force is expressed in two additional different ways, namely drag force/unit of surface area and drag force/denier.

Table 9. Drag Force Results for the Multifilament Yarns Used.

Fiber Type	Yarn Denier	# of Filaments	Total Drag Force (gms)	Drag Force Force/unit area of Fiber Surface (gms/cm^2)	Drag Force per Denier (gms/Denier)
Nylon	100	50	42.14	6.29	.421
Nylon	100	34	38.9	8.52	.389
Nylon	100	26	36.8	10.59	.368
Polyester	70	34	34.3	11.19	.490
Polyester	100	34	38.9	9.93	.389
Polyester	220	50	54.6	6.07	.248
Polyester	440	100	97.5	3.84	.222

Comparing the data for 100/50 nylon and 70/34 polyester yarns to those for the other yarns listed in the table, it is evident that the finer the component filaments the higher the drag force/denier. This could be attributed to the fact that the ratio of circumference to the cross-sectional area of a circular cross-section decreases as the diameter of the circle increases.

Also, from the drag force per unit of fiber surface area data for both the nylon and polyester multifilament yarns (Table 9), it is evident that as the number of fibers in a yarn decreases the drag force/unit of fiber surface area increases. This can possibly be explained as a shielding effect, whereby the outer fibers of the yarn prevent a complete fiber - fluid interaction from taking place at the surface of the inner fibers. Thus the total number of fibers effectively interacting with the fluid is reduced.

To verify this explanation the drag force/unit area of fiber surface was calculated for the monofilament yarns (see Table 10). A case where the shielding effect is completely eliminated. As shown in Table 10, the drag force/unit of surface area is approximately the same for all monofilaments used.

Table 10. Results for Monofilament Yarn when Expressing Drag Force as Drag Force/Unit of Surface Area (gms/cm^2)

Monofilament Diameter	Drag Force (gms)	Drag force/unit of surface area (gms/cm^2)
.0126"	16.4	42.87
.015"	19.3	42.38
.018"	23.2	42.51
.021"	26.78	42.00

Although not reported here, some drag force measurements have been carried out using cotton yarns. The drag force recorded was so low that the initial drag force peak could hardly be detected. Since cotton yarn, in comparison to a continuous filament yarn is highly twisted, the shielding effect seems to play a significant role in reducing the total drag force.

The effect of changing the pump spring constant on the drag force was investigated using springs with different constants. To compare the effect of using a stiffer spring the conditions of test number 29 (.015" diameter monofilament nylon) and test number 43 (220/50 polyester) were duplicated with the exception of using a higher spring constant.

The data in Table 11 show that by using the higher constant spring the initial drag force will increase. This can be attributed to the higher initial water pressure and its consequent effect on drag force as previously discussed (see discussion of parameter three).

Table 11. Effect of Spring Constant on Drag Force.

	Drag Force (gms)	
Type of Strand	63.5 lb/in Spring Constant	68 lb/in Spring Constant
Monofilament	19.3 gms	23.57 gms
Multifilament	55 gms	64.3 gms

CHAPTER V

CONCLUSIONS

The drag force measuring apparatus and testing procedure described in this thesis are suitable for obtaining measurements of the initial drag force exerted on the weft yarn by the fluid elements of the water jet.

It is concluded that without the addition of fluid additives or major redesigning of the picking components the initial drag force can be significantly increased by the optimization of the existing picking component variables and weft yarn variables. By increasing the pump pressure (therefore the water pressure), the initial drag force will increase.

The yarn guide end should be positioned in the constant diameter zone of the nozzle body. Also by increasing the radial width of restriction zone the fluid energy loss will be minimized, thereby increasing the drag force.

The higher the pump spring constant the greater the water pressure, therefore the greater initial drag force.

It has also been found that the water volume per pick (provided water pressure is not affected) can be reduced without affecting the initial drag force. Minimizing the water volume per pick will lead to a shorter picking cycle, with a reduction in the picking duration the likelihood of weft buckling is lessened. Of the yarn variables studied, it is concluded that the greater the surface area of the yarn the higher the drag force will be, provided that all the fibers in the yarn are interacting with the water-jet.

It has been found that for multifilament yarns, the effective surface area that is interacting with the yarn is a function of the yarn surface area. The fibers below the yarn surface are shielded from the jet and as a result as the number of fibers in the yarn decreases the drag force/unit of fiber surface area increases.

Finally, the finer the component filaments, the higher the drag force per denier, due to an increase in effective fiber surface area per unit volume.

APPENDIX A

DESCRIPTION OF ALL TESTS AND CORRESPONDING INITIAL CONDITIONS

Test No.	Condition varied	Description of Test	K Value in inches	A Value in inches	Position of Yarn Guide
1	yarn protruding length	0" protrudion	.25"*	.475*	# 1
2	yarn protruding length	1.0" protrudion	.25"	.475	# 1
3	yarn protruding length	1.5" protrudion	.25"	.475	# 1
4	yarn protruding length	2.0" protrudion	.25"	.475	# 1
5	yarn protruding length	2.5" protrudion	.25"	.475	# 1
6	yarn protruding length	3.0" protrudion*	.25"	.475	# 1
7	yarn protruding length	3.5" protrudion	.25"	.475	# 1
8	yarn protruding length	4.0" protrudion	.25"	.475	# 1
9	yarn protruding length	5.0" protrudion	.25"	.475	# 1
10	monofilament diameter	.0126" diameter	.25"	.475	# 1
11	monofilement diameter	.015" diameter	.25"	.475	# 1
12	monofilament diameter	.018" diameter	.25"	.475	# 1
13	monofilament diameter	.0216" diameter	.25"	.475	# 1
14	pump pres./water pres.	248.1 psi*	.25"	.475	# 1
15	pump pres./water pres.	197.3 psi	.50"	.475	# 1
16	pump pres./water pres.	146.6 psi	.75"	.475	# 1
17	pump pres./water pres.	95.38 psi	1.00"	.475	# 1
18	pump stroke	A value=.475"*	.25"	.475"	# 1
19	pump stroke	A value=.783"	.25"	.783	# 1
20	position of yarn guide end in nozzle	Position # 1	.25"	.475"	# 1
21	"	Position # 2	.25"	.475"	# 2
22	"	Position # 3	.25"	.475"	# 3
23	"	Position # 4	.25"	.475"	# 4
24	"	Position # 5	.25"	.475"	# 5
25	yarn guide end dia.	Yarn guide* end dia.=1.0 mm	.25"	.475"	# 1
26	yarn guide end dia.	"	.25"	.475"	# 1
27	yarn guide end dia.	"	.25"	.475"	# 1
28	yarn guide end dia.	"	.25"	.475"	# 1
29	yarn guide end dia.	" 1.4 mm	.25"	.475"	# 1
30	yarn guide end dia.	" 1.4 mm	.25"	.475"	# 1
31	yarn guide end dia.	" 1.4 mm	.25"	.475"	# 1
32	yarn guide end dia.	" 1.4 mm	.25"	.475"	# 1
33	yarn guide end dia.	" 1.6 mm	.25"	.475"	# 1
34	yarn guide end dia.	" 1.6 mm	.25"	.475"	# 1
35	yarn guide end dia.	" 1.6 mm	.25"	.475"	# 1
36	yarn guide end dia.	" 1.6 mm	.25"	.475"	# 1
37	yarn & yarn surf.area	100 denier nylon 50 fil.	.25"	.475"	# 1
38	yarn & yarn surf. area	100 denier nylon 34 fil.	.25"	.475"	# 1
39	yarn & yarn surf. area	100 denier nylon 26 fil.	.25"	.475"	# 1
40	yarn & yarn surf. area	100 denier poly-ester 34 fil.	.25"	.475"	# 1

*indicates a maximum condition

Test No.	Condition varied	Description of Test	K Value in inches	A Value in inches	Position of Yarn Guide
41	yarn & yarn surf. area	70 denier polyester 34 fil.	.25"	.475"	# 1
42	yarn & yarn surf. area	440 denier polyester 100 fil.	.25"	.475"	# 1
43	yarn & yarn surf. area	220 denier polyester 50 fil.	.25"	.475"	# 1
44	spring constant	63.5 lb/in	.25"	.475"	# 1
45	spring constant	68 lb/in	.25"	.475"	# 1

Test No.	Yarn Guide End Diameter (in mm)	Yarn used and Description	Water Vol Per Pick	Multifilament Yarn Surface Area (sq. in)
1	1.4	.015" mono-filament nylon	2.24 cc's	
2	1.4	.015" mono-filament nylon	2.24 cc's	
3	1.4	.015" mono-filament nylon	2.24 cc's	
4	1.4	.015" mono-filament nylon	2.24 cc's	
5	1.4	.015" mono-filament nylon	2.24 cc's	
6	1.4	.015" mono-filament nylon	2.24 cc's	
7	1.4	.015" mono-filament nylon	2.24 cc's	
8	1.4	.015" mono-filament nylon	2.24 cc's	
9	1.4	.015" mono-filament nylon	2.24 cc's	
10	1.4	.0126" diameter	2.24 cc's	
11	1.4	.015" diameter	2.24 cc's	
12	1.4	.018" diameter	2.24 cc's	
13	1.4	.024" diameter	2.24 cc's	
14	1.4	.024" diameter	2.24 cc's	
15	1.4	.024" diameter	1.94 cc's	
16	1.4	.024" diameter	1.72 cc's	
17	1.4	.024" diameter	1.44 cc's	
18	1.4	.024" diameter	2.24 cc's	
19	1.4	.024" diameter	1.38 cc's	
20	1.4	.024" diameter	2.24 cc's	
21	1.4	.024" diameter	2.4 cc's	
22	1.4	.024" diameter	2.5 cc's	
23	1.4	.024" diameter	2.7 cc's	
24	1.4	.024" diameter	2.8 cc's	
25	1.0	.0126" mono nylon	2.48 cc's	
26	1.0	.015" mono nylon	2.48 cc's	
27	1.0	.018" mono nylon	2.48 cc's	
28	1.0	.021" mono nylon	2.48 cc's	
29	1.4	.0126" mono nylon	2.24 cc's	
30	1.4	.015" mono nylon	2.24 cc's	
31	1.4	.018" mono nylon	2.24 cc's	
32	1.4	.021 mono nylon	2.24 cc's	
33	1.6	.012" mono nylon	1.38 cc's	
34	1.6	.015" mono nylon	1.38 cc's	
35	1.6	.018" mono nylon	1.38 cc's	
36	1.6	.021" mono nylon	1.38 cc's	
37	1.0	100 denier nylon 50 fil	2.48 cc's	1.037 in
38	1.0	100 denier nylon 34 fil	2.48 cc's	.704 in
39	1.0	100 denier nylon 26 fil	2.48 cc's	.593 in
40	1.0	100 denier polyester 34 fil	2.48 cc's	.636 in
41	1.0	70 denier polyester 34 fil	2.48 cc's	.535 in
42	1.4	440 denier polyester 100 fil	2.24 cc's	3.94 in
43	1.4	220 denier polyester 50 fil	2.24 cc's	1.392 in
44	1.4	.015" dia monofilament	2.24 cc's	
45	1.4	220 denier polyester 50	2.24 cc's	1.392 in

APPENDIX B

CALCULATION OF AVERAGE DRAG FORCE FOR ALL TESTS, BASED ON # OF DIVISIONS BEAM WAS DISPLACED FROM REFERENCE LINE ON OSCILLOSCOPE

Test One
.2
.2
.2 x 28.57 = 5.7 gms

Test Two
.7
.96
.8
.75
.8 x 28.57 = 22.8 gms

Test Three
1.0
1.0
.9
1.0
.975 x 28.57 = 28.00 gms

Test Four
1.0
1.0
.95
1.1
1.0125 x 28.57 = 28.92 gms

Test Five
1.5
1.3
1.6
1.4
1.45 x 28.57 = 41.4 gms

Test Six
1.4
1.6
1.5
1.3
1.45 x 28.57 = 41.4 gms

Test Seven
1.6
1.3
1.4
1.3
1.4 x 28.57 = 40 gms

Test Eight
1.4
1.4
1.2
1.25
1.31 x 28.57 = 37.5 gms

Test Nine
1.1
1.3
1.4
1.3
1.275 x 28.57 = 36.7 gms

Test 10
.6
.5
.6
.55
.5625 x 28.57 = 16.1 gms

Test 11
.7
.95
.8
.75
.8 x 28.57 = 22.8 gms

Test 12
.9
.9
.85
.75
.85 x 28.57 = 24.3 gms

Test 13
1.0
.85
1.0
.9
.9375 x 28.57 = 26.8 gms

Test 14
1.0
.9
.95
.9
.9375 x 28.57 = 26.7 gms

Test 15
.85
.80
.85
.85
.8375 x 28.57 = 23.92 gms

Test 16
.55
.55
.50
.55
.5375 x 28.57 = 15.36 gms

Test 17
.3
.3
.35
.25
.3 x 28.57 = 8.57 gms

Test 18
1.0
.95
.95
.95
.9625 x 28.57 = 27.4 gms

Test 19
.99
.95
1.0
.95
.9725 x 28.57 - 27.8 gms

Test 20
1.0
.95
.95
.95
.9625 x 28.57 = 27.5 gms

Test 21
1.0
.99
.95
.95
.9725 x 28.57 = 27.8 gms

Test 22
.8
.95
.90
.85
.875 x 28.57 = 25.0 gms

Test 23
.8
.75
.75
.75
.76 x 28.57 = 21.8 gms

Test 24
.03
.035
.035
.03
.33 x 28.57 = 9.3 gms

Test 25
.75
.65
.60
.50
.625 x 28.57 = 17.85 gms

Test 26
.70
.75
.70
.75
.725 x 28.57 = 20.7 gms

Test 27
.75
.80
.825
.9
.82 x 28.57 = 23.4 gms

Test 28
.80
.90
.80
1.0
.875 x 28.57 = 25.0 gms

Test 29
.7
.6
.5
.5
.575 x 28.57 = 16.4 gms

Test 30
.5
.7
.8
.7
.675 x 28.57 = 19.3 gms

Test 31
.75
.95
.80
.75
.8125 x 28.57 = 23.25 gms

Test 32
1.0
.9
1.0
.9
.9375 x 28.57 = 26.78 gms

Test 33
.3
.3
.3
.3
.3 x 28.57 = 8.57 gms

Test 34
.4
.4
.4
.4
.4 x 28.57 = 11.4 gms

Test 35
.4
.3
.35
.4
.3625 x 28.57 = 10.35 gms

Test 36
.6
.6
.5
.55
.5625 x 28.57 = 16.1 gms

Test 37
1.4
1.4
1.6
1.5
1.475 x 28.57 = 42.14 gms

Test 38
1.4
1.45
1.4
1.2
1.3625 x 28.57 = 38.9 gms

Test 39
1.0
1.3
1.5
1.35
1.2875 x 28.57 = 36.8 gms

Test 40
1.4
1.2
1.5
1.35
1.3625 x 28.57 = 38.9 gms

Test 41
1.4
1.0
1.1
1.3
1.2 x 28.57 = 34.3 gms

Test 42
3.4
3.3
3.35
3.60
3.4 x 28.57 = 97.5 gms

Test 43
1.8
1.65
2.0
2.2
1.9 x 28.57 = 54.6 gms

Test 44
.8
.8
.8
.9
.825 x 28.57 = 23.57 gms

Test 45
2.0
2.0
2.5
2.5
2.25 x 28.51 = 64.3

APPENDIX C

DETERMINATION OF WATER VOLUME PER PICK FOR THE THREE YARN GUIDE DIAMETERS USED

Procedure

The loom was run for a total of 10 seconds with the total amount of water collected in the graduated cylinder. The amount of water is then divided by 10 to obtain the average volume of water/sec. Dividing this average volume by 50 will give the water volume/pick for a loom running time of 300 picks/minute.

For each yarn guide diameter used the procedure was repeated 10 times.

Yarn Guide End Diameter		
1.0 mm	1.4 mm	1.6 mm
134 cc's	112 cc's	62 cc's
131 cc's	112 cc's	65 cc's
128 cc's	112 cc's	64 cc's
129 cc's	110 cc's	63 cc's
125 cc's	112 cc's	65 cc's
129 cc's	114 cc's	61 cc's
130 cc's	114 cc's	67 cc's
127 cc's	112 cc's	63 cc's
129 cc's	113 cc's	65 cc's
128 cc's	112 cc's	65 cc's
1290 cc's	1123 cc's	640 cc's
1290/10 = 129 cc's	1123/10 = 112.3 cc's	640/10 = 64 cc's
129/50 = 2.58 cc's	112.3/50 = 2.246 cc's	64/50 = 1.28 cc's

APPENDIX D

EQUATIONS USED TO CONVERT DENIER TO DIAMETER AND SURFACE AREA

I. Equation used to convert denier to diameter (ref. 12)

$$\underset{\text{(in cm)}}{\text{Diameter}} = \sqrt{\frac{4 \times \text{denier}}{\pi \times 9 \times 10^5 \times \rho}}$$

where

denier = total yarn denier

ρ = density of material

(for nylon ρ = 1.14 gms/cc)

(for polyester ρ = 1.38 gms/cc)

9×10^5 = expression for linear density of a one denier yarn

II. Diameter for 100 denier nylon

$$D = \sqrt{\frac{4 \times 100}{9 \times 10^5 \times 1.14 \times \pi}} = \frac{.011 \text{ cm}}{2.54 \text{ cm}} = .0044''$$

III. Surface area for the nylon multifilaments used

A. 100D/50 fil. nylon

$50 \times .0044'' \times \pi \times 1.5'' = 1.037$ sq in

B. 1000/34 fil. nylon

$34 \times .0044'' \times \pi \times 1.5'' = .704$ sq in

C. 100D/26 fil. nylon

$26 \times .0044'' \times \pi \times 1.5'' = .539$ sq in

IV. Surface area for the polyester multifilaments used

A. 100D/34 fil polyester

$34 \times .00398'' \times \pi \times 1.5'' = .636$ sq in

B. 70D/34 fil. polyester

$34 \times .0033'' \times \pi \times 1.5'' = .535$ sq in

C. 220 denier/50 fil. polyester

$50 \times .0059'' \times \pi \times 1.5'' = 1.392$ sq in

D. 440 denier/100 fil. polyester

$100 \times .0084'' \times \pi \times 1.5'' = 3.940$ sq in

APPENDIX E

CONVERSION OF "K" VALUES INTO WATER PRESSURE (PSI)

Water pressure = Force on plunger/area of plunger

For case where there is no pre-loading of pump spring (i.e "K" = 1")

$$\text{Water pressure} = \frac{63.52\text{lbs} \times 0.472''}{\pi/4\ D^2p}$$

where

63.52 lbs = spring modulus

.472" = length of pump stroke

Dp = plunger dia.

$$= \frac{63.52 \times 4 \times 0.472''}{\pi \times D^2p}$$

$$= \frac{38.158}{D^2p} = 95.83\ \text{16/sq in.}$$

For "K" 0.75"

$$\text{Water pressure} = 95.83 \times \frac{(472 + .25)}{.472}$$

$$= 146.58\ \text{psi}$$

For "K" 0.50"

$$\text{Water pressure} = 95.83 \times \frac{(472 + .5)}{.472}$$

$$= 197.34\ \text{psi}$$

For "K" = 0.25"

$$\text{Water pressure} = 95.83 \times \frac{(.472 + .75)}{.472}$$

$$= 248.1 \text{ psi}$$

LITERATURE CITED

1. Lord, P. R., and Mohamed, Weaving: Conversion of Yarn to Fabric, Merrow Publishing Co. Ltd., Great Britain, 1973.

2. V. T. Cheung, M. S. Thesis, University of Manchester Institute of Science and Technology, Manchester U.K., 1971.

3. J. C. Brooks, U. S. P., 1,096,283.

4. V. Svaty, et al., B. P., 773,531.

5. K. Greenwood, "Weft Insertion by Water Jet," Modern Developments in Weaving Machinery, ed. V. Duxbury and G. R. Wray (Manchester and London U.K.; 1962) pp. 127-146.

6. Dawson, R. M. and J. F. Moseley, J. Textile Inst., 639, Vol. 65, No. 12 (1974).

7. Dawson, R. M., J. Textile Inst., 645, Vol. 65 No. 12 (1974).

8. Dawson, R. M., J. Textile Inst., 648, Vol. 65 No. 12 (1974).

9. Dawson, R. M., J. Textile Inst., 654, Vol. 65, No. 12 (1974)

10. Nissan Motor Co., Ltd. Service Manual for Nissan Jet-Loom Model Lw 41.

11. Shapiro, A. H., Shape and Flow, Anchor Books, Doubleday, 1961

12. Freeston, W. D., unpublished, Class Lecture notes.

OTHER REFERENCES

1. Gasiorek, J. M. and W. G. Carter, Mechanics of Fluids for Mechanical Engineers, Blackie & Son (London, 1967).

2. Schtlichting, H., Boundary Layer Theory, trans. Dr. J. Kestin, New York, 1960.

3. Tayebi, A. Private communication during course of thesis work.