Factors governing the choice of supply yarns suitable for air-jet texturing

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Supply (feeder) yarns used for conversion by the air-jet texturing process have been the yarns developed for the traditional deform-and-heat-set processes such as the false-twist texturing process. Because the market for air-jet textured yarns was comparatively smaller than that for false twist textured yarns, fiber producers have not seriously considered de-veloping supply yarns specifically for the air-jet texturing process. Perhaps, the fact that so lit-tle was understood about the mechanism of the air-jet texturing process, thereby providing little knowledge regarding the specification of the yarn properties required for this process, hindered such developments. In this paper I will attempt to identify certain requirements of the supply yarns for the air-jet texturing pro-cess.

Of course one of the most important factors in processing filament yarns by air-jets is the fluid forces acting on the filaments, because they primarily determine the resultant forces acting on the filaments. Filaments with varying fine-ness, different cross-sectional shapes and dif-ferent filament numbers within the yarn bundle will behave differently in the air flow. These properties of the supply yarns will be analysed together with other factors, such as the applied spin finish, which affect the choice of suitable supply yarns. Firstly an understanding of the fluid forces acting on the filaments is required.

Fluid forces acting on the filaments

In the air-jet texturing process the forces acting on the filaments are the forces due to the prim-ary flow (F_p), the forces due to secondary flow (F_5) and the frictional forces (F_1) as shown in Fig. 1. Fluid forces due to the primary and sec-ondary air flows in a texturing nozzle, as well as the frictional forces, all affect the resultant force acting on the filaments. In particular fric-tional forces play an important role in the tex-turing process [1]. In the following analysis of the fluid forces, only primary flow effects will be considered, but it should be noted that the ap-proach used here could also be applied to the secondary flow.
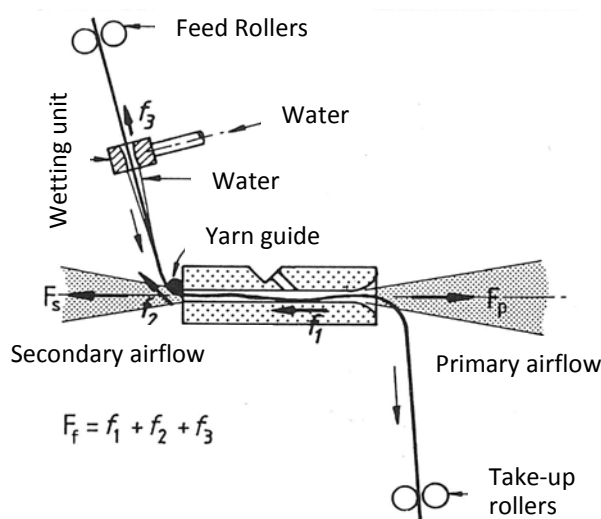

Fig. 1 Schematic diagram of the texturing nozzle showing the frictional forces acting on the filaments

In order to simplify the analysis, a short incre-mental section of a single filament, subject to the air flow in the texturing nozzle, as shown in Fig. 2, is considered. It is assumed firstly that this filament increment is rigid (in order to apply the laws of mechanics) and secondly its mo-tion is two-dimensional i.e., on the xy plane. The resultant forces and moments acting on the filament are generated by the relative vel-ocity between the fiber and the surrounding air flow. Fluid forces acting on the filaments in the x and y directions (D_x and D_y respectively) can be expressed in terms of the pressure- and frictional-drag forces, D_p and D_f respectively [2]. These fluid forces in the x and y directions are:

$$D_x = D_p \sin\phi + D_f \cos\phi \qquad\qquad (1)$$

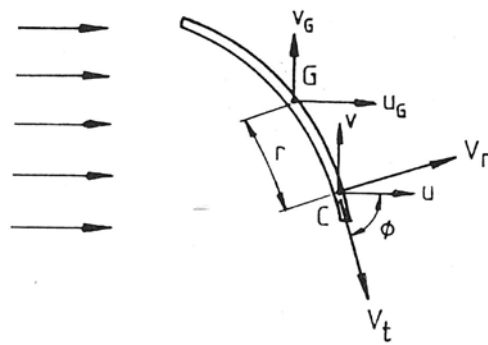$$D_y = D_p \cos\phi + D_f \sin\phi \qquad\qquad (2)$$

Fig. 2 Model of a textile fiber in an air flow: $V_n = (u-u_G)\sin\phi + (v-v_G)\cos\phi + r(d\phi/dt)$
$V_t = (u-u_G)\cos\phi + (v-v_G)\sin\phi$

As equations 1 and 2 indicate, the fluid forces in the x and y directions are functions of the angle of attack, 0, of the air flow and the drag forces D_p and 01. These drag forces are func-tions of the normal and tangential components of the flow velocity, V n and V1, and the pro-jected and surface areas A_P and A_S of the fiber within the flow.

The resultant force (F,) acting on a filament in an air-jet texturing nozzle is determined by the primary and secondary fluid forces, i.e., F_p and F_s , acting on the segment of the filament within the nozzle and by the frictional forces (F_1), due to contacts it makes with the nozzle internal surfaces (f_1), with the yarns guides (f_2) and with the wetting unit (f_3) (Fig. 1). In addition to these frictional forces, there occurs also a further fric-tional force due to the longitudinal movement of the filaments relative to each other [1]. Since the primary flow is much stronger than the secondary flow, because of the greater momentum transferred to it from the incoming jets owing to the orientation of their inlet bores, the resultant fluid force acting on the filaments is in the direction of the primary flow, i.e., F ,Fs. The resultant force (F,) acting on a filament is therefore:

$$F_r = F_p - F_s - F_t \qquad\qquad (3)$$

Factors effecting fluid forces

The drag force acting on a filament under any given flow conditions is a function of the local air velocity and of the filament surface and the projected areas exposed to the flow. The air

velocity is mainly determined by the air supply pressure, whereas the velocity gradient is de-termined by the design of the nozzle [3,4]. The surface and projected areas exposed to the flow are determined by the width (diameter for a circular filament) and length of the filament exposed to the air flow, and also by the position of the filament across the nozzle and its orien-tation.

Filament position

The surface area of a filament exposed to the flow is determined by the length of the filament in the air stream at any instant, whereas the in-stantaneous projected area depends on the position of the filament in the nozzle. Although the surface area of a filament subject to the flow in the nozzle does not vary significantly with its position, its projected area does vary considerably. A filament within the upper part of the nozzle has a greater projected area than a filament within the lower part for downward take-up (Fig. 3) and vice versa for the upward take-up, and therefore is subject to higher fluid forces in a flow even with a uniform velocity · distribution. A non-uniform velocity profile of course would enhance the variations in forces acting on the filaments. Different fluid forces acting on the filaments at different positions in the nozzle at any instant cause them to travel at different speeds and hence to be displaced longitudinally relative to each other.
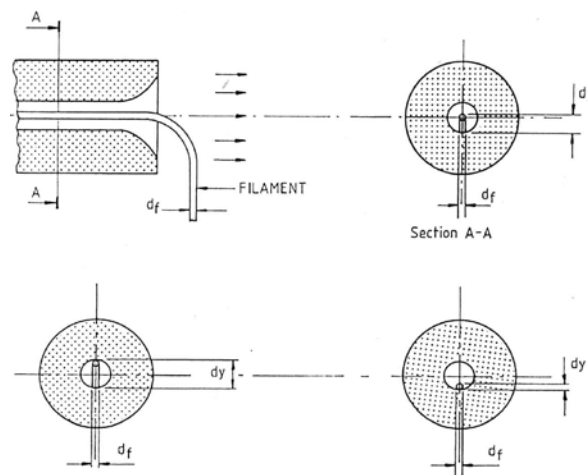

Fig. 3 Schematic illustration of the variation of the filament projected area with its position in the nozzle

Filament fineness

A circular filament of larger diameter will give rise to greater drag forces owing to its greater projected area and surface area i.e., F, is proportional to d1. On the other hand, its inertial resistance to the fluid forces is expressed in terms of the momentum flux required to trans-port these filaments, which can be expressed as follows:

$$m_t\, V_t = (\pi/4)\rho_t\, d_t^2\, V_t^2 \tag{4}$$

where m, is the mass-flow rate of the filaments; Qi is the filament density; and V_1 is the filament velocity. This is a function of the filament cross-sectional area, i.e., it is proportional to d. An increase in filament diameter thus causes the fluid forces to increase proportional with the fi-lament diameter, but the force required to overcome the inertia and to transport

this thick-er filament will increase with the square of the filament diameter. Consequently an increase in the filament diameter will cause it to be blown out at a lower speed. In other words, coarser filaments will require greater forces than the relatively finer filaments to overcome their inertial resistance.

When "ultrafine" filament yarns with linear den-sities about 1 dtex per filament are used in air-jet texturing there may be further complica-tions such as pre-mingling of the filaments as they enter the nozzle, which affects the textur-ing conditions adversely. Hence, it can be argued that there is a limit to the filament fine-ness and the optimum range of linear density per filament is 1-2 dtex for the supply yarns and for the state of the art texturing nozzle in the apparel range.

All these· factors lead to the conclusion that, in general, supply yarns that are composed of fin-er filaments should texture more satisfactorily than coarser filament yarns, but it should be borne in mind that filaments finer than a certain dtex may not be suitable for certain types of texturing nozzles and texturing conditions.

Number of filaments

As the number of filaments increases, an en-hancement in yarn quality is rightly expected because the potential for mutual filament entanglement is increased. However experi-ments with different types of nozzles have re-vealed that the above statement holds only for a certain range of numbers of filaments for a gi-ven filament fineness which a particular design of nozzle can texture effectively at given pro-cess conditions. When this optimum range is exceeded deterioration in yam quality is ob-served.

Fig. 4 illustrates that, the optimum number for the T100 HemaJet at typical texturing condi-tions is less than 66 filaments, for the particular 1.67 dtex per filament yarn (110 dtex/66 polyester) used. However this optimum range is much wider for the T341 HemaJet nozzle at the same texturing conditions, as also indi-cated in Fig. 4, thereby verifying that some nozzles are more suitable than others for par-ticular yarn and process conditions.

In conclusion, we can argue that a suitable tex-turing nozzle should always be chosen for a particular supply yarn with a given number of filaments, bearing in mind that other process and supply yarn parameters also affect the tex-turing conditions and the resultant yarn quality.

Filament cross-section

The area-dependent mechanical properties of the filaments vary with the shape of their cross-sections." Different cross-sectional shapes will require different forces to deflect the filaments at right angles as they emerge from the nozzle. The flu.id forces acting on the filaments will also vary owing to the different surface and pro-jected areas arising from non-circular cross-sectional shapes. These factors may have an effect on the loop formation process.
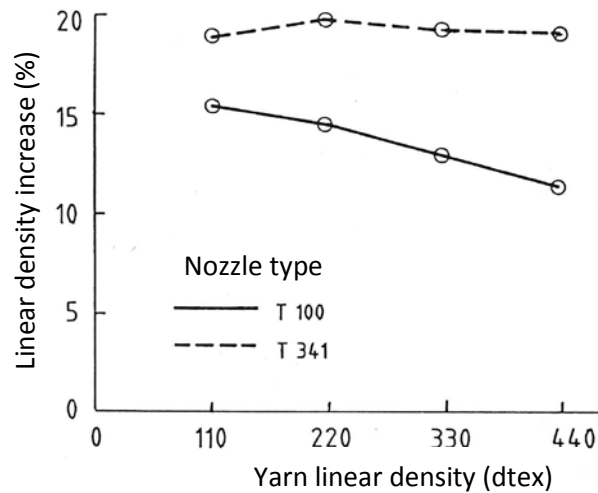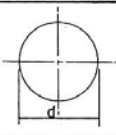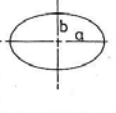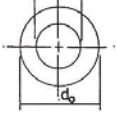
Fig. 4 Effects of total supply yarn linear density on the textured yarn linear density increase

In order to analyse the effect of the shape of the filament cross-section on loop formation, fi-laments with various cross-sectional shapes but ·with the same cross-sectional areas (i.e., identical linear densities) may be considered; regardless of the cross-sectional shapes, the inertia that has to be overcome in order to transport the filaments then remains the same. The analysis presented here is confined to the comparison of circular filaments, with hy-pothetical filaments of elliptical and hollow cir-cular cross-sections. Examples of other cross-sections, such as trilobal, octalobal, etc (which are admittedly more representative of com-mercially available filament types), could also have been considered; however the three ty-pes are sufficient to illustrate the principal effects. Furthermore, the recent increase in the volume of air-jet textured yarn output jus-tifies some effort from the fiber producers to develop filaments with cross-sections suitable for air-jet texturing; these two hypothetical shapes are only two suggestions. Some area properties of the three assumed cross-section-al shapes are given in Tab. 1.

Table 1. Area properties of circular, elliptical and hollow circular cross-sections

Cross-section	Moment of Inertia (I)	Polar moment of Inertia (J)	Circumference
	$\pi d^4/64$	$\pi d^4/32$	πd
	$I_x = \pi ab^3/4$ $I_y = \pi a^3 b/4$	$\pi ab(a^2+b^2)/4$	$\pi\sqrt{2(a^2+b^2)}$ (approx).
	$\pi(d_o^4 - d_i^4)/4$	$\pi(d_o^4 - d_i^4)/2$	$2\pi d_o$

Effects on the drag forces

Since the total drag force acting on the fila-ments is dependent on the surface and pro-jected areas of the filaments in the flow, vary-ing the shapes of the filament cross-sections will affect the drag force.

When an elliptic filament bends about its major diameter under a bending moment, its pro-jected area is [n 112] times, and its surface area is [(n2+1)/2n]112 times, as large as that of a cir-cular filament of equal cross-sectional area, where n is the ratio of the major to minor diameter of the ellipse (Tab. 2). Hence the drag force acting on an elliptic filament will be larger than that acting on a circular filament of equal fineness. The higher the ratio of major to minor diameter the greater the drag forces become. A similar argument is valid for a hollow cross-sectional filament (Tab. 2), which will also gen-erate a greater drag force.

Consequently it can be argued that, from the viewpoint of drag forces, elliptic and hollow cir-cular cross-sectional filaments are better suited for the air-jet texturing process than fila-ments having a solid circular cross-section.

Table. 2 Comparison of moment of inertia, polar moment of inertia, surfaces area and projected surface area of filaments with a circular, elliptical and round hollow cross-sections

Cross-section	Moment of Inertia (I)	Polar moment of Inertia (J)	Surface area (A_S)	Projected area (A_S)
Circular	1	1	1	1
Elliptical	$1/n$	$2n/(n^2+1)$	$[(n^2+1)/2n]^{1/2}$	$n^{1/2}$
Hollow- circular	$(n^2+1)/(n^2-1)$	$(n^2+1)/(n^2-1)$	$n/(n^2-1)^{1/2}$	$n/(n^2-1)^{1/2}$

Effects on the mechanical properties

During the texturing process, the filaments emerging from the nozzle make a right-angled turn with respect to the nozzle axis. Fig. 5 rep-resents a single filament emerging from the nozzle during the texturing process on the assumption that it forms a circular arc while making a right-angled turn. The leading end (A) of the filament is instantaneously fixed within the textured yarn, and the fluid forces causing the filaments to be blown out of the nozzle are assumed to be acting at the trailing end (B). This filament may also be subjected to a twisting action (as was consistently observed experimentally as a result of the swirling effect of the flow obtainable with certain texturing nozzles), and is therefore subject to both a bending moment and a torque. These will cause instantaneous vertical ·and horizontal deflections of point B as well as a torsional de-flection of the filament.
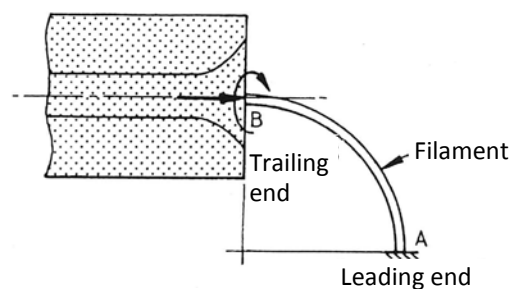

Fig. 5· Model of a filament making a right angle turn on emerging from the nozzle

Bending and torsional stiffnesses are directly proportional to the second moment of area ab-out a diameter and to the polar second mo-ment of area, respectively; the smaller these second moments of areas the smaller are the forces and torques required to bend and twist the filament, respectively. Hence, filaments with smaller diameters have a lower bending and torsional stiffness, which facilitate the loop formation process.

Table 2 shows that both second moments of areas of an ellipse are smaller than those of a circle of equal cross-sectional area; it may be concluded that smaller forces and torques are required to deflect a filament that has an elliptic cross-section and that the higher the ratio of the major to minor diameter (n=a/b), the smaller become the forces and torques required to deflect that filament. In addition to bending and torsion, this filament may also be subjected to buckling. Since the critical buckling load is proportional to the smaller principal second moment of area of a cross-section, buckling of an elliptic filament occurs about its major axis, and the critical buckling load for an elliptical cross-section is smaller than that for a circular cross-section.

Table 2 also shows that both the second mo-ment of area and the second polar moment of area of a hollow-circular fiber are larger than those for a solid circular fiber of equal fineness. This leads to the conclusion that larger forces and torques are required to deflect the hollow fiber than are required for the solid circular fiber.

Spin finish

It is quite well known in industry that some types of spin finish reduce the efficiency of the process within a very short time period by con-taminating the texturing nozzles [5]. Although it has now been proven that only a very small amount of water is entrained into the texturing nozzle and the rest is blown off from the sur-face of the yarn under the influence of the sec-ondary air flow [1], the author has failed to cite any published information regarding what happens to the spin finish on the yarn during the air-jet texturing process.

A recent experimental study that the author conducted has shown that hardly any spin fin-ish is removed from the surface of the yarn when dry textured (Fig. 6), but the level of spin finish is reduced to about 0.1 % from its original level of about 0.3% for the particular yarn used. With another type of yarn the amount of spin finish was reduced from 0.7% to 0.1 % after wet texturing. Experiments also showed that the type of nozzle and the water temperature did not make any significant difference to the level of spin finish removed (Fig. 7). The amount of water used in the process also made little effect on the spin finish removal from the yarn (Fig. 8). Process parameters
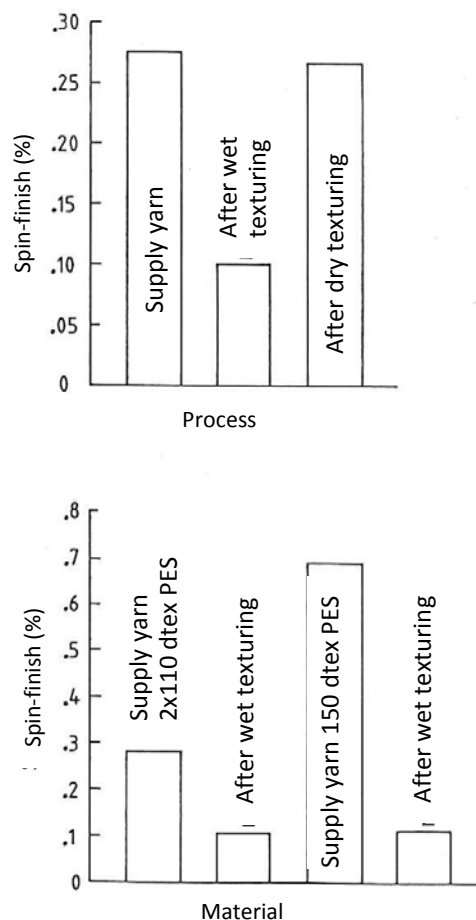
Fig. 6 a) Spin-finish removal with dry and wet pro-cessing, and b) spin finish removal with different yarns (and spin finishes)

such as texturing speed and air pressure also seem to have very little effect on the spin finish removal (Fig. 9). This experimental work clearly demonstrates that, whilst dry texturing removes hardly any spin-finish, wet texturing removes most of the spin finish from the yarn surface. Variations in process parameters, amount of water used, nozzle type and water temperature do not make any significant difference to the level of spin finish removal. The only factor which affects the amount of spin finish removal is the type of spin finish itself.
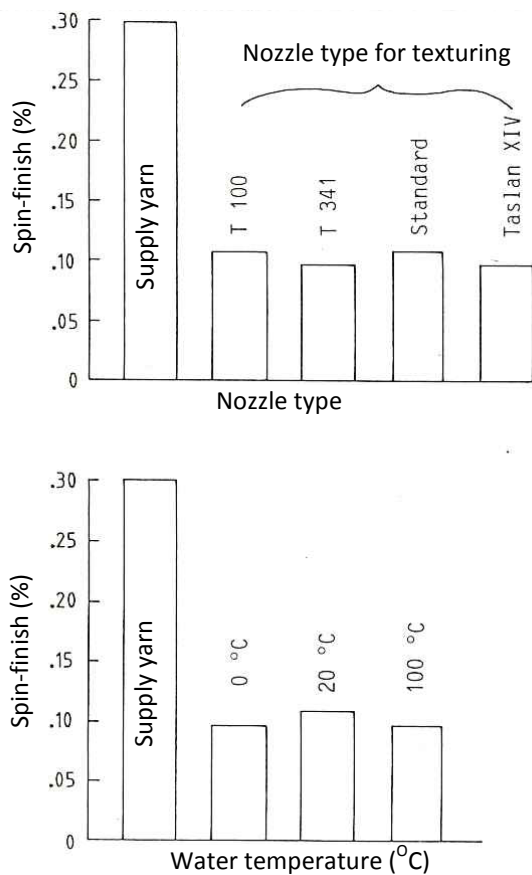

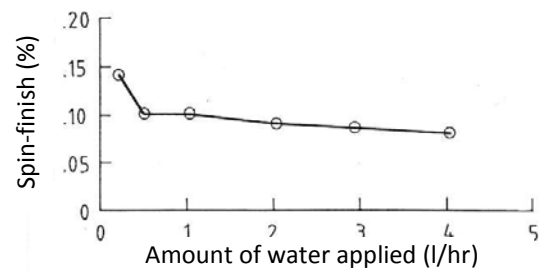Fig. 8 Effect of amount of water used on the spin finish removal, applied

Fig. 7 Effects of a) nozzle type and b) water temp-erature on the spin finish removal
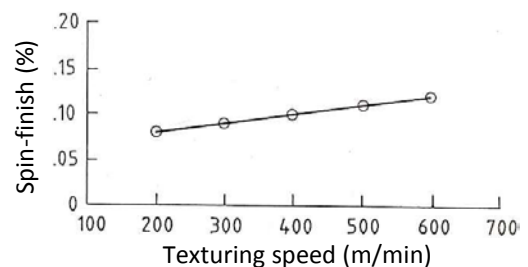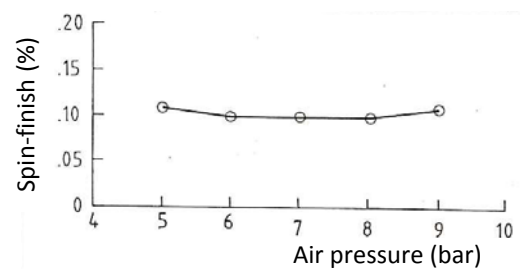
Fig. 9 Effects of a) air pressure and b) texturing speed on the spin finish removal

It can be concluded that the air-jet texturing process may be significantly improved by choosing yarns with suitable types of spin fin-ish applied to them. There is a wide scope for the lubricant manufacturers to investigate and develop suitable types of spin finishes to be applied to the yarns for air-jet texturing. Furthermore additives which can be mixed into the water used during texturing may also improve the texturing conditions and this also warrants further investigation. There are now new wet-ting systems available, such as Heberlein's 'Hemawet Plus', which have new features that facilitate mixing additives into the water at pre-cisely measured quantities.

Discussion and conclusions

The considered model assumes that the fila-ments make a circular arc and that the fluid for-ces are concentrated at the trailing end of the filament. This is usually not the case, the

real situation being much more complex. Fila-ments, although they make a right-angled turn may assume shapes rather than circular arcs and these would affect the bending and tor-sional behaviour of the filaments as well as the fluid forces acting on them. Nevertheless, all the filaments make an eventual right-angled turn with respect to the nozzle axis and they are subject to fluid forces that make them bend, twist and buckle. The following general conclusions derived from the discussions in this paper are valid, in essence, for any textur-ing conditions:

- filaments with finer linear densities are more suit-able .for air jet texturing because their bending and torsional stiffnesses and their inertial resistance are smaller; smaller drag forces are required to blow them out of the nozzle, and hence they bend more easily during loop formation; it is suggested that a yarn suitable for air-jet texturing should have a filament linear density less than 2 dtex;
- for a given texturing nozzle there is an optimum range for the number of filaments tor a given dtex per filament which can be textured more effective-ly; therefore the nozzle type should be carefully chosen when a particular yarn is to be textured, or vice versa;
- non-circular and hollow filaments have larger sur-face areas than that of a circular filament of equal linear density and are thus subjected to greater frictional-drag forces relatively to their inertias; .a similar situation occurs with pressure drag forces because the projected areas are also greater, in view of the tact that non-circular filaments have a preferred bending direction about a major axis;
- hollow filaments have a greater surface area and projected area but are also stiffer in both torsional and bending modes; in this case, it is not clear where the advantages lie, but one advantage may be increased bulk due to the hollow structures of the filaments.

It is concluded that the texturing of supply yarns composed of non-circular and hollow fi-laments could be worthy of experimental in-vestigation, since, for some applications, they may have technological advantages over the air-jet texturing of yarns composed of conven-tional circular filaments.

Spin finishes applied to the supply yarns and additives which can be mixed into the water used during texturing also warrant further investigation by the lubricant producers with a view to developing specific lubricants and wa-ter additives for the air-jet texturing process.

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