There is a kind of stumbling awkwardness to a thick page—I think of those single section poetry books printed on something approaching cover stock, folded against the grain, stapled, springing at random like a drawer full of grocery bags.

Clifford Burke, *On Printing Poetry*

**Introduction**

A visit to any Rare Book Room will furnish examples of expensive limited editions with splayed boards, paper that is too thick, signatures that erupt from spines too tightly sewn, or badly registered printing. These problems, caused in part by ignoring the grain in paper, can be exacerbated when more than one craftsman works on a book project. A mistake in the type of paper selected or in how it is cut becomes a permanent feature of each book. The behavior of paper when it is stressed by being moistened and redried is a cross-disciplinary problem of interest to book conservators, binders, artists, and printers of both letter-press and offset.

Often, details, such as the direction a text paper prefers to be folded, are more important in the collective book arts encompassed by limited edition publishing than in any of the separate book arts. Paper is the foundation upon which all the type and illustrations build. It is important for the publisher to choose compatible materials for use in a book, whether the later steps in production are delegated or performed in-house. The board, the cloth, and the glues, if used, as well as the papers, all impinge upon one another.

Problems associated with inattention to grain direction include the impossibility of printing type in register if the paper is dampened and expands twice as much along the cross-direction as in the machine direction. Another typical difficulty occurs when the text-block is printed with the grain running at right angles to the spine, and the book will not open properly.

A major reason fiber alignment in paper is ignored is lack of forethought. The budget constraints within which most small publishers operate can lead to cutting the parent sheet with the grain going any which way, in order to maximize the number of resulting leaves. This is especially true if the format is small and the parent sheet large. These monetary constraints often preclude the option of chucking the paper entirely when the printer or binder runs into grain problems.

A mistake made initially in the cutting of the paper cascades problems through each stage of the book production. If the paper is cut commercially (or by someone other than the printer) for an expensive book, it seems unfair for the problem of unpredictable paper behavior to be passed on to the printer, then the binder.

As producers of both books and handmade paper for over ten years, Neal Bonham and I feel that problems related to fiber alignment have a direct bearing on what we do with paper and what we expect others to do for us. What is taken for granted by a specialist in one field can sometimes be overlooked by another if there is not a direct cause and effect. An example of this relationship exists in paper formation as it pertains to fiber alignment, which in turn manifests itself in dimensional stability, drape, or stiffness of a given sheet. If the papermaker and the printer are not binders, the potential of a tight turning radius happening when the paper is bound into a book probably will not
occur to them. But this angle of bend at the spine can be adversely affected if the paper has been printed with the grain running at right angles to the spine.

The presence of grain can easily be ignored by the producer of the paper, but not by the end user. As letter-press printers trying to preserve our limited resource of type, we have had to think about paper expansion when damp printing, whereas if we had never used our own or other handmade papers we probably would not have questioned the adage that handmade papers have little or no grain.

The tests for fiber alignment in paper are simple, and the problems of registration of type, warpage of boards, and stretch of paste-downs so aggravating that it seems odd so little is written about the subject as it affects the books. The focus here will be on the areas where we have some experience, especially papermaking and damp printing. The discussion of how grain affects binding and conservation techniques will be left to others better qualified.

Grain and the Standard Mythology
One of the tenets of paper mythology is that Western handmade paper, when properly formed, has no grain. We had noticed a slight directional orientation to colored fibers on the wire side of some handmade sheets, but had ignored it, until some comments made to us by binders using a range of handmade papers caused us to reexamine our assumptions.

We proceeded to explore the subject by the means, albeit limited, at our disposal—informal experiments in our mill and research at the University of Washington Special Collections and at the University of Washington Forestry Library. We found corroboration in an old paper textbook that handmade paper does indeed have grain. In his 1907 *Chapters on Papermaking*, Clayton Beadle asserts that,

The effect of the two sets of shakes [of the paper mold] is to dispose the fibres in layers: the fibres in each layer being different in direction to the one above it. This is a great improvement on machine-made paper, but is by no means perfect, as the paper is disposed in layers instead of consisting of one mass of fibres disposed in all directions. It must be remembered also that it is almost impossible for an operator to so adjust the shakes as to make one set of fibres just compensate for its neighbour, and so produce a paper of equal strength in all directions.¹

This information was published at a critical time in the history of papermaking—the transition from handmade to machine-made paper as a source of mass supply was all but completed, yet examinations were still being conducted for entrance into the guild organizations in London. Beadle administered the guild examinations and wrote a five volume set of essays, including detailed questions and answers to be used in preparation for taking the exams. His interesting observation, above, has become obscured with time, and his reputation forgotten with the break in the tradition of making paper by hand. We were curious if some of his assumptions about paper and its layered formation were still held to be correct by the scientific community today.

We had a difficult time finding direct references to the term *grain* outside of commercial catalogues selling paper and craft textbooks.² As technical treatises seem devoid of its appearance, *machine direction and cross direction (MD and CD)* being the terms of choice, we could only infer that the use of *grain* is limited to craftsmen and is part of their vernacular.

I have chosen to retain the term *grain* because it is shorter than saying *machine direction* and applies to handmade paper as well as to machine-made. It is a clear descriptive term that includes, in addition to alignment of fiber during formation, conditions (such as drying method) which create the perception of directional preference in a sheet of paper. As I am not a paper conservator or paper scientist but a practitioner of the craft, this plainspoken vocabulary will have to be taken on sufferance.

Like the grain in a tree or a board, fiber alignment in paper creates a structure that is directional rather than random. In both wood and paper, expansion and shrinkage occur more in one direction than another. Paper tears just as wood splits, in line with the grain. Either wood or paper, when moistened on one side, will curl parallel to the direction of the grain, not counter to it.

Most paper is formed from fibers whose length is 100 to 3500 times their width.³ These are suspended in water and, by various methods, the pulp is deposited on a mesh, leaving a mat of fiber when the water drains away. With most forming methods, the first dip of pulp washes over the mesh in a single motion, causing those fibers in contact with the wire to align predominantly in that direction. This holds true for both machine and handmade, with a few notable exceptions, such as the Nepalese method.

Paper Formation and Its Effect on Fiber Alignment
Five major categories of paper, as distinguished by method of formation, are *nagashi-zuki*, *tame-zuki*, poured or cast, fourdriner, and cylinder-made or mould-made. The first three of these are hand papermaking methods and the last two methods describe machine-made papers. Each method affects the degree to which fibers are aligned directionally.⁴

Tim Barrett gives the best definition for the first two methods.⁴ *Nagashi-zuki* is “a laminating form of papermaking used in Japan that is characterized by: the use of several charges from the vat and energetic action during sheet forming . . . ” This method is highly directional not only because of the repeated dipping, but the considerable length of the fibers (kozo, misumata, and gampi) used. *Tame-zuki* is a “Japanese term for the Western style of hand papermaking that employs one charge from the vat, a gentle shake during sheet forming . . . ” The shake is in both directions and usually results in a thicker sheet than *nagashi-zuki* with, Barrett feels, less grain direction.

Sheet forming by casting or pouring is characteristic of paper made in India, Nepal, and Southeast Asia, as well as in the more controlled environment of paper laboratories, where the term *leaf-casting* or *hand sheet* is used. A measured amount of the slurry is poured into a mold, where it is held in suspension while the fibers are distributed.
evenly. Water is prevented from draining until the mold is lifted, giving the papermaker time to spread the pulp, presumably in a non-directional manner. The mold is not shaken while the water drains through the mesh. This method results in the least amount of fiber direction.

Fourdrinier-made paper involves pulp flowing onto a moving wire surface. Controlling the slice, the aperture through which the pulp runs onto the screen; the side-to-side shake of the wire; and the draws, or degree of pull exerted on the web, help determine the fiber alignment in a given sheet.

Cylinder-made or mould-made papers are made using a mechanized technology, where the pulp can be deposited in a highly directional fashion on a revolving drum partially submerged in a dilute slurry. These papers can manifest some of the characteristics of Western handmades, such as chain lines and deckles, but there is some controversy as to the degree of squareness or absence of grain attainable using this method. The stock is run at 1% fiber concentration, twice that of a fourdrinier, which would detract from the squareness. (Square sheet is a term used to describe a paper or paperboard which has equal tensile strength and tearing resistance in machine and cross directions. A ratio of 1:1 is a square sheet.) Other sources, however, mention the highly directional nature of cylinder-made papers.

James d’A. Clark, a widely respected paper chemist and educator with over fifty years of experience in the paper industry, explains it this way:

The effect of the rotation of the cylinders in the vat of stock causes the substantial proportion of the fibers to become oriented in the machine direction, much more so than happens on a fourdrinier machine, especially at higher speeds. This considerably detracts from ‘squareness’...

The speed differential between the flow of pulp and the speed of the wire on a fourdrinier is less than what typically occurs when hand-forming sheets. There are many similarities between the two systems, hand vs. machine forming of paper, such as fiber length and consistency as it bears upon formation, and the motion of the pulp over the screen, including the presence or absence of lateral shake. In machine-made papers, the draws, which can vary from operator to operator, have more impact on fiber alignment than the actual technique used to form the paper. Another important variable is drying method as it affects grain.

While either cylinder or fourdrinier machines, when run properly, are capable of forming a nearly square sheet of paper, both systems typically use restraint drying. This inherently creates directional strength properties.

A paper that is loft dried or allowed to shrink while drying exhibits more stretch and less tensile strength than a sheet that is dried under restraint. The tensile strength rises and the stretch decreases for the latter. Usually, as tensile strength rises, both proportional tear strength (the ratio between tear test results in the CD vs. the MD) and stretch decrease in a sheet. In a book paper, tensile strength is not as important as durability, measured by folding endurance and tear tests.

Sizing and restrained drying may improve paper stability. "Every humidity expansion depends on the shrinkage during the drying process. The most effective remedy for unwanted expansion in paper is to apply appropriate tension during drying," according to Francis Bolam in his book, The Fundamental Properties of Paper Related to its Uses.

Paper catalogues and art textbooks reinforce the commonly held belief that mould-made paper is superior to machine or fourdrinier paper in performance as well as appearance. The term itself, mould-made, is enigmatic — inferring a compromise between machine and hand methods of formation. In fact, mould-made papers are formed on a cylinder machine in which a perforated drum revolves partially submerged in a vat of pulp. The uniflow system has less potential for fiber alignment than the counterflow system because the fibers are moving in the same direction as the cylinder rotation. The fibers do not know how they are moving, what matters is the speed of the pulp relative to the mold surface. The pertinent issue of how fast the pulp moves across the mold determines the degree to which the fiber aligns itself in one direction.

Edwin Sutermeister, in The Story of Papermaking, states that paper made on a cylinder characteristically exhibits a wide difference in its tearing strength with and across the grain. This is much greater than in fourdrinier-made papers. We can only conclude that the four deckles, the sizing and the real chain and laid lines (as compared to dandy-rolled impressions) are what gives the mould-made papers their selling advantage over fourdrinier papers.

Many people's knowledge of paper comes from confused or mistaken statements by acknowledged experts or dubious commercial sources such as art supply catalogues. An illustration of this confusion would be this exchange between Clifford Burke and Harry Duncan, in a review of On Printing Poetry: Clifford Burke's book was the first reference we found corroborating this surprising characteristic of mould-made vs. fourdrinier paper:

... Mouldmade paper has a grain as pronounced as the commercial stuff and that grain will cause some concern when damping because it makes the paper cockle easily. And in planning a book it is never possible to ignore grain direction.
His [Clifford Burke's] plea for using handmade paper is especially eloquent—it leads him to impugn mouldmade paper as a compromising imitation of handmade paper more dishonest than a 'good commercial sheet.' And I wonder whether the agitator in the mold vat really does nothing whatever to alleviate grain and whether, from Burke's point of view, the product of Fourdrinier machines, including the pleasant stock he ordered for this book, should not be considered even less reasonable a facsimile.\(^{10}\)

Neal and I have not found any references to agitators in mould-made systems (although this does not mean none exist). We have seen diagrams of baffles built to create turbulence in the flow of pulp before it reaches the intake point. Perhaps Duncan's definition of agitation differs from ours. I hesitate to question such a respected printer and do so only to illustrate the level of confusion and misunderstanding about grain and its origins in all types of paper.

**Fiber Bonding and Alignment**

Paper fibers themselves are on such a minute scale, one tenth as big as a human hair or 10 to 15 microns, that what we experience as grain is the cumulative effect of the alignment of thousands of fibers and fibrils. As the chemical and mechanical bonds between fibers are weaker than the fibers themselves, a sheet of paper will be strongest and most flexible, and will fold most easily in the direction of alignment. It will tear more readily along the fibers than across them.

When paper fibers absorb water, they expand, because of their hygroscopic nature. The natural affinity cellulose molecules have for water causes the paper fibers to expand. This swelling of the fiber is negligible in length, but pronounced in width, because water, forcing its way between the molecules, wedges them apart. If the fibers in a sheet of paper are aligned a greater degree in one direction, the expansion due to moisture will be much greater across the grain or perpendicular to the alignment direction of the fibers.

Beating procedures as well as fiber types\(^{11}\) radically affect bonding; some cellulose fibers are far more hygroscopic than others. Abaca absorbs up to 50% of its weight in moisture when exposed to steam-saturated air; new cotton fibers, fully saturated, will absorb 15% of their weight. Ramie, on the other hand, is quite impervious to moisture (and is very resistant to rotting as a result).\(^{12}\)

What concerns the printer and binder is dimensional change, due to shrinkage once the water is removed a second time from the sheet, after either damp printing or pasting down endsheets. For every expansion there is going to be a complimentary shrinkage of the sheet. The capillary action exerted by the water as it evaporates from the sheet is tremendous. Conservative estimates place these forces, known as the Campbell Effect,\(^{13}\) at 100 atmospheres or 1300 PSI.

Papers with a pronounced grain direction show a high degree of preferential fluctuation, upon wetting and redrying, because the cellulose fibers expand and contract in width to a far greater degree than in length. The Campbell Effect describes the force of water's surface tension drawing fibers together during drying which is responsible for paper shrinkage and such phenomena as endsheets cupping leather boards.

The Campbell Effect begins at about 29% moisture content. At 12% moisture content, paper is undergoing maximum shrinkage strain in drying. There is a direct correlation between longer beating time and an increase in capillary contraction forces, and the resulting degree of shrinkage in the finished sheet. Glassine papers, which are extremely dense and well-beaten, exert much more pull and shrinkage than a typical book paper.

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**Uniflow Machine**

A-vat; B-back vat circle; C-front vat circle; E-cylinder mold; F-couch roll; G-fibers depositing on cylinder; H-felt and sheet; I-stock intake; L-white-water outlet.


**Counterflow Machine**

A-vat; B-back vat circle; C-front vat circle; D-overflow dam; E-cylinder mold; F-couch roll; G-fibers depositing on cylinder; H-felt and sheet; I-stock outlet; K-stock overflow; L-white-water outlet; S-stock overflowing and recirculating.

Grain and What Determines Its Presence in Paper

Each vatman has his own stroke, the act of dipping, withdrawing, and shaking the mold. I suspect this individuality is especially strong in the United States because there has been no continuous tradition of hand papermaking. Neal’s stroke involves slicing a layer of the pulp from the surface of the vat with the mold. The mold is not totally submerged and the thickness of the slice (or the depth of the dip) depends on how much pulp is needed to fill the deckle to the desired depth (which helps determine the weight of the paper). The dip is immediately followed by the shake. Since the shake’s initial purpose is to level the pulp on the mold, its motion, front to back or side to side, depends on which direction the pulp needs to be spread. As the water drains from the pulp, the shake is reduced to vibrations in alternate directions to break up the cloudy lumps and allow the fibers to relax and defloculate.

The papermaker’s stroke as the mold enters the vat is directional, in and down as he pulls the mold towards himself, aligning a first deposit of fibers with the chain-lines. There is no way to avoid this initial layer of aligned fiber.

Whether paper is made by hand or on a machine, three factors influence formation: 1. drainage due to gravity acting at right angles to the screen, 2. oriented shear or the fibers aligning themselves parallel to the screen as the mold is shaken laterally, and 3. turbulence or the random placement of fibers in relation to the screen. 14 It is very rare to find up-ended fibers enmeshed vertically in the web or unpressed sheet, according to Bolam. He finds that fiber alignment is minimal in the plane vertical to the mold’s surface, known as the z-direction. 15

Formation Experiments

We experimented with some simple alterations in sheet forming technique to try to isolate the effects of dipping and shaking. These trials were neither conclusive nor exhaustive, but the twenty combinations of dipping the mold and shaking it provided us with a logical way of examining the phenomenon of fiber alignment and its origins in the vat. We hope that someone with more time will do additional, controlled testing and publish their findings in language accessible to craftspeople rather than the soporific prose common to scholarly journals.

Cotton half-stuff from Cheney (grade 865) was used for our test sheets with a few blue jean threads ⅛” in length added as visual references. This was beaten for 1.5 hours in our Wark beater at a 2% consistency, approximating what we do for book paper. The floc size was ⅛”, which indicates a medium beat. The pulp measured about ⅛” in height on the mold before couching, the dilution in the vat being approximately 0.5% to 1%. The laid mold we used measures 15” × 21” with laid wires spaced 14” to the inch.

The samples were single pressed then dried under restraint for 24 hours at 100°F. What little shrinkage occurred was equal in all directions. Expansion tests were measured to .01 mm accuracy and rounded to the nearest .1 mm, and Elmendorf tear tests were measured to the nearest gram-centimeter.

We tried to keep the fiber to water ratio the same as well as the preliminary agitation of the slurry, so that these factors would not affect our test results. Unfortunately, our tests did not encompass different types of fiber, fiber length, or degree of beating. Certainly sizing and fiber type can affect comparisons between tearing and expansion tests. Our prior experience has shown that paper that has a large proportion of soft materials, such as cotton linters beaten quickly and dried under restraint will expand less when moistened.

To vary the fiber alignment in paper, Neal dipped a laid mold in five different fashions and shook it in four different ways, for the twenty possible combinations of dips and shakes. These are listed below. While none of the dips would be used in normal Western sheet formation, the “half dip” most closely approximates a normal stroke. Neal’s goal in these tests was to exaggerate the motions of the mold in the vat, in order to isolate the portion of the stroke responsible for fiber alignment.
The Dips
1. Full dip: the mold enters the vat at a 25-30% angle, slicing a layer of pulp from the surface of the vat. It is not lifted out of the vat until it has been completely submerged. As the mold is lifted clear of the vat, its motion is perpendicular to both its own surface and that of the vat.

2. Half dip: the mold is dipped at right angles to the surface of the slurry to about half its width. The deckle is not totally filled and no excess pulp is cast off, but a complete sheet is formed by the pulp flowing across the mold. The purpose of this dip was to try to accentuate the speed of the pulp across the mold surface.

3. Push-pull dip: the mold is pushed into the vat at a 25-30% angle and pulled straight out, with no change in the angle of the mold as it enters the slurry. The two surfaces are always parallel to one another, while attempting to keep pulp flow gentle and even in all directions. There is usually a near void in the center of the sheet.

4. Pull dip: the mold is held vertical and pulled toward the vatman as it is being submerged. It is then turned horizontally and lifted free of the vat.

5. Push dip: the mold is held at a 10% angle, pushed away from the vatman, then turned backward to allow flow over the top of the deckle. This motion is just the reverse of the pull dip. There is a slight change of angle as the mold is revolved down to allow flow over the top of the deckle before it is pulled out. The idea is to cut down the relative motion of the pulp against the wire by having water pushed through the back of the mold.
The four kinds of shakes are described as follows. For all of them the mold was held at a fixed height, parallel to the surface of the vat. All shaking was horizontal within this plane.

The Shakes
1. No shake: No movement in any direction, back and forth or side-to-side, once the mold is above the water.
2. Side-to-side shake only: All movement once free of the water is in a side-to-side direction in relation to the vatman.
3. Front-to-back shake only: All motion is in a front-to-back direction in relation to the vatman.
4. Alternating shakes: Movements in both front-to-back and side-to-side directions are performed. This motion most closely approximates what normally occurs with Western sheet forming.

After drying all twenty variations of dips and shakes, we first subjected them to a visual test to ascertain the degree of flocculation and visually perceivable fiber alignment, one side of the sheet as compared to the other. The colored threads in the pulp helped to accentuate this feature. When alignment was random on both the felt and wire side of the sheet, the formation was flocculated. We noted random alignment consistently on the felt side in all the tests, and various degrees of directional alignment on the wire side running with the chain lines.

In the first three sets of shakes, we were unable to increase apparent grain to any significant amount. The effect of the traditional shake on better formation appears to be less influential than we had originally thought. Achieving good formation must take into consideration drying techniques, the percentage of fiber to water, and the amount of agitation in the vat.

We conducted some informal tests on our twenty samples to ascertain whether there was a variation in grain direction front to back. We did find a difference in curl direction between the wire side and the felt side when the samples were moistened on one side only, which indicated differing fiber alignment. Every handmade tested, when dampened on the felt side only, curled along the axis of the chain-lines. The same papers, when dampened on the wire side only, curled at right angles to the axis of the chain lines.

Tear Tests
Tearing tests using an Elmendorf Paper Tester provided much more accurate data about fiber alignment, but the machine averages both sides of the sheet, masking the variation we could see visually, wire side to felt side. What the Elmendorf Tester furnishes is a set of figures for how much resistance a sheet gives when torn first in the MD, then in the CD. We tested not only our own twenty samples but also a selection of commonly used book papers: Nideggen, Rives Heavy Weight, Arches Cover, Frankfurt, Hayle, and Umbria. Of these commercial papers, all are mould-made with the exception of Hayle and Umbria.

Professor Joseph Brown of Rochester Institute of Technology (RIT), duplicated our tearing tests and applied both tensile and fold tests to our array of samples, corroborating some of our findings. One surprise was that Tovil, a paper by Barcham Green, was unique among the handmades tested, in that its alignment was more with the laid lines than across, as would be expected. This finding was initially viewed as an aberration by both Prof. Brown and ourselves.

We have contacted mill representatives in order to obtain information about each of the papers, such as furnish, sizing, methods of formation and drying, and any test results conducted in-house to determine squareness. To date we have only received a response from the Zerkall Mill in West Germany, which produces Frankfurt and Nideggen. Zerkall stated that they could not give accurate, uniform values for shrinkage in their mould-made papers, because the sheets shrink more freely at the edges of the web than the center as they pass through a cylinder drier.

This variation across the web in shrinkage values means damp printing should be approached with caution, as these papers cut squarely may not expand symmetrically when moistened. (We have printed dry on Frankfurt Creme and found it very receptive to ink, so damp printing is not necessary with this paper.)

We cut our samples into 76 mm × 63 mm strips, taking note of the grain direction. We did not take comparative samples from the middle and edges of individual sheets because we originally thought grain was primarily caused by formation, not drying technique. The temperature and humidity in our shop are relatively stable, though not strictly controlled.
Expansion Tests
The same papers listed above were tested for expansion when wet as compared to when dry. We tried to make sure the atmospheric conditions were fairly consistent when we cut samples as near to 100 mm square as was practical. A line was then marked the length of the sample about 1 cm from each edge. This gave us two measurements in each direction on the sample and ensured that the wet and dry measurements could be taken at the same points. The samples then were measured dry, immersed in water overnight, and measured again while wet using a vernier caliper. The place from which the sample was taken from the larger sheet was noted for direction so as to indicate whether the sample had a preferential expansion in the cross or machine direction.

Rives Heavy Weight and Arches Cover showed the most variation between cross and machine direction expansion, but far less total expansion than the two commercial handmades tested. This lack of expansion may be attributable to their sizing. Our tests with Umbria exhibited more than 2% increase in size in each direction. Hayle, which was well-sized, was similar to our own papers.

Fiber Alignment As It Relates to Printing
Whether printing damp or dry, fiber alignment must be taken into consideration. Imposition of type front to back becomes impossible if a paper is changing shape between press runs. This can happen even when printing dry if the temperature and humidity alter radically in the pressroom, due to direct sun on the press itself or forced air heating being turned on and off in a severe climate. Imposition is extremely tricky when printing damp as the paper is in an unstable state. Dropping in a second color near the first printed section can be a hair-tearing experience if the paper is unevenly dampened.16

Paper is more likely to shift and change shape when there is a predominant direction of fiber alignment. Completely random fiber alignment would give equal expansion in all three dimensions. Paper is typically aligned in two, not three, dimensions and consists of layers sandwiched together. The phenomenon of curl illustrates the layered structure of paper. In tearing thick handmade paper, delamination often happens, indicating the strength of the fiber bonds is running mostly in a horizontal plane, parallel to the surface of the sheet.

There are at least four ways to test for fiber alignment. 1. Dampen the sample on one side and check the direction of the curl. The moisture will expand the fibers on the wet side, causing the axis of the curl to be in the direction of the fiber alignment. 2. Tear a sample in both directions and check for straightness (the tear will be more straight with the grain). 3. Fold the sample twice at 90 degree angles to ascertain which direction provides the most resistance. 4. Let the paper drape over the edge of a table, then turn it 90 degrees and try it again. This last method is especially useful for comparing the grain in two or more papers.

One needs to test for overall expansion when damp printing. As stated before, our immersion tests, though limited in scope, showed Umbria to have the greatest increase in overall size — 2% in both directions. The Hayle from Barcham Green was similar to Sea Pen's papers in that it expanded .6% and .65% in both directions. Two of the four mould-mades tested, Rives Heavy Weight and Arches Cover, showed the most variation between cross and machine direction, but less total expansion than the waterleaf handmades tested.

Sometimes paper from two different lots gets mixed together on one job, resulting in unpredictable paper expansion due to sizing variations. When tub sizing is used, the amount of sizing can vary even within a sheet if improperly done. Gelatin tub sizing is used in such papers as Arches. Some grades of gelatin sizing can swell up to four times their former volume when exposed to water.17 Obviously, this will affect the dimensional stability of a paper, especially if the proportion of alum used to fix the sizing fluctuates.

An uneven damp pack, where some of the sheets contain more moisture than others, can also play havoc with registration. The solution I have used is to reload the pack and start printing the next day, after the water has had time to redistribute itself uniformly between the blotters and interleaved sheets.

As paper curl and fit are critical to fine presswork, care should be taken to let paper acclimatize itself to shop conditions before it is cut to size. Some printers use a hygrometer to monitor the relative humidity as it affects paper. A change in the ambient temperature is usually reflected in the relative humidity.

Paying close attention to paper selection is important in the initial stages of planning an expensive book, as is preparing a prototype of the binding and testing the papers for stretch. This is especially true if a cylinder press (such as a Vandercook) is used. Certain illustration techniques, such as lithography, put intense directional strain on paper. Whether printing from a stone or a ground plate, the fiber alignment of the paper should move in the same direction as the litho-press operates. (To simulate this effect many lithographers calender their paper to pre-stress it in one direction.)

Summary
The grain in paper is a misunderstood and little-studied subject in the book arts, yet it affects every step in the production of a book, from cutting the paper to binding the printed leaves.

It is often assumed that machine-made paper has grain and that handmade and even mould-made paper has none or very little. In fact, it may be impossible to make grainless paper with traditional European, Japanese, Chinese, or Korean techniques. All these methods involve dipping a mold into a vat in ways which cannot avoid depositing a layer of highly directional fiber on the mold. By contrast, in Burma, Thailand, and Nepal, paper is made by a much slower casting process. Relatively grainless paper is possible but its manufacture is impractical for production mills, because the process is very slow.

The choice, then, is between understanding and testing for grain in the paper you use, or taking the chance of producing an inferior product by ignoring it. The
consequences of ignoring fiber alignment in paper can lead to numerous problems, including bindings that warp, paper that is changing shape between runs on the press or while you are printing, and endsheets that stretch more than expected when pasted out.

Our limited research, while pointing to some answers, opens areas for further inquiry by others perhaps more experienced in the various book arts than ourselves. As most hand papermakers know, access to testing equipment and expertise to interpret the data are limited — this leads to the promulgation of misconceptions about paper properties. The filter of empirical experience gained by handling and testing paper directly is an important counterweight when evaluating the published literature. Joe Brown, of RIT, proved to be an invaluable resource to us. He spent time confirming and extending tests on some of the papers we investigated and provided insights on testing procedures.

One inescapable conclusion is that no book project should be undertaken without making a prototype. Previewing problems in this way allows one to accommodate for them in the final production. Paying attention to grain direction in the materials used is a key factor in the success or failure of the book as a system for ordering information. The mechanical structure of the book yields the book event to the reader. If you cannot easily open a book, you will not read it.

Afterthought
A thud, a rain of driplets, a pause, the sudden uprush of displaced water, and again the thud of the deckle being removed to the horn, or is it the felt brush being cast aside? The house amplifies the work sounds at night, but I cannot connect all of them accurately with specific movements unless I watch Neal forming paper. Each fiber aligning itself along whatever axis recalls the larger motion of the water slurry in the vat, across and back. The visual cues are echoes in this microscopic dance of fiber in water. Their secret is frozen as the sheet subsides into its final shape — be it floced or clear. The grain reveals itself when the finished sheet is cut, pasted, torn, or dampened, but remains dormant to the casual observer.

Fiber Alignment
Laid lines are parallel with the axis of the cylinder in mold-made paper, or parallel with the long dimension of the mold on handmade paper.

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</tr>
<tr>
<td>Higher</td>
</tr>
<tr>
<td>Lower Reading</td>
</tr>
<tr>
<td>Higher</td>
</tr>
<tr>
<td>Lower</td>
</tr>
<tr>
<td>Higher</td>
</tr>
<tr>
<td>Lower</td>
</tr>
<tr>
<td>Higher</td>
</tr>
<tr>
<td>Lower</td>
</tr>
<tr>
<td>Higher</td>
</tr>
<tr>
<td>Lower</td>
</tr>
<tr>
<td>Higher</td>
</tr>
<tr>
<td>Lower</td>
</tr>
</tbody>
</table>

(How Joe cut the test strips out.)

Higher readings were obtained along the top three samples, except for tearing. Lower readings were obtained along the bottom three samples, except for tearing. Drawing by Suzanne Ferris.

Notes:
5. I have read, however, of solutions as dilute as 0.1% being run for Arches or Rives, in *Paper, Art and Technology* (World Print Council, San Francisco, 1979).

<table>
<thead>
<tr>
<th>Paper Tested</th>
<th>Tensile</th>
<th>Folding</th>
<th>Tearing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Handmade</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Pen — medium beat cotton rag</td>
<td>1.08</td>
<td>2.27</td>
<td>1.17</td>
</tr>
<tr>
<td>standard dip and shake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Pen — medium beat cotton half-stuff half-dip, no shake</td>
<td>1.37</td>
<td>2.37</td>
<td>1.11</td>
</tr>
<tr>
<td>Sea Pen — medium beat cotton half-stuff half-dip, side-to-side shake</td>
<td>1.29</td>
<td>2.08</td>
<td>1.35</td>
</tr>
<tr>
<td>Sea Pen — medium beat cotton half-stuff half-dip, front-to-back shake</td>
<td>1.23</td>
<td>2.26</td>
<td>1.17</td>
</tr>
<tr>
<td>Sea Pen — medium beat cotton half-stuff half-dip, alternating shake</td>
<td>1.19</td>
<td>2.86</td>
<td>1.41</td>
</tr>
<tr>
<td>Sea Pen — heavy beat vat leavings standard dip and shake</td>
<td>1.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mould-made</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barcham Green Tovil</td>
<td>.76</td>
<td>.57</td>
<td>1.09</td>
</tr>
<tr>
<td>Fabriano Umbria</td>
<td>1.12</td>
<td>1.38</td>
<td>1.03</td>
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<tr>
<td><strong>Mould-made</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lana Laid</td>
<td>2.10</td>
<td>1.65</td>
<td>1.5</td>
</tr>
<tr>
<td>Nidegan</td>
<td>1.6</td>
<td>4.55</td>
<td>1.09</td>
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<tr>
<td>Frankfurt</td>
<td>1.8</td>
<td></td>
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<tr>
<td>Arches Text Laid</td>
<td>1.67</td>
<td>2.33</td>
<td>1.25</td>
</tr>
<tr>
<td>Fabriano Ingres Antique (50% cotton)</td>
<td>1.84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tensile, folding, and tearing strength tests done on various handmade and mould-made papers. All measurements are ratios of strength across the grain to strength in the grain direction. Ratios closest to 1 for each test might be used as an indication of squareness in the paper. Tests were done on only one sheet per type of paper and are, thus, subject to experimental and statistical error. All testing was done by Prof. Joseph E. Brown, Rochester Institute of Technology, School of Printing Management and Sciences, Paper Laboratory.