Outlook for StereoJet™ Three-Dimensional Printing

The Rowland Institute for Science
Cambridge, Massachusetts

OUTLOOK FOR STEREOJET™

THREE-DIMENSIONAL PRINTING TECHNOLOGY

Prepared for the Board of Directors

THE ROWLAND INSTITUTE FOR SCIENCE, CAMBRIDGE MASSACHUSETTS

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By

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This document reflects our current understanding of StereoJet™ imaging technology and its potential commercial markets as of January 2001. It is an internal document prepared for the Board of Directors of the Rowland Institute and is specifically not intended as a prospectus. As with all new technologies that have had limited testing in commercial markets, our information is necessarily incomplete, often based on informal reports from third parties, and our conclusions are at best tentative. There is considerable financial risk in introducing any new and untested product to the commercial marketplace particularly in the current fast-moving competitive environment for technology. Readers of this document are strongly encouraged to contact third parties mentioned in this report to confirm our impressions of their experiences and to pursue independent inquiries and market testing to evaluate the commercial potential of the StereoJet imaging process. This document was prepared for internal review and while it may be shared with outsiders interested in our own understanding of StereoJet technology and is prospective markets, it should not be used to evaluate the commercial viability of StereoJet printing which is a new and therefore commercially untested technology.

EXECUTIVE SUMMARY

StereoJet™ is a photographic quality 3-dimensional hardcopy technology developed by The Rowland Institute for Science in Cambridge, Massachusetts. With this novel printing process, inexpensive desktop inkjet printers produce stunning, full-color, high-resolution stereoscopic prints and transparencies for use as hardcopy for many areas of imaging and visual computing. The present embodiment of StereoJet has reached a state of reliable, high quality performance, and marketing experience has suggested it is commercially viable. Particularly attractive fields for marketing would seem to include photogrammetry, remote sensing, and graphical information systems. Royalties returning to the Institute from licensing the technology are projected to be several million dollars annually after 5 years if a properly qualified Master Licensee can be identified. This Master Licensee must have the ability to identify, enlist, and motivate capable sub-licensee companies operating in the separate and heterogeneous markets for StereoJet imagery.

Table of Contents

INTRODUCTION

StereoJet™ is a photographic quality 3-dimensional hardcopy technology developed by The Rowland Institute for Science in Cambridge, Massachusetts. With this revolutionary printing process, inexpensive, desktop inkjet printers, without modification of either software or hardware, can be used to make stunning full-color, high-resolution, three-dimensional prints and transparencies.

The color, vibrancy, and the sense of realism provided by stereoscopic StereoJet prints and transparencies, whether of a soaring basketball player, the awesome topography of Mt. St. Helens seen from the sky, the arid and stony fields of Mars as recorded by NASA's Pathfinder, a supercomputer simulation detailing oil reserves under the Gulf of Mexico, or the computer visions of an architect or a special effects artist, delight and amaze all who see them.

StereoJet imaging is based on the principle of light polarization. The process comprises the back-to-back printing of polarizing stereoscopic image pairs, with left- and right-eye images polarized at 90 degrees to one another. Transparencies are displayed by rear illumination or projected by overhead projectors onto conventional non-depolarizing silver screens. Prints are displayed under reflected light. Both prints and transparencies are viewed through polarizing viewers of the type used for viewing stereoscopic motion pictures.

StereoJet was developed, in part, as a form of hardcopy for three-dimensional computer modeling, a burgeoning field that justifiably has been called "a second computer revolution" because of its broad impact on design, medicine, engineering, and science. Just as the word processor changed the way most people prepare documents, three-dimensional computer modeling changes the way we create and manipulate three-dimensional designs and data. This new kind of computing, now routinely pursued on desktop personal computers, requires an appropriate form of hardcopy that, unlike conventional forms of hardcopy, does not collapse the three dimensions represented in the computer.

StereoJet is the hardcopy of choice for designers generating images with computer graphics, for photogrammetrists and microscopists working with stereo images, for researchers working with computational fluid dynamics, three-dimensional medical images, finite element models, molecular models, or other computer-based simulations. StereoJet is also intended for a wide range of publishing applications, such as postcards, souvenirs, training manuals, children's books, and textbooks. It is a means of making high quality stereoscopic imagery a routine part of business, scientific and technical communications, as well as a medium for entertainment and education. Both U.S. and foreign patents issued to the Rowland Institute for Science protect the proprietary inks and substrate that are used in the StereoJet process.[1]

BACKGROUND

Institute member Jay Scarpetti, a longtime member of Edwin H. Land's inner circle of photographic researchers, proposed inkjet-based three-dimensional printing in 1991. Scarpetti was familiar with the Vectograph™ color imaging technology developed by Land and others at the Polaroid Corporation to produce stereoscopic prints and transparencies.[2] Vectograph dye imbibition processes successively transferred sets of three or more dichroic dyes to a two-sided sheet, each surface comprising a layer of oriented polyvinyl alcohol (PVA) molecules. The imbibed dye molecules became efficient polarizers as they aligned with oriented PVA molecules. The system involved laborious darkroom preparation of gelatin matrices and a multistep transfer process.

Scarpetti's proposal was to bypass the demanding dye imbibition process by utilizing digital images and inkjet technology, which had become the preferred method for color desktop imaging, to deliver dichroic dyes to an oriented receiving sheet. Scarpetti reasoned that the resulting process would have the benefits of the Vectograph process without its difficulties and would be a convenient low-cost method for making stereoscopic prints and transparencies. This approach seemed particularly appealing with the increasing use of desktop workstations and personal computers for three-dimensional computing and with the fast-moving pace of improvements in desktop

[1] Appendix I lists patents and pending patent applications.

[2] For a further discussion of Vectograph processes and their applications, see Appendix II. See also Land, E.H., Vectographs: Images in Terms of Vectorial Inequality and Their Application in Three-Dimensional Representation, *J. Opt. Soc. Amer.* **30**, 230-238 (1940).

inkjet printing, which promised, and delivered in the 1990s, low-cost desktop photographic quality.

The convergence of trends in desktop printing and computer-based three-dimensional modeling suggested that many consumers would value a "3-D" hardcopy process. Just as word processing led to a large increase in the consumption of paper (rather than to the paperless office some predicted), three-dimensional computing requires a hardcopy medium that presents the computer model more effectively than it can be viewed on a two-dimensional screen. There was a time, ten or fifteen years ago, when color was thought by many to be irrelevant to desktop computing and that color screens and desktop printers would never be embraced by consumers. Today, color screens are the standard and high-quality, low-cost color printers are ubiquitous and thought to be essential by most consumers. Similarly, there should be widespread demand, at least among those creating three-dimensional designs on computers, for StereoJet hardcopy because it is a better and more accurate way of depicting the full dimensionality of the data in the computer.

RESEARCH AND DEVELOPMENT

Scarpetti's first experiments, which utilized inkjet cartridges hand-filled with inks formulated with dichroic dyes and substrates made from traditional Vectograph material, did not produce images. The inks simply ran off the surface. Steps taken to improve dye imbibition included surface hydrolysis of the PVA layers and the coating of each surface with a thin layer of a non-oriented polymer that would meter the imbibition of dyes into the PVA layers.

In subsequent years, Scarpetti and the Stereo Imaging Group, which included Philip DuBois, Vivian Walworth, Richard Friedhoff and MaryAnn Nilsson; consultants Lawrence Gogolin, Mary McCann, and Ralph Burpee; and interns Jason Figueiredo, Tobin Curran, Ella Laramee and Christine Blehm, developed the materials and procedures that now produce striking images in polarization, utilizing inexpensive off-the-shelf inkjet printers.

The StereoJet materials include a quartet of proprietary inks (cyan, magenta, yellow and black) in standard inkjet cartridges and a complementary printable substrate. The substrate comprises a cellulose triacetate (CTA) support and surface-hydrolyzed layers of oriented polyvinyl alcohol (PVA) overcoated with thin layers of carboxymethylcellulose (CMC). This CMC layer holds the wet ink in place to modulate imbibition of the dyes into the oriented PVA and thus the formation of polarizing images. The inks, substrates and method of inkjet printing of stereoscopic images have been thoroughly described in Rowland Institute patents,[3] as well as in various technical and scientific publications.[4]

StereoJet substrate is a proprietary modification of contemporary Vectograph sheet. In the course of their research, Scarpetti and his group have identified dyes with spectra and dichroic properties that optimize the color fidelity and polarization of the StereoJet images. They formulated an ink carrier vehicle that is compatible with both thermal and piezo-electric inkjet printers, developed the permeable CMC layer that modulates imbibition of the dichroic dyes into the PVA, and overcame significant manufacturing problems. For the StereoJet printing process, significant developments have included stereoscopic registration techniques and methods for minimizing the visibility of ghost images, i.e., unwanted "other eye" images.

MANUFACTURING PROCESSES AND MATERIAL COSTS

StereoJet Substrate

StereoJet substrate could not be made in quantity until June of 2001 because of a series of manufacturing challenges related to scaling hand laboratory procedures to larger volume manufacturing. During this development period, however, individuals and

[3] See Appendix 1 for list of issued and pending United States and foreign patents.

[4] Examples include:

J. J. Scarpetti, P.M. Dubois, R. M. Friedhoff, and V. K. Walworth, Full-Color 3-D Prints and Transparencies, *J. Imaging Sci. Technol.* **42**, 307-310 (1998).

J. J. Scarpetti, P. M. DuBois, R. M. Friedhoff, R., and V. K. Walworth, "Developments in StereoJet Technology," Stereoscopic Displays and Virtual Reality Systems VII, January 24-26, 2000, San Jose, CA, (*Proc. SPIE*, **3957**, 288 (2000).

service bureaus interested in the StereoJet process purchased limited amounts of substrate from the Institute that resulted from research in collaboration with our manufacturers. Indeed, it was generally the case that all the substrate that was produced was sold. These sales facilitated valuable market exploration.

It is relevant to the economics and business potential of the StereoJet process that the Polaroid Corporation manufactured Vectograph sheets for more than 50 years. The sheet comprised stretched and oriented PVA on both surfaces of a transparent carrier sheet. The orientation of the PVA is 45 degrees to the direction of the roll, with the two PVA layers oriented orthogonally. The Polarizer Division of Polaroid Corporation manufactured Vectograph sheet until the spring of 2000, when this division was sold to the 3M Corporation. 3M Corporation has made a commitment to continue production of the sheet, although 3M charges more than Polaroid had. 3M is currently the only source of this sheet, because it is manufactured on a unique machine, the 45-degree stretcher designed and built by Polaroid and now owned by 3M.

Present concerns regarding the StereoJet substrate are the need for a continuing supply through a Master Licensee, the present small inventory of substrate, and the need for a definitive agreement with 3M covering specifications, as well as pricing. Another goal is to develop an additional supplier, utilizing PVA oriented in the running direction of the roll, and that will require new procedures and further research.

Vectograph sheet is generally produced by 3M in lengths of one thousand feet or more in rolls that are 22" wide. After stretching the PVA and laminating it to the CTA base, the surfaces of the PVA are hydrolyzed by 3M to increase the penetrability of StereoJet dyes into the PVA. 3M then trims both edges, reducing the width to 20", and winds the roll with a tissue paper interleaf.

The rolls are then shipped to Arkwright Corporation of Fiskeville, Rhode Island, for the CMC coating. After coating and covering with polyethylene, Arkwright either cuts and trims the 20" roll to provide two 8.5" rolls or sends 17" rolls directly to the Institute. The 8.5" rolls are sent to Innova Corporation of Bloomfield, Connecticut for perforation into 11" segments (8.5 x 11" sheets). The 17" rolls are cut into 17 x 22" sheets or other custom lengths of 17" sheet as required. 3M will manufacture short rolls at $15.50 per linear foot. A two-thousand-foot roll thus will cost $31,000 from 3M. Arkwright Corporation coats the roll with CMC for an additional $6,000. As the additional costs of perforating, boxing, and the like are minimal, the quantity gleaned from 2000 linear feet can be purchased for approximately $37,000.

StereoJet Inks

The American Ink Jet Company of Billerica, Massachusetts formulates StereoJet inks to specifications developed by the Stereo Imaging Group. These inks are currently used to fill cartridges compatible with the Epson 3000 inkjet printer. Four cartridges, cyan, magenta, yellow and black are required to make prints. American Ink Jet charges the Institute approximately $50 per filled and boxed cartridge.

MARKETING EXPERIENCES

CUSTOM PRINTING

Custom printing is defined as production of small quantities of StereoJet prints or transparencies on a demand basis.

Service Bureaus

Service bureaus can offer three-dimensional StereoJet prints and transparencies to their customers for presentations, marketing materials, displays and other applications. The Rowland Institute has worked with a pilot service bureau, San Francisco Imaging Services (SFIS), since 1998. The experience has provided a good opportunity to understand the service bureau market for StereoJet products. SFIS has been very successful in developing a wide range of clients for StereoJet prints and transparencies, including commercial firms, non-profit institutions, and museums. Commercial firms include those specializing in architecture, civil engineering, automotive design and manufacture, pharmaceutical research, and product design. StereoJet exhibits have been made for art museums, for special effects designers, and for theme park attractions.

SFIS has served clients working in prototype rendering (General Motors), scientific imaging (Jet Propulsion Laboratories), motion picture production (Universal Studios), and museums (the Monterey Bay Aquarium). SFIS reports that their client list in 2001 was long, varied, and growing. General Motors alone intended to place more than $10k worth of orders in 2001 with SFIS, pending availability of substrate.

A key aspect of the success of SFIS has been its proactive marketing of StereoJet prints and transparencies, not only to existing clients, but also to new prospects. Indeed, SFIS has utilized StereoJet demonstrations as an occasion to re-visit existing clients, as well as an opportunity to solicit new clients. SFIS reports, furthermore, that those demonstrations were very successful in securing additional business for their existing product line, as well for selling StereoJet services. This is significant because it will justify investment in marketing StereoJet at other service bureaus.

Graphical Information Systems and Photogrammetry

In the service bureau sector there appears to be a great, if as yet unmeasured, potential in the graphical information systems (GIS) and photogrammetry fields. GIS is a very important tool for the development and management of oil, gas, minerals and other natural resources and is increasingly used for urban planning, store location planning, and other applications involving human construction. In photogrammetry, a field that increasingly uses GIS tools, stereo imaging is already essential, so that photogrammetrists can readily turn to StereoJet as their hardcopy of choice.

GIS is, furthermore, a sizable worldwide industry, consuming nearly $7B in goods and services each year.[5] Two photogrammetry service companies, Aero Geomatrix, Ltd., and Integrated Mapping Technologies, both based in Vancouver, British Columbia have been getting high level of interest in response to test marketing StereoJet images to their clients in the oil and gas industry and in the forestry products field, as well as with the Provincial Government of British Columbia and the Government of Canada. From the reports of these two companies, GIS and photogrammetry would appear to be very big markets for StereoJet. When stereo is a routine tool, it is only a small step to stereoscopic hardcopy.

[5]From: Graphical Information Systems Markets and Opportunities—Worldwide Sales, Datatech, Inc., 2001, www.datatech.com.

Trade Show Exhibits

Our own experience attending three trade shows, as well as providing StereoJet images to a variety of companies for their trade show booths, suggests that large format StereoJet imagery, properly marketed, could do well in this industry.

The StereoJet booths at the large Siggraph computer graphics shows in 1999 and 2000, were always filled with prospects, even when most other booths in the same area were more or less empty. Arresting StereoJet images draw crowds. People will wade through a crowd for the experience of seeing pleasing stereoscopic images. Handing out the inexpensive paper-framed polarizing viewers, furthermore, creates a unique opportunity, almost like a handshake, to initiate conversation with prospects and thus sets the stage for an intimate moment, a bonding experience if you will, when the prospect suddenly experiences the StereoJet image in three dimensions. The inexpensive polarizing viewers also give prospects something memorable to take with them that can be printed with, for example, the name, phone number, and website of the exhibitor. StereoJet imagery is, furthermore, a powerful medium for focusing the attention of prospective customers on a new design or new and visually interesting products. As the prospect has the fun of experiencing the three-dimensional image, he or she is also scrutinizing the exhibitor's new product. In short, large format, backlit StereoJet transparencies appear to be potentially powerful sales tools for exhibitors at trade shows.

Institutional Users

Researchers at the Jet Propulsion Laboratory (JPL) have worked closely with both SFIS and the Rowland Institute to utilize StereoJet technology in several JPL imaging programs. Indeed, two JPL scientists who received StereoJet training at The Rowland Institute have installed an in-house StereoJet production facility, which is gearing up for a number of proposed and ongoing satellite imaging missions. A related military field of current significance is aerial reconnaissance.

Individual Licensees

Several individuals who specialize in stereoscopic imaging have also been licensed by the Rowland Institute to produce StereoJet images. These licensees are David Burder in London, Ron Labbe in Maynard, Massachusetts, and Peter Sinclair in Toronto, Ontario.

Although each produces excellent images, their custom printing volumes have been limited. In addition to custom printing, Peter Sinclair makes and sells 3¼ x 4¼-inch mounted transparencies of classical paintings that have been converted by computer from two-dimensional to three-dimensional images.

Non-Manufacturing Service Bureaus

Although SFIS has been particularly effective at producing and marketing excellent StereoJet prints and transparencies to businesses and institutions throughout the Bay area, not all service bureaus need make such a comprehensive commitment to participate in the StereoJet business. An alternative strategy is to let a successful service bureau, such as SFIS, place StereoJet displays in service bureaus that do not actually make StereoJet prints. Preliminary discussions with New York and Los Angeles service bureaus have suggested the viability of this marketing strategy for extending the reach of StereoJet services.

In such locations service bureaus would use backlit 17 x 22" StereoJet displays featuring stunning images with the tag line "Ask Us About 3-D Printing," and accompanying brochures outlining the benefits of StereoJet technology, costs, and procedures. The resulting orders would then be passed along, through overnight delivery or, preferably, electronically via the Internet to SFIS for fulfillment. The non-manufacturing service bureau would receive a commission for writing and servicing the order. Such displays would generate inquiries and orders and serve to build the StereoJet service bureau business. Some non-manufacturing service bureaus with sufficient volumes could eventually become manufacturing facilities. We believe that this is a low-stress way for a service bureau to test the waters regarding the StereoJet business and therefore a potentially important means for promoting awareness of StereoJet three-dimensional printing and enlarging the StereoJet business.

This arrangement should also be used to encourage service bureaus to recruit new service bureaus that will offer StereoJet services. We do not know the sizes of all of the various markets of interest to service bureaus or of other unrecognized markets, but several are likely to be quite substantial. SFIS indicates that with the availability of an uninterrupted supply of substrate they would order approximately 200 8.5 x 11" sheets and an additional 100 17 x 22" sheets, a total of 390 square feet, on a monthly basis. If this were to be repeated at 100 similar service bureaus around the world, with a number of those focused on specialized markets such as photogrammetry and trade shows, including service bureaus providing imagery to non-manufacturing service bureaus, then the figure of 100 SFIS equivalents seems a reasonable goal to achieve in the course of three years. At this rate, the service bureaus would consume approximately 450k square feet of substrate per year and return to the Institute, presuming a royalty of $2.50 per square foot for service bureau grade substrate, approximately $1.125M per year after two or three years.

In-House Printing

Although the amounts of substrate we were able to supply were quite limited, we have experimented with creating incentives so that SFIS, our pilot service bureau, would market to customers who want to print StereoJet images in-house. In-house printing is an important matter because three-dimensional information is often proprietary. The automotive companies, for example, have well-guarded designs that they will not export to an outside service bureau. An oil and gas company, similarly, is likely to protect its data regarding natural resource reserves. Many commercial firms and other kinds of organizations will likely require privacy with respect to StereoJet printing.

Pricing StereoJet substrate so that bulk buyers can obtain meaningful discounts will help to encourage service bureaus who are StereoJet printers to have their clients set up in-house printing facilities. In this instance, the service bureau will become a reseller of StereoJet materials at a profit. Clients who express concerns about the confidentiality of their data will become customers for StereoJet materials rather than for finished images. To create a ceiling for the price of StereoJet substrate, StereoJet should therefore be offered on the StereoJet website at what might be called suggested retail prices.

Projected Consumer Market

Our discussions with the major inkjet printer manufacturers over recent years indicate that a consumer-friendly StereoJet process would be most welcome and of great commercial significance in the inkjet industry. Each of the major manufacturers is searching for a proprietary feature to offer exclusively with its printer line because of the highly competitive nature of the inkjet printer market, and it would be hard to surpass "Prints in 3-D" as a singularly enticing feature. A great many people faced with a choice of printers with otherwise identical pricing and functionality would be reluctant not to choose the printer that can uniquely produce three-dimensional prints and transparencies. Thus StereoJet could be a critical strategic element for one of the major manufacturers to surge ahead of the others in placing printers in the hands of consumers and business users. By this means, they would enlarge their highly profitable cartridge business, whether or not consumers were actually purchasing cartridges containing StereoJet inks.

Provision of a consumer version of StereoJet would require additional research and development effort. A somewhat simpler process needs to be developed, preferably with reduced holding time and without the wash step. This is a likely focus for future research on StereoJet printing.[6]

PUBLISHING MARKETS

Publishing is defined as the production of images in quantity for use as postcards and souvenirs, in books or magazines, or for other purposes. An individual image is reproduced in quantities of hundreds, thousands, or more.

SFIS, working with the Rowland Institute, recently conducted a test to determine the market acceptance of StereoJet postcards. A small Lucite display stand featured various stereoscopic views of the Golden Gate Bridge, and the stand was placed in Golden Gate Bridge Gift Shop, a shop frequented by tourists from all over the world. Each "You Are There! ™" postcard was in a transparent envelope along with a visible pair of paper-framed polarizing viewers, forming a package that could be addressed and mailed. Without any attention from sales personnel, per the agreement with the gift shop, when properly maintained, SFIS reports that the stand sold an average of 7 postcards per day at a unit price of $5.95. On a weekly basis, such sales result in an average of approximately $420 per week in gross sales. This is a potentially significant finding when multiplied by all of the conceivable locations around the world where such postcards might be sold.

During the last two years, a number of publishing firms have shown an interest in using StereoJet prints and transparencies in books. For example, Hyperion Books, a unit of

[6] The Rowland Institute has secured the rights to produce a stereo calculator that would be an important asset to stereoscopic photographers and designers, especially those not well acquainted with the requirements of effective stereo photography.

the Walt Disney Company, expressed interest in developing StereoJet books for children in our discussions with them two or three years ago.

The ViewMaster Division of Fisher-Price Toys, which itself is a division of Mattel Corporation, designed a prototype product using StereoJet images. ViewMaster, of course, is famous throughout the world as the manufacturer of stereoscopic viewers that utilize cardboard reels containing stereo image pairs. This product is still popular. In the year 2000, they reportedly sold approximately 30 million ViewMaster reels. Their proprietary StereoJet product design has not been described to us in detail but apparently involves something similar to a deck of cards, each of which is a stereo view. For the ViewMaster product to be viable, however, the cost of production of StereoJet images will need to be very low.

ECONOMICS OF CUSTOM PRINTING AND PUBLISHING

The economics and production methods of these two markets, custom printing and publishing, are completely different from one another. The custom printing business is relatively impervious to high substrate costs, as the cost of the substrate is a relatively small fraction of the retail price. Additional costs accrue through hand production of low quantities of each image, and retail prices are, relatively speaking, high but accepted without difficulty by customers interested in a few specialized prints. The publishing business requires low substrate cost, low labor-cost production, low pricing and large volumes. Table 1 shows the impact of substrate cost on the price of postcards, a market typical of publishing applications. Substrate costs would be still lower for the trading card size images required, for example, by ViewMaster.

The SFIS postcard tests at the Golden Gate Bridge Gift Shop indicated price sensitivity as the retail price reached seven dollars ($6.95). To keep the retail price of the postcards below $7, the cost of substrate must be below $6 per linear foot.

The price set by 3M requires that an alternative be found to their double-sided 45-degree Vectograph sheet. Our discussions with several polarizer manufacturers indicate that this is possible. However, additional research would be required to adapt their present base materials for StereoJet printing.

Conventional sheet for polarizers is single sided, and the PVA stretch is in the direction of the run, unlike Vectograph sheet that orients the PVA at 45 degrees to the direction of the run and has orthogonally oriented PVA on both sides. There are, however, possible strategies for adapting the less expensive conventional sheet to StereoJet printing, and fortunately the resulting publishing grade substrate has some distinct advantages for publishing applications.

By printing the image on the diagonal (rotated 45°) with one member of the image pair adjacent to the other on the same side of the sheet, for example, and folding the sheet over in the fashion of a greeting card, to superimpose the images, it is possible to bring together two images with orthogonal axes of polarization which is the fundamental requirement for StereoJet. This same side printing strategy has an important additional advantage apart from economy: images can be printed without loss of registration, as images are sequentially paired on the same side of the sheet. This kind of printing is more suitable for large-volume printing than our present method of StereoJet printing but creates a print with an air gap between the members of the folded image pair.

In order to make this an acceptable product, an inexpensive method is needed to laminate the members of the image pair together. Publishing applications will usually involve small size prints, because of the inherent cost of the base material. As with the present substrate, the PVA on this material will need to be hydrolyzed and coated with CMC to properly accept StereoJet dyes.

Combining the two images inexpensively seems minor compared with the vastly greater technical difficulties that have already been solved and given the tremendous market for StereoJet imaging that a low-cost substrate might enable. Traditional polarizer base material can be very inexpensive, in the one or two dollar per linear foot range, which would enable not only postcards but children's books and products such as those proposed by ViewMaster even though, twice as much substrate is required because standard polarizing base material has PVA on only one surface.

It should be noted that publishing applications, even with low-cost substrate and serial printing, require a low labor cost environment, as StereoJet printing is more labor-intensive than traditional printing. The Rowland Institute has had a series of discussions with the Thailand-based Sirivatana Division of the Singapore National Printing Company (SNP), a company partly owned by the Government of Singapore, which offers a wide range of specialty printing services, ranging from bank notes to children's pop-up books. SNP has indicated that they are interested in exploring scaling up StereoJet printing by utilizing gangs of inkjet printers. Their objective would be to produce quantities of thousands or tens of thousands of copies at a reasonable cost. The manufacturing costs for StereoJet postcards in Column 4 of Table 1 are based on a

Table 1. Substrate Price vs. Retail Price of Postcards

Substrate Price/Linear Foot Without Coating	Institute Royalty per Linear Foot (two square feet)	Post-Card Sized Without Coating (Linear Foot Cost Divided by 6)	With Coating, Printing and Mounting (plus $1)	Margin for Manufacturer (plus $1)	Margin for Distributor (plus $1)	Retail Price (Wholesale Cost x 2)	
1.00	1.00	$0.33	$1.33	$1.83	$2.83	$5.67	
2.00	1.00	$0.50	$1.50	$2.00	$3.00	$6.00	
3.00	1.00	$0.67	$1.67	$2.17	$3.17	$6.33	
4.00	1.00	$0.83	$1.83	$2.33	$3.33	$6.67	
5.00	1.00	$1.00	$2.00	$2.50	$3.50	$7.00	
6.00	1.00	$1.17	$2.17	$2.67	$3.67	$7.33	
7.00	1.00	$1.33	$2.33	$2.83	$3.83	$7.67	Volume drops in this range!
8.00	1.00	$1.50	$2.00	$2.50	$3.50	$7.00	
9.00	1.00	$1.67	$2.67	$3.17	$4.17	$8.33	
10.00	1.00	$1.83	$2.83	$3.33	$4.33	$8.67	

rough estimate suggested by an SNP representative with knowledge of the StereoJet printing process. The actual cost may vary, depending upon the efficiencies they are able to achieve.

Our considerable experience with SFIS and others and a variety of pricing schemes suggests that an appropriate price for a finished custom image from a service bureau should be in the range of $80 for an 8.5 x 11" image and $350 for a 17 x 22" image, prices that support substrate costs of $20 and $80 respectively. The 3M price for manufacturing substrate is approximately $10 for the 8.5 x 11" sheet and $40 for the 17 x 22" sheet,[7] or half the cost charged to service bureaus. This suggests that a reasonable royalty, respecting these two constraints, would be $2.50 per square foot for the present

[7] Assuming a 90% manufacturing yield, which is typical with the CMC coating formulation.

sheet manufactured by 3M and used for custom printing. Table 1 indicates that the royalty would need to be significantly less for substrate used in publishing applications, perhaps on the order of $1/linear foot or less.

STEREOJET™ CUSTOM PRINTING AND PUBLISHING MARKET FORECASTS

Our measures of prospective markets for StereoJet custom printing are based on pilot programs that actually sold materials into specific markets or at least negotiated with prospective customers. Assuming the availability of a low cost publishing grade substrate, the publishing fields discussed earlier could also develop substantially.

For example, marketing postcards at 1000 or more locations with sustained volumes equivalent to the Golden Gate Bridge store test, as shown in Table 2, might be expected to return approximately $2M annually in gross revenue to the licensee and royalties of approximately $0.5M to the Institute based on a $.50/linear foot royalty. The proposed Viewmaster product and book publication should yield similar royalties.

Table 2 below summarizes royalty projections based on the assumptions regarding various market segments discussed above. The table establishes five-year goals for both substrate consumption and royalties, based on assumptions about the StereoJet market gleaned from our test marketing experiences over the last several years and from the interest expressed by large-scale publishers. The intermediate goals for years 1-4 describe a linear growth function culminating in the projected goal for the fifth year. Clearly, it will take some time to establish a foothold in these markets and a marketing mechanism that is designed to grow, and so the actual function is probably not linear. Indeed, the purpose of this table is to establish clearly for a potential Master Licensee the end goal rather than to characterize the exact rate of growth. Furthermore, there are in all likelihood additional products and markets yet to be discovered that would enlarge this table.

Table 2. Five Year StereoJet Substrate Royalty Projections

	Market Segment	Royalty Rate	Year 1	2	3	4	5
	Custom Imaging	Per Sq Ft					
Quantity of Substrate (000 sq ft)	Service Bureaus	$2.50	90	180	270	360	450
Royalty ($'000)			225	450	675	900	1,125
Gross Revenue to Distributor ('000)			765	1,530	2,295	3,060	3,825
	Publishing						
Quantity of Substrate (000 sq ft)	Postcards & Souvenirs	$0.50	100	200	300	400	500
Royalty ($'000)			40	80	120	200	500
Gross Revenue to Distributor			232	464	696	1160	2900
Quantity of Substrate (000 sq ft)	Toys	$0.50	200	400	600	800	1000
Royalty ($'000)			80	160	240	400	1000
Gross Revenue to Distributor			464	928	1392	2320	5800
Quantity of Substrate (000 sq ft)	Books	$0.50	150	300	450	600	750
Royalty ($'000)			150	300	450	300	750
			870	1740	2610	1740	4350
	Total Royalties ($'000)		495	990	1485	1800	3,375
	Total Revenue to Distributor		2,331	4,662	6,993	8,280	16,875

Two kinds of financial projections are of particular interest: the royalties returned to the Institute from the licensee and the gross revenue returned to the licensee. Both quantities are dependent upon the same variable, the volume of substrate that is consumed. In the case of the custom printing business, an 8.5 x 11" sheet is manufactured for approximately $10 and sold for $20. Out of the $10 margin, the licensee will in all likelihood pay the Institute a $2.50 royalty. Thus, the gross profit (the difference between revenue and the cost of goods sold) will be $7.50 per 8.5 x 11" equivalent.[8] Thus, the projection of gross revenue for the licensee, as indicated in Table 2, is simply the Rowland royalty multiplied by the factor 3. If the licensees can meet the objectives described in this report, they need only estimate the costs for meeting those objectives to determine the net profitability of the endeavor.

[8] We make no attempt to estimate net profit for the distributor because we do not know the marketing strategy or costs for the distributor to meet the objectives described in this report.

Although the publishing business works somewhat differently, a similar strategy can be used to project gross revenue and net profitability if the stated goals are accepted. For example, in the case of postcards, a reasonable business model based on a substrate cost of three dollars or less per linear foot, as shown in Table 1, returns to the Institute a royalty of $0.17 per postcard and a dollar per postcard to the licensee. Thus, the factor for projecting gross revenue for the distributor from the Rowland royalty is approximately 5.8. A licensee would need to agree to those goals, or define others, and estimate the cost of meeting those goals in order to translate gross revenue projections into net profit projection.

Qualifications of the Master Licensee

A Master Licensee would do well to note that any long-term plan to commercialize StereoJet printing must focus first on stereo intensive fields, such as GIS and photogrammetry, where there is no need to educate prospects about the techniques and benefits of stereo imaging as a prelude to promoting the consumption of StereoJet hardcopy. Stereo imaging is widespread in the two overlapping areas of GIS and photogrammetry, so the benefits of StereoJet hardcopy should be widely and easily appreciated in these fields.

Furthermore, the most efficient means for reaching the diverse markets for StereoJet products is to work with companies already selling goods and services in these fields. As noted above, the firm that is adept in reaching the photogrammetry market would be an unlikely candidate to develop the postcard business because the two businesses are completely different. The trade-show business is clearly a different kind of business from children's books. An appropriate Master Licensee, rather than trying to develop all of these heterogeneous markets, should have sufficient capital and competencies to find and motivate capable sub-licensees in all the important markets for StereoJet. In addition to continuing to identify new markets, these are probably the key competencies required of a Master Licensee: the ability to identify, enlist, and motivate suitable companies operating in the heterogeneous markets for StereoJet imagery.

In any license agreement, furthermore, key terms are the licensing fee and minimum guarantees. These are especially important here because of the substantial investment, approximately $6m, which the Rowland Institute has made in this product. The prospective Master Licensee should demonstrate a firm commitment to promoting the full range of prospective StereoJet businesses in an efficient manner through payment of a fee to acquire the license and by guaranteeing minimum sales as a condition for maintaining the license.

STEREOJET RESEARCH AND PRODUCT SUPPORT

Now that it is possible to manufacture high-quality StereoJet substrate reliably in quantity, the costs for research and development can be reduced substantially. Whether undertaken by the Rowland Institute or by a Master Licensee, the programs described above, for example, developing the consumer version of StereoJet printing for the inkjet printer industry or a much lower priced substrate for a broad range of publishing applications, calls for further research and development, as well as product support.

The principal expenses for continuing StereoJet research and development are delineated below in Table 3, which shows a total of $244,800 annually. The ongoing support of the existing StereoJet products, which is necessary for maintenance of quality control over the manufacturing process, would involve much less time and effort on the part of the researchers than a basic research program and would be substantially less expensive than indicated in the table.

Table 3. Staffing and Other Expenses

Staff Position	
Principal Investigator	132,400
Full-Time Laboratory Assistant	37,400
Part Time Lab Assistant	17000
Coating Consultant	12000
Microscopy Consultant	6000
Communications	15000
Miscellaneous	25000
Total Annual Research Expenses	244,800

SUMMARY AND CONCLUSIONS

The present embodiment of StereoJet has reached a state of reliable, high quality performance, and marketing experience has demonstrated its commercial viability. Particularly attractive fields for marketing include photogrammetry, remote sensing, and graphical information systems.

The current StereoJet system is ready for adoption by a distributor or master licensee, given suitable royalties to the Rowland Institute. Provision for ongoing product support is essential. Transfer of detailed information on manufacturing specifications, sources of materials and equipment, prior research and development, and consultant services will be essential to the continuing success of the StereoJet system.

Further research and development can provide a simplified procedure and associated aids and instructions that constitute a version practical for consumer use. Such a version has potentially important strategic value as a proprietary feature offered by an inkjet manufacturer.

Development of a low-cost substrate and associated procedures can enable a StereoJet publishing market. Such a system will require additional research.

APPENDIX I: PATENTS

LIST OF PATENT RIGHTS

ON INKJET STEREOSCOPIC IMAGING TECHNOLOGY

THE ROWLAND INSTITUTE FOR SCIENCE

A. ISSUED U.S. PATENTS

U.S. Patent No. 5,591,508 issued January 7, 1997

"Coating Methods and Compositions for Production of Digitized Stereoscopic Polarizing Images." based on USSN 08/380,941 filed January 31, 1995.

U.S. Patent No. 5,552,182 issued September 3, 1996

" Inking Methods and Compositions For Production of Digitized Stereoscopic Polarizing Images." based on USSN 08/380,949 filed January 31, 1995.

U.S. Patent No. 5,764,248 issued June 9, 1998
"Production of Digitized Stereoscopic Polarizing Images by Ink Jet Printing."
based on USSN 08/381,131 filed January 31, 1995.

U.S. Patent No. 5,758,036 issued May 26, 1998
" Production of Improved Digitized Stereoscopic Polarizing Images."
based on USSN 08/594,110 filed January 30, 1996.

U.S. Patent No. 6,013,123 issued May 26, 1998
" Inking methods and Compositions for Production of Digitized Stereoscopic Polarizing Images."
based on USSN. 08/903,889 filed July 31, 1997 (CIP of USSN 08/381,131 filed January 31, 1995).

B. PENDING U.S. APPLICATIONS

US Patent Application Serial No. 09/480,502 filed January 10, 2000

" Inking Methods and Compositions for Production of Digitized Stereoscopic Polarizing Images."

DY of USSN, 08/903,889 filed July 31, 1997 (CIP of USSN 08/381,131 filed January 31, 1995)

C. ISSUED FOREIGN PATENTS

European Patent No. 0 807 024 Granted December 2, 1998

"Coating Methods and Compositions for Production of Digitized Stereoscopic Polarizing Images." based on European Patent Application Serial No. 96 90 3684.7 filed January 30, 1996

National Processing Activated in: DE, FR, GB, ES, IT

D. PENDING FOREIGN APPLICATIONS

Canadian Patent Application Serial No. 2,211,626 filed January 30, 1996

"Coating Methods and Compositions for Production of Digitized Stereoscopic Polarizing Images."

Japanese Patent Application Serial No. 8-523632 2 filed January 30, 1996

"Coating Methods and Compositions for Production of Digitized Stereoscopic Polarizing Images."

Mexican Patent Application Serial No. 975770 filed January 30, 1996

"Coating Methods and Compositions for Production of Digitized Stereoscopic Polarizing Images."

APPENDIX II: THE VECTOGRAPH PROCESSES

The original Vectograph process devised by Land and his colleagues utilized iodine ink transferred from gelatin relief images to a transparent receiving sheet bearing on each surface a layer of polyvinyl alcohol (PVA) that had been stretched and laminated to the support.. As with Land's H polarizer, the transferred iodine molecules aligned with the oriented PVA molecules. Here they formed black-and-white polarizing images, with the density in each image area proportional to the thickness of the gelatin relief image. Stereoscopic image pairs of gelatin relief images were preregistered and hinged face-to-face so that left- and right-eye images were printed simultaneously. For this work Polaroid developed its unique 45-degree stretcher that could stretch and laminate polyvinyl alcohol sheet at 45 degrees to the running edge. The Vectograph sheet comprised two such layers oriented at 90 degrees to one another.

The black-and-white Vectograph process had significant value as a medium for military aerial reconnaissance during World War II. Aerial strip cameras provided stereoscopic image pairs that were printed as Vectographs in the field by Polaroid-trained military technicians. Such images were used in briefing sessions to familiarize military personnel with terrain details of the beaches of Normandy and of many of the Pacific islands.

Black-and-white Vectograph technology is still used today. A Chicago company produces Vectograph images for use in ophthalmologic testing of binocular vision. Such test images are particularly important for detection of depth perception in children. Additional images provide corrective exercises for patients with deficient binocular vision.

Vectograph color processes developed during the 1950s utilized sets of three or more dichroic dyes. A full color print required three pairs of matrices for each image and three consecutive transfers. A defect in any of the six matrices could ruin a print. Though the resulting color images were outstanding, color Vectograph printing was costly and labor-intensive. Polaroid produced a number of images for display, but the process was never commercialized. It is worth noting that Vectograph images formed by the dye imbibition process are highly stable. Images printed in the 1950s show no discernible fading or color change after more than 50 years under ambient conditions.

For several years in the 1950s Polaroid and Technicolor collaborated in research on Vectograph color motion pictures, using the Technicolor imbibition transfer technology. A number of successful test strips and one cartoon short were completed on a Technicolor pilot machine in the course of the project.