Abstract

In this paper we examine two major shifts occurring in manufacturing: the economy's affect on product development and production and how companies are realigning their outsourcing strategy, and the "new industrial revolution" and how it is changing the race to market for entrepreneurs and small businesses through micro-manufacturing hubs. Additionally, we will explore how Roland's subtractive rapid prototyping and manufacturing technology, the MDX milling machine, is changing the way companies, like Questa Design Limited, are designing and bringing products to market.

As competition increases and profit margins narrow, companies are looking for solutions that provide better, faster, cheaper ways of producing prototypes and manufacturing parts. Companies like Questa Design Limited that have integrated the Roland MDX milling machine into their rapid prototyping and manufacturing process have realized the benefits of bringing the subtractive technology in-house. The MDX takes all of the key features and benefits of an industrial CNC machine and enables designers and engineers to build repeatable high-precision prototypes and parts right from their desktop. Unlike traditional CNC machines, the MDX milling machine does not require the designer or engineer to be an expert machinist or know how to program G-Code.

Table of Contents

Introduction

Two major shifts are changing the world of manufacturing that will evolve the way companies rapidly design, develop and manufacture products. The first shift is on the economic front. The continually rising costs of outsourcing product development and manufacturing are prompting companies to re-establish the business model of co-locating project teams and moving manufacturing closer to consumption[1], thus reducing product development time, eliminating costly errors and reducing the cost of bringing products to market.

The second shift occurring in the manufacturing industry is the increasing entrepreneurial spirit of small businesses bringing products to market on-demand known as the "new industrial revolution."[2] This trend is enabled by two elements -- the emergence of new tools that foster the democratization of product design and by the Internet, which has enabled the easy sourcing of product production through micro-manufacturing hubs. In essence, the new industrial revolution is driven by the emergence of small companies, service providers/bureaus and individual entrepreneurs, utilizing low-cost, modern fabrication equipment, such as 3-D printers and desktop CNC machines, to quickly design, prototype and manufacture their products. This business model brings to market products that are produced in low volume and can be personalized for the consumer without having to source large manufacturing facilities to produce designs and concepts -- effectively, reducing the consumer price and shortening the time it takes to bring a product to market.

To meet the changing needs of today's designers, engineers and manufacturers, newer and more flexible rapid prototyping and manufacturing (RP&M) machines are emerging. These new, high-demand machines are helping to fuel current market dynamics. Recent innovations are providing both the cost benefits and flexibility needed to bring prototyping and manufacturing back in-house, profitably, regardless of a company's size. RP&M machines utilizing subtractive and additive processes each offer benefits in the new age of manufacturing. The decision to invest in one or the other technologies comes down to two factors: flexibility in material choice and performance of the machine throughout the workflow process. This paper will outline the pros and cons of each technology and the role these complementary technologies play.

Hyper-Competition Moves Companies to Manufacture Closer to Consumption

With the rise of oil and transportation costs, the productivity gains of outsourcing are not as substantial as they once were. Additionally, outsourcing poses some security risks to supply chains. All these factors have influenced many companies to go where their customers are instead of where the raw materials are[3]. Independent of a company strategy to outsource, or retain and in-source design and production, maintaining a flexible manufacturing environment becomes more critical as the demand for products grows. In some cases, outsourcing production has impeded the ability to sustain a competitive advantage. By outsourcing, companies lose a key aspect of their business, neglecting their own capabilities and losing critical integration within the innovative and manufacturing processes. The feedback loop from the manufacturing floor to the rest of manufacturing operation – a critical element in the innovation process – is eventually broken.

Producing a prototype in-house can reduce the time-to-market and ultimately the cost of a new product – not to mention the frustration of designers seeking quicker feedback. For years, companies have benefited from the global sourcing of labor and manufacturing either to meet cost reduction requirements or to compensate for a lack of capabilities in-house. This trend is silently reversing itself.

Prior to the late 1980s, validation of a design during product development was a much slower and more expensive process than it is today. When a company needed to verify a prototype for form-fit-function it often had to go through the manufacturing process just as if the product were full-scale, production ready. Design errors during the process were very costly. As the prototype became scrap material, the design was returned to engineering for time-consuming modifications.

Over the last three decades, there has been a surge of flexible rapid prototyping and manufacturing machines on to the market. Additive technologies, such as 3-D printers, and subtractive technologies, such as desktop milling machines and engravers, have changed the way companies design and develop new products (either in-house or through a service provider). As the RP&M machines developed over the years, they evolved from large stand-alone machines into smaller (including desktop), office-friendly, automated machines making the technology available to everyone from the designer, to marketer, engineer and production team. The RP&M machines have pushed the boundaries of what engineers design and manufacturers produce, and have reduced the time-to-market cycle by enabling quick iterations and proof of concepts. As a result, companies today can deliver products focused on "right-cost" and "right-features"[4] faster and more profitably than ever before.

New Industrial Revolution

As new RP&M machines emerged, a new industrial revolution began to evolve, driven by an entrepreneurial spirit. Additive and subtractive technologies for prototyping and manufacturing are making it easier for small businesses, service providers and entrepreneurs to innovate and create new products on a smaller scale without incurring the high cost of outsourced manufacturing. As the "traditional" manufacturing industry begins to fragment, and the new industrial revolution emerges, more and more individuals and small businesses are embracing what is also known as "the Maker Movement" or the "Do-It-Yourself" (DIY) generation[5, 6]. No longer are design engineers tied to the machining center. Need a part today? Now you can produce it yourself right in your workspace with little or no production expertise. As software and hardware continue to enhance the end-user's capabilities, the lines between "old" school manufacturing and "new" school manufacturing will blur, leaving the manufacturing world with highly productive tools that are seamless for part to production.

People want to engage with making products. Today's desktop rapid prototyping and manufacturing machines, such as 3-D printers and Roland's MDX milling machine, are simple to use and enable the end-user and small businesses the ability to design and manufacture products in the home or office with the material of their choice. With the emergence of additive and subtractive RP&M machines, the world of manufacturing will continue to evolve and end-users will continue to look for ways to produce high quality parts and prototypes in hours versus days, weeks or even months.

Rapid Prototyping and Manufacturing Solutions

There are two distinctive rapid prototyping and manufacturing methods that are constantly evaluated and compared when companies look at systems to implement into their design to manufacturing process, additive and subtractive. Each manufacturing methodology has its place for different applications and different business criteria. As companies look for systems that deliver quality, expedite delivery times and reduce costs, subtractive technologies are at the forefront, providing the user with the ability to design, prototype and manufacture in end-materials. Additive manufacturing, by contrast, provides prototypes and parts, typically in a secondary material, but with a high degree of structural flexibility and complexity.

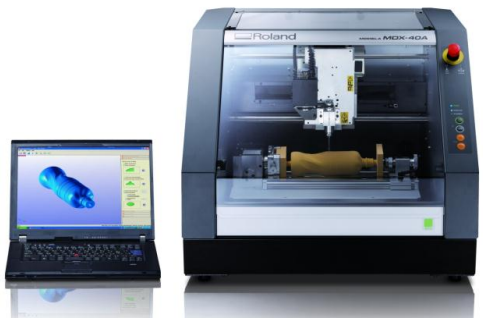
Additive and Subtractive Technologies			
Technology	**Description**	**Process**	**Material**
3DP Technology	Jets binder onto powder	Additive	Composites, casting, elastomeric (uses proprietary material)
CNC – Computer Numerically Controlled	Desktop milling machine	Subtractive	ABS, Acetal Coplymer, Acrylic, Aluminum, Brass, Delrin, HDPE, HMW, LDPE, Lexan, Lucite, Nylon, PEEK, PVC, Phenolic, Plexiglass, Polycarbonate, Polypropylene, Rulon, Teflon, UHMW, Ultem, Wood, FDA and Government approved materials
CNC	Industrial Machining Centers	Subtractive	ABS, Acetal Coplymer, Acrylic, Aluminum, Brass, Delrin, HDPE, HMW, LDPE, Lexan, Lucite, Nylon, PEEK, PVC, Phenolic, Plexiglass, Polycarbonate, Polypropylene, Rulon, Teflon, UHMW, Ultem, Wood, FDA and Government approved materials
Film Transfer Imaging	Solidifies liquid photopolymer	Additive	Proprietary acrylate photopoylmer
FDM – Fused Deposition Modeling	Extrusion of material by nozzle	Additive	ABS, soluble support material
Inkjet Printing	Inkjet-like printheads	Additive	Proprietary thermoplastics Proprietary acrylate thermoplastic
Impact Printers	Desktop industrial marking machine	Subtractive	Gold, silver, copper, platinum, brass, aluminum, iron, stainless steel, acrylic, etc.
Laser Engravers	CO_2	Subtractive	Fabric, leather, glass, metals, natural materials, paper, plastic, rubber, stone, wood
Laser Engravers	Fiber	Subtractive	Fabric, leather, glass, metals, natural materials, paper, plastic, rubber, stone, wood
Rotary Engravers	Rotary	Subtractive	Acrylics, aluminum, brass, stainless steel, and glass
SL – Stereolithography	Solidifies liquid photopolymer	Additive	Thermoset plastics, nanocomposites
LS – Laser Sintering	Sinters plastic powder material	Additive	Polystyrene, polyamide, elastomer, metal powders

Note: Chart represents some of the additive and subtractive technologies available on the market today.

Additive Manufacturing (AM) also known as Direct Digital Manufacturing, is the process of joining materials by either fusing, binding or solidifying materials such as liquid resin, powders usually layer upon layer to produce an object from 3-D model data.

Subtractive Manufacturing (SM) is the process of removing layers of material from a block of material to produce an object either from 3-D model data, 2-D CAD data or G-Code.

No G-Code Required - Subtractive Technology, Not So "Old School"



Advantages of the MDX Desktop Prototyping and Manufacturing Milling Machine:

- Superior surface finish without post processing
- Higher dimensional accuracy for precision assemblies
- Greater choice of materials for accurate, repeatable prototypes and parts
- Reduce time-to-market by producing prototypes in-house on production materials
- Enable seamless transition from R&D to production

Both subtractive and additive technologies are vying for the attention of the engineer. With the introduction of additive technologies in the 1980s, subtractive technologies, such as milling machines (introduced in the 1940s) and engravers have been reinventing themselves to reduce time to market and accelerate the release of new product iterations based on consumer demands. Engineers and product designers appreciate being able to push a button, walk away and come back to evaluate the result. This is now possible with both additive and subtractive technologies. Typically thought of as "old school," subtractive technologies are advancing, becoming smaller, more powerful and easier to use, factors that are making them a critical component of design and development processes early in the product development cycle.

Over the last 20 years, subtractive technologies have dramatically changed. Part of the "old school" production model was the time consuming and often-tedious task of writing code for the CNC program. Not an easy task -- one wrong line of code and a production part was scrapped, increasing the overall cost of production. Although 3-D CAD software was introduced in the 1970s, it wasn't until the 1980s that 3-D complex surface modeling CAD software was introduced. The introduction of 3-D complex surface modeling opened a door to technologies that typically used G-Code to produce a part. This streamlined the process and integrated CAD software programs took the place of writing code. Understanding that this painful part of the process had significant ramifications if the coding was not done properly, subtractive technology companies, such as Roland, began to implement processing software upfront in the process, thus eliminating the need for manual coding.

Roland's Subtractive Rapid Prototyping™ (SRP) has moved CNC beyond its traditional roots with its MDX product line. Unlike CNC machines of the 1940s, today's CNC machines are highly automated using CAD/CAM programs. CNC automation has reduced user errors, and improved consistency and quality from part to part. With the advent of newer technologies, such as Roland's MDX milling machine, no longer is the designer or engineer required to be an expert machinist or know how to program G-Code. With its integrated easy-to-use software, the prototyping process has been simplified to provide CNC technology without the traditional CNC complexity.

The MDX milling machines take all of the key features and benefits of an industrial CNC machine and enable designers and engineers to build repeatable, high-precision, prototypes and parts right from their desktop. Companies can increase their competitive position by taking full advantage of advancements in subtractive technology. The MDX allows designers and engineers to optimize workflow processes, improve operation efficiencies and expand customized applications. By bringing the process in-house, designers and engineers can quickly prototype, produce limited production runs, and test new materials for production in a matter of hours versus days or weeks.

Pro's and Con's of Additive and Subtractive Technology

	Pro's	Con's
Additive	- Flexible part shape/structural complexity - High degree of automation - Accuracy (dependent upon material) - Part durability (dependent upon material) - High repeatability	- Limited material selection - Slow, sequential - Hard to recycle - Requires post processing
Subtractive	- Wide material selection - Good dimensional control - Good surface finish - High degree of automation - High repeatability	- Some material waste - Some geometry limitations

Flexible Material Choice

Material flexibility refers to the ability to process a broad range of materials throughout the product design and development process, as well as through the supply chain. Additive technologies typically require a specific material to be processed, and can be proprietary to the machine, while many of the subtractive methods have the ability to process multiple materials, which makes them more flexible.

The multi-material processing technology allows R&D and Engineering to prototype and experiment on end-production material resulting in real-world feedback and form-fit-function testing. Prototyping in one material, then manufacturing in another adds an inherent risk that the part will not perform as expected. To reduce and/or eliminate costly prototype mistakes, companies are shifting their prototype process to build in materials that are similar or the same as the production products they will ultimately build. Materials play a large role in creating functional prototypes for testing fit, finish, product durability, structural thermal and electrical testing, and with the MDX, prototypes can be built and tested in the material used in production, including FDA and government approved materials.

Roland's MDX milling machines provide processing flexibility in material choices and workflow positioning. The software and hardware together offer the ease of use of 3-D printers and the benefits of CNC machining. The MDX provides functional parts and prototypes milled from a wide variety of materials with smooth surface finishes and tight tolerances. Designers and engineers can generate functional prototypes before committing to injection molding tooling or high volume machining. From engineered plastics, resin and wood to non-ferrous metals, the MDX quickly removes layers of material to produce a final product.

As companies adopt new RP&M machines into their design and development cycle, the technology must be adaptive and easily integrate into the company's product life cycle workflow. A flexible RP&M machine should streamline the number of tools companies need to produce design concepts, prototypes and end-use parts, and not lock the company into one manufacturing method. Subtractive technologies, such as the MDX, allow the user to prototype and manufacture in a wide variety of production materials. Although other additive technologies can handle some thermoplastics, they do not offer the broad range of material choice for processing nor run the exact material that will be used in the final product, such as aluminum.

Workflow Flexibility

Time to market is always a critical factor. In today's economy, companies in all stages of maturity may find themselves financially limited and not be able to invest in new machines to streamline the product development cycle. As companies are assessing new tools and enhancing their design and production center, flexible machines that provide a good return on investment (ROI) and additional gains from the design process to the supply chain to the customer will be at the forefront of the decision-making process.

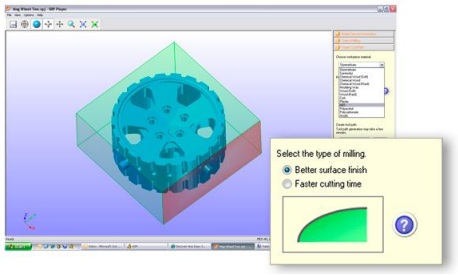
For companies that already impart a co-location methodology of design to production, and for companies that are changing their method of design-to-part production, enabling the designers and engineers to have flexibility not only in their material choice, but in the environment of production must be a fundamental function of the machine. Most often thought of as shop floor production tools, subtractive technologies have evolved into an office – even desktop – solution ideal for engineers and designers to quickly produce, validate and iterate before going to production.

The MDX is designed to fit into a company's workflow process. From design concept, R&D, prototyping, product development, packaging, and end-product production, the MDX easily adapts to meet the needs of each stage of the workflow. By bringing the MDX in-house companies are finding that they have reduced delays and costs for die manufacturing, immediately implemented corrections and adjustments to designs, and have instant visibility and verification of product design. The MDX can be combined with a 3-D printer, or used as a stand-alone system for the production of one-off customized parts, product-concept models, functional prototypes, master patterns and expendable patterns for the production of end-use parts.

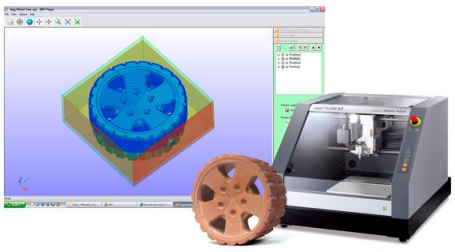
Roland MDX Mill Workflow

1. Design your 3-D model, then export a 3-D CAD model in a .STL, .DXF, .3DM, or .IGS/IGES file.

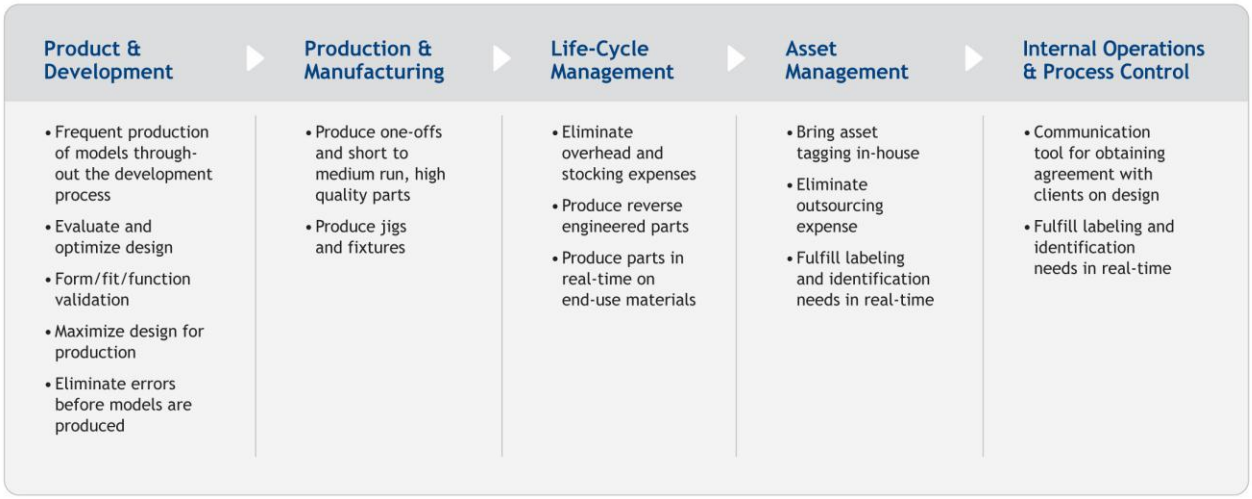
2. Open the 3-D CAD file in Roland's SRP Player software (provided with the MDX). Follow the five-step wizard process. The software will determine the feeds and speeds, cut depth, surface selection and will write the G-Code program for you.



3. SRP Player automatically orients the part, generates toolpaths and provides you a finished preview. Just click Send to Machine to mill your finished part with smooth surfaces, tight tolerances



Subtractive Rapid Prototyping in the Workflow Process



Unlike traditional CNC machines, Roland's MDX milling machines have removed the complex control panels and implemented a user-friendly, easy-to-use control system that simplifies the process. No longer does a company need to hire an experienced CNC coder to program the machine. The software walks the user through the process to determine the appropriate tool to use, as well as automatically programs how fast and deep it will cut, along with how fast the tool should turn – all based on material selection. No longer do you need to be a CNC machinist to mill your part. Now precision desktop milling with powerful CAM software makes it easy to produce models with industry leading speed and accuracy.

Conclusion

As companies start to reassess their manufacturing strategy, and the development of micro-manufacturing hubs increase as part of the new industrial revolution, one thing is certain, demand will continue to rise for new technology that provides a better, faster, cheaper way of getting product to market. The solution to meet the changing needs of designers, engineers and manufacturers will be a combination of new, more flexible rapid prototyping and manufacturing machines employing either additive or subtractive methods. Additive and subtractive technologies allow companies to innovate product design, business models and manufacturing processes. By bringing the RP&M solution in-house, companies, manufacturers and micro-manufacturing hubs gain shorter design iterations and data security, and reduce prototyping and manufacturing costs.

The decision to invest in technology should be based on the end-part material required for prototypes and manufactured parts, and how the technology can fit into a company workflow. Technologies, like Roland's MDX milling machine, let designers and engineers optimize designs and maximize performance. Incorporating the MDX into the prototyping and manufacturing process was an easy process for Questa Design Limited. In the following case study, learn how the engineering and manufacturing company was able to seamlessly implement the MDX-540SA into their workflow and provide their engineering and manufacturing customers with precision prototypes and parts faster and more cost-effective.

Case Study: Questa Design Limited

Aki Hirano loves a challenge, and each day at Questa Design Limited provides a new one. Questa is a design, engineering and manufacturing firm in Scarborough, Ontario, Canada, that specializes in high-tech, product design and development along with low- to mid-production manufacturing. In the 1970s, they manufactured geophysical instruments for the exploration of Canada's vast mineral resources. With changing times came changing needs, and although the company still manufactures scientific instrumentation, they also design and produce everything from heat sinks to broadcast video assemblies.

"We do work for a lot of engineers, scientists and other professionals, people who are careful by nature and who depend on our designs to perform for them in the field or the laboratory," said Hirano, vice president of Questa. "For our firm, rapid prototyping is really rapid manufacturing (RM) or digital product manufacturing (DPM), since our clients expect the prototype to function *exactly* as the finished product would."

Questa operates at the forefront of RM and each step in their manufacturing process makes maximum use of the initial design data, thereby drastically reducing the need for manual input or user intervention. "What sets us apart is our ability to efficiently handle the entire product development cycle," said Hirano. "Most other companies in Canada specialize in either design or manufacturing. We do all of that and more."

To manufacture prototypes that meet their clients' aesthetic and mechanical requirements, Questa relies on their Roland MDX-540SA milling machine. They use the MDX SRP® System to produce prototypes with the same tolerances, surface finish and materials as production volume parts.

Questa values the MDX-540SA's versatility, noting that no other rapid prototyping process allows them to use such a wide variety of production materials, including ABS, polypropylene, and aluminum. "Other machines can handle some thermoplastics, but none have the range of the Roland," said Hirano. "With the MDX, we can run the exact material that will be used in the final product."

They also appreciate the MDX's easy operational set up, noting that Roland's SRP Player CAM software quickly creates tool paths and the optional fourth axis makes fixturing easier. "The MDX offers us a cost-effective way to try out design alternatives before we present our ideas to our clients," said Hirano.

Questa's client list includes companies in the medical, broadcast, automotive, and consumer electronics industries. They have even designed camera parts and consoles for a company that produces remote broadcast systems that can be used in conflict zones. The robotic camera and console unit allows a correspondent to produce a live shot broadcast without a camera operator, and send it out via the Internet. Another client produces speakers using enclosures prototyped by Questa, while a third had Questa design a boarding system for less-abled motor coach passengers.

Questa also produces its own products, such as their innovative skate guard "kootsu™." kootsu was originally designed and modeled on the computer, then run as a prototype in FDM ABS. After checking geometries to ensure the prototyped parts fit together correctly, Questa then produced a model on the MDX using polypropylene, a common injection molding plastic. When physical testing revealed that polypropylene was too hard and slippery for practical application, Questa ran another model in low-density polyethylene, a softer grade of plastic, which tested successfully. "The Roland allowed us to test multiple materials quickly and easily," said Hirano.

In the current economy, Questa finds its prototyping business shifting from single runs to short production runs. "Fortunately, the MDX can handle both types of runs," said Hirano. Questa also uses the MDX to produce additional parts clients occasionally request, saving set up time on larger production machinery. "With the MDX, there's no post-processing, and no finishing on plastics," said Hirano. "It comes off the machine and goes right to the client."

"It's always hard for me to answer people who ask what we do," said Hirano. "Every project is different, and versatility is critical for our business model. The MDX's range of applications, from prototyping to finished products, really helps us meet the challenges we face every day."

For more information, contact Questa Design Limited at www.questadesign.com.

The MDX Product Line

Roland's MDX product line includes the MDX-540, MDX-40A, MDX-20, and MDX-15. The SRP (Subtractive Rapid Prototyping) technology is bundled with Roland's SRP Player CAM software that automates the prototyping process and generates tool paths with high speed and precision. The user-friendly, wizard-based program offers uniform 3-D scaling, support for four-axis milling, and simulation of finished parts.

In addition, Roland offers milling solutions for the jewelry industry with the JWX-30 Jewelry Milling Machine, and the dental industry with the DWX-50 and DWX-30 Dental Milling Machines.

About Roland DGA Corp.

Headquartered in Irvine, Calif., Roland DGA Corp. serves as the U.S.-based marketing, distribution and sales arm of Roland DG Corp. in Hamamatsu, Japan. Professionals worldwide rely on Roland solutions everyday in the sign, grand-format, sublimation, UV inkjet, digital graphics, vehicle graphics, fine art, photography, packaging, label, dental, engraving and 3D modeling industries. Roland DGA is ISO 9001:2008 certified, and Roland DG is ISO 9001:2000 and 14001:2004 certified. For more information on Roland DGA products, please call (800) 542-2307 or visit the website at www.rolanddga.com

[1, 4] **The Importance and Promise of American Manufacturing.** April 2011. Michael Ettlinger and Kate Gordon. Center for American Progress.
[2] **In the Next Industrial Revolution, Atoms Are the New Bits.** January 25, 2010. Wired Magazine. Chris Anderson, Editor-in-Chief, Wired.
[3] **US Groups Weigh Asia Exit As Costs Rise.** Hal Weitzman in Chicago. Published by Financial Times: March 20 2011 22:45, http://www.ft.com/cms/s/0/18d090c4-5328-11e0-86e6-00144feab49a.html#axzz1HDrZH200
[5] **How to Make Stuff.** April 2011. Wired Magazine.
[6] **The New Industrial Revolution: Autodesk at Wired Business Conference.** May 10, 2011: Wired Business Conference video http://www.dexigner.com/news/23025.