**Lost Foam Casting Quantifier Program
Inventions and Innovation Program
DE-FG36-01GO11032
Industrial Analytics Corporation
Final Report
March 31, 2003**

Abstract

The lost foam casting process is sensitive to the properties of the EPS patterns used for the casting operation. In this project Industrial Analytics Corporation (IAC) has developed a new low voltage x-ray instrument for x-ray radiography of very low mass EPS patterns. IAC has also developed a transmitted visible light method for characterizing the properties of EPS patterns. The systems developed are also applicable to other low density materials including graphite foams.

A. Brief Summary of the Original Project Goals

The Objective of this project was to build a prototype of a production floor machine and demonstrate its use in a casting improvement program with a major industry supplier. The technologies to be incorporated into the project were a single channel x-ray detector system and a laser based EPS foam fusion measurement.

B. Variance from Project Goals

As the project developed, several events took place that drove changes in the technology, schedule, and budget of the project.

1. During the summer of 2001 Industrial Analytics Corporation (IAC) sold a Quintek Measurement Systems (QMS) x-ray system to General Motors, our proposed Industrial Partner for this project. Since the technology of the QMS machine was quite similar to the technology of our original proposed design, it was felt that it would be necessary to make a technology revision to a next generation design in order to have something to catch the attention of our industry partners. Our response to this was the 2 dimensional x-ray camera concept that was incorporated into the revised program with start date 02/01/2002. After the initial results using the x-ray camera were successful, further work on the single channel x-ray detector was suspended and all work focused on the 1024 x 1024 pixel x-ray camera based system.
2. IAC completed a study for one of our commercial customers, Foseco-Morval that indicated that the laser fusion system we had proposed for this project suffered from a slow data acquisition rate and a too small, non representative data sample. Work on the laser fusion measurement was stopped in April 2002. A decision was made in late 2002 to develop a two dimensional foam fusion measurement method using area and line scan cameras. Initial images have been captured and levels of fusion are clearly apparent to the eye.

3. The original program called for the construction of two prototype machines. As a part of the revision to the technical scope of work described above, IAC decided to retrofit our research machine with a new x-ray generator and an x-ray camera. This allowed us to reuse most of the hardware and software from that system and to drastically reduce our time to first measurement. The second machine built was then a prototype based on the successes from the first machine.
4. The second machine, or prototype, was designed and built to have the capability to capture images for tomographic reconstruction. The development of tomographic reconstruction software is beyond the scope of the subject project; however, that is being pursued under a separate activity.
5. The original project Principal Investigator did very little on the project and left Industrial Analytics Corporation in November of 2001. IAC applied for a change of PI and a revised schedule and budget. DOE was kind enough to agree to these changes.

C. Narrative Discussion of Project Results

1. Optical Sensor – A two dimensional optical sensor system for determining the fusion level of EPS foam has been developed and proof of concept experiments show that the two dimensional approach is feasible.
2. X-Ray Sensor – A two dimensional x-ray method for imaging EPS foam has been developed. This system is now in use on a DOE funded project: DOE IOF DE-FC07-02ID14235 Quantification and Standardization of Pattern Properties for the Control of the Lost Foam Metal Casting Process.
3. Industrial Partner – Our primary industrial partner for the development of this system is General Motors Casting Validation and Development Center (CVDC), Saginaw, MI.
4. As a part of our IOF program, IAC has x-rayed 60 GM test plates. These test results will be compared to results from GM's QMS machine and other measurement technologies in field trials to determine best methods for determining the quality of EPS foam as used for the lost foam casting process. During this process, previously unknown high density inclusions were identified in the foam patterns. This led to an investigation of the pattern production system in use at GM CVDC where it was discovered that reject bead materials were being reintroduced into the production system. While not yet confirmed, it

is believed that the dense inclusions are composed of reject bead materials.

5. Other Applications – The x-ray systems have been used to take x-ray images of graphite foam for Oak Ridge National Laboratory. The density of this material is of interest to industrial licensees. Images of Southeastern American Indian Pottery have been taken, courtesy of the Frank H. McClung Museum. Images of tree ring samples have been taken for Quintek Measurements Corp., a key instrumentation supplier to the Timber Industry.
6. Support for DOE project DE-FC36-02ID14235 Quantification and Standardization of Pattern Properties for the Control of the Lost Foam Metal Casting Process (Pattern Quantification Project) has been provided by the use of the x-ray systems created under this project. This has provided a completely new way of nondestructively imaging EPS foam patterns.
 - a. With this method we are able to image the interior structure of foam with 50 micron resolution. We are seeing bead boundaries, small voids, and dense inclusions in an entirely new way.
 - b. The structure and density of the material reflects the bead fill process during the pattern molding process, thereby providing the opportunity to perform experiments related to improving bead fill and document the results.
 - c. The presence of dense inclusions raises the question of their contribution to mold production mechanisms.
 - d. Narrow regions of low density foam tend to confirm the hypothesis of diffusion channel formation now being investigated in the Pattern Quantification Project.
 - e. As a part of the Pattern Quantification Project we are now designing an experiment that will subject EPS test patterns to a range of characterization methods and then conduct instrumented metal pours to determine if the measured properties of the patterns have a measurable effect on metal fill behavior.
7. Reporting the use of equipment produced under the I&I program is a method for publicizing the capabilities of the equipment and is a part of our commercialization strategy.

Attachment A

Original Milestone Table

Task Number	Task Title	Estimated Completion Date	Responsible Individual/Organization	Projected Cost (Federal)	Projected Cost (Cost Share)
Task 1	Electronics Packaging	04-15-01	R. Ramsey	\$2,600	
Task 2	Optical Sensor Packaging	05-15-01	K. Thomas	\$4,500	
Task 3	Mechanical Design	06-07-01	K. Thomas	\$4,000	
Task 4	Production	07-11-01	Ramsey, Thomas, Pat Alexander	\$7,000	
Task 5	Computer Hardware	08-02-01	Pat Alexander	\$14,000	
Task 6	System Software	08-23-01	Engineering		\$3,000
Task 7	Assembly, Startup & Calibration	10-10-01	Engineering	\$25,000	
Task 8	Submit Semi-annual Report (covers work through 9/30/01)	10/31/01	IAC	Cost covered under Task 12	
Task 9	Find Industry Partner	11-29-01	G. Walford	\$5,000	\$5,000
Task 10	Attend Annual Project Review	TBD	PI, OGT	\$1,000	
Task 11	Conduct In-Plant Testing & Foam Analysis	02-15-02	IAC & Industry Partner	\$44,000	\$40,000
Task 12	Project Management and Submit Final Technical and Financial Status Reports	03-15-02	IAC & Industry Partner	\$3,000	\$4,000

Note: Because tasks in original program and revised program are different, milestone tables are separate. Cost Share for above table (taken from original submission) appears to be incomplete.

Final Revised Milestone Table

	Milestone/Task Title	Original Planned Completion Date	Revised Planned Completion Date	Actual Completion Date	Responsible Organization	Original Projected Cost (Fed/Non-Fed)	Revised Projected Cost (Fed/Non-Fed)	Actual Completed Cost (Fed/Non-Fed)	Milestone Notes
1	optical sensor		Mar 31, 2002	03/31/03	IAC		\$3,445.58 \$1,680.00	\$10,193.85 \$4,365.22	Work suspended, sensor redesigned, and completed
2	x-ray system		June 30, 2002	12/31/02	IAC		\$48,465.22 \$3,600.00	\$43,186.73 \$7,889.71	
3	mechanical design of system		July 31, 2002	10/15/02	IAC		\$1,600.00 \$7,200.00	\$1,381.25 \$4,080.00	
4	Purchase and fabricate chassis		Sept 30, 2002	10/15/02	IAC		\$5,004.79 \$46,000.00	\$2,974.71 \$40,860.50	
5	Electrical assembly and software development		Nov 30, 2002	02/15/03	IAC		\$16,910.20 \$74,480.00	\$16,987.98 \$92,414.00	x-ray camera software much more complex than foreseen
6	Startup and calibration		Dec 15, 2002	03/15/03	IAC		\$4,025.00 \$6,800.00	\$719.95 \$4,636.00	
7	Industry partner		Mar 31, 2003	03/31/03	IAC		\$3,899.00 \$6,985.99	\$4,311.25 \$12,823.64	
8	In house testing		Sept 30, 2002	10/01/02	IAC		\$0.00 \$7,600.00	\$0.00 \$0.00	
9	In plant tests		Mar 31, 2003	03/31/03	IAC		\$3,400.00 \$10,400.00	\$936.00 \$650.00	Tests for GM conducted in house at their request
10	reporting		Oct 31, 2002	03/31/03	IAC		\$0.00 \$1,412.01	\$0.00 \$760.00	
11	Project management		Mar 31, 2003	03/31/03	IAC		\$23,350.21 \$6,800.00	\$30,128.32 \$11,225.75	Much more time consuming than foreseen

Attachment B: Final Program Schedule

month	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Task	02/02	03/02	04/02	05/02	06/02	07/02	08/02	09/02	10/02	11/02	12/02	01/03	02/03	03/03
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														

Attachment C: Updated Energy, Waste, and Economic Savings (Conventional vs. Proposed vs. Actual)

Energy, Environmental, and Economic Savings for I&I

The installed unit for the *I&I project* technology is the average sized lost foam foundry.

The installed unit for the *comparable competing* technology as presented in the original proposal is the average sized lost foam foundry .

Energy Savings

Provide the energy savings for the project technology versus the comparable competing technology.

The *projected* energy consumption for the *project* unit in Btu/yr/unit was (at the beginning of the project) 0.111 trillion BTU/YR/Unit.

The energy consumption for the *I&I project* unit in Btu/yr/unit is 0.1068 trillion BTU/YR/Unit.

Provide assumptions and references for the derivation of your values. (*Refer to Attachment H for energy conversion factors*)

Energy benefits occur through the application of advanced understanding of materials and processes to the metal casting industry. Improvements in the technology of the lost foam casting processes will improve the casting yield of Aluminum. While other metals are cast using lost foam, the problems of the process addressed by this program are chiefly with the casting of Aluminum. Also, the growth opportunity in lost foam lies with Aluminum. The June 23, 2003 issue of Modern Casting magazine states that "Aluminum casting shipments are expected to grow 8.4% to 2,244,000 tons this year. Nearly two-thirds of this tonnage is used by the motor vehicle sector." They project that the accelerated conversion of iron engine blocks and heads to Aluminum will result in a 10.6 percent rise in shipments this year [2003].

The below calculations are based on projections of the impact that process improvements brought about by the use of the equipment developed in this program will have on the Lost Foam casting industry. It may not be necessary to have a testing machine at each and every foundry.

Assumptions: 235 Trillion BTU/yr for foundries plus 93 from captive foundries = 328 Trillion BTUs per year consumed by casting industry, including captive foundries (Metalcasting Industry of the Future 2002 Annual Report). 2956 foundries in US during 1997, from Energy and Environmental Profile of the U.S. Metalcasting Industry (Profile). $328/2956 = 0.111$ Trillion BTU/yr for one average sized unit. 19 trillion BTU/yr for all Al except Die Casting Table N32 DOE EIA. $328/235 \times 19 = 26.75$ trillion BTU/yr to correct for captive foundries. This includes sand and lost foam casting of Aluminum. Assume 35% of those foundries are Lost Foam Process. 84.37 average sized units of 0.111 TBTU/yr. Assume current yield rate of 90% for Al increasing to 95% over 5 years due to process improvements; thereafter at 95%. Assume Aluminum casting output to grow at 4% per year (Profile, pg. 4). In year 10 this is 124.9 average sized units.

	Current Technology (trillion BTU/YR/Unit)	Proposed Technology (trillion BTU/YR/Unit)	Energy Savings (trillion BTU/YR/Unit)	No. of Units in 10 Years	Cumulative Energy Savings (trillion BTU/YR/Unit)
	A	B	C = A - B	D	E = C * D
Total Energy	9.3614	9.0117	0.3497	100.00%	
Total per Unit	0.1110	0.1068	0.0041	124.8831	0.5176

Table showing Energy Savings

The energy consumption for the *comparable competing* unit in Btu/yr/unit is 0.111 trillion BTU/YR/Unit.

At this time, there is no comparable technology.

Provide assumptions and references for the derivation of your values. (*Refer to Attachment H for energy conversion factors*)

Environmental Savings

Provide the environmental savings for the project technology versus the comparable competing technology.

Assume 200 tons NO_x displaced per trillion BTU.

Assume 22 Thousand Tons Carbon Equivalent per trillion BTU

Total Energy saving in year 10		TBTU	Nox displaced	Thousand TCE
Lost Foam		0.52	103.53	11.39

Table showing Reduction of NOx and Carbon Equivalent

The *projected* wastes other than power generation emissions for the *project* technology in tons/yr/unit using the *I&I project* unit described above (at the beginning of the project) were:

Waste 1 Polystyrene – 0.82 tons per year per unit

Waste 2 _____

Waste 3 _____

Identify wastes other than power generation emissions for the *I&I project* technology in tons/yr/unit using the *project* unit described above:

Waste 1 Polystyrene – 0.51 tons per year per unit

Waste 2 _____

Waste 3 _____

Identify wastes other than power generation emissions for the *comparable competing* technology in tons/yr/unit using the *comparable competing* technology unit described above:

Waste 1 Polystyrene – 0.82 tons per year per unit

Waste 2 _____

Waste 3 _____

Provide assumptions to allow reviewers to understand the derivation of the stated values.

One average completed pattern weighs 200 grams. 21000 patterns per year cast at one foundry. Assume 15 foundries for this computation. Current yield of patterns is 85%. After improvement, yield goes to 90%. Based on these assumptions, current consumption is 81.6 tons per year, with 12.24 tons of waste. Projected consumption at 90% yield is 77.1 tons, with 7.7 tons of waste. The above numbers are based on 15 units.

Economic Savings

Provide the economic savings for the project technology versus the comparable competing technology.

Fuel	Percent	trillion BTU/yr.	Quantity		Value
Nat. Gas	60.00%	0.3106	302.71	MCF	\$1,159,381.38
Elect	27.00%	0.1398	40959890.49	KWH	\$2,662,392.88
Coke & Breeze	12.00%	0.0621	2993.1192	Tons	\$83,807.34
Other	1.00%	0.0052	Ignore		
Totals		0.52			\$3,905,581.60

Table showing Cumulative Savings in Year 10.

Based on Cumulative Energy Savings above

The *projected* unit cost for the *I&I project* technology (at the beginning of the project) was (no projection made)

Define the unit cost for the *I&I project* technology \$806,000.

Define the unit cost for the *comparable competing* technology \$837,000.

Provide assumptions to allow the reviewers to understand the derivation of the stated values.

Energy for one unit		0.1110	trillion BTU/yr.	Energy per unit	
Fuel	Percent	trillion BTU/yr.	Quantity		Value
Nat. Gas	60.00%	0.0666	64.89	MCF	\$248,526.14
Elect	27.00%	0.0300	8780202.71	KWH	\$570,713.18
Coke & Breeze	12.00%	0.0133	641.6080	Tons	\$17,965.02
Other	1.00%	0.0011	Ignore		
Totals		0.1110			\$837,204.34

Original Unit

Energy for one I&I unit		0.1068	trillion BTU/yr.	Energy per unit	
Fuel	Percent	trillion BTU/yr.	Quantity		Value
Nat. Gas	60.00%	0.0641	62.47	MCF	\$239,242.41
Elect	27.00%	0.0288	8452216.76	KWH	\$549,394.09
Coke & Breeze	12.00%	0.0128	617.6406	Tons	\$17,293.94
Other	1.00%	0.0011	Ignore		
Totals		0.1068			\$805,930.43

I&I Unit

Attachment D: Fuel/Energy Source Btu Conversion (Table)

Fuel /Energy Source Btu Conversion

Fuel Source	Btu/Barrel	Btu/Gallon	Btu/Pound	Btu/ft³
Crude Oil	6 x 10 ⁶	142 x 10 ³	18.6 x 10 ³	1 x 10 ⁶
Fuel Oil – 6	6.2 x 10 ⁶	150 x 10 ³	17.8 x 10 ³	1.1 x 10 ⁶
Fuel Oil – 2	6 x 10 ⁶	140 x 10 ³	18.6 x 10 ³	1 x 10 ⁶
Gasoline	5.2 x 10 ⁶	126 x 10 ³	18.9 x 10 ³	940 x 10 ³
Propane – L	3.8 x 10 ⁶	92 x 10 ³	19.9 x 10 ³	690 x 10 ³
Wood	-----	-----	6.5 x 10 ³	148 x 10 ³
Natural Gas	87 x 10 ⁶	2 x 10 ³	21 x 10 ³	1 x 10 ³
Methane	87 x 10 ⁶	2 x 10 ³	21 x 10 ³	1 x 10 ³
Methanol	2.9 x 10 ⁶	69 x 10 ³	9.6 x 10 ³	517 x 10 ³
Ethane	-----	-----	20 x 10 ³	1.8 x 10 ³
Ethanol	3.7 x 10 ⁶	87 x 10 ³	12 x 10 ³	652 x 10 ³
Hydrogen	-----	-----	51 x 10 ³	270
CO	-----	-----	4.3 x 10 ³	316
Coal - Bit.	-----	-----	12.6 x 10 ³	800 x 10 ³
Coal - Lig.	-----	-----	8.6 x 10 ³	541 x 10 ³
Coal - Ant.	-----	-----	12.6 x 10 ³	800 x 10 ³
Carbon	-----	-----	14.6 x 10 ³	1.9 x 10 ⁶
Ethylene	-----	-----	20 x 10 ³	1,477

Electrical Generation (32.4% efficient Power Plant) – 10,500 Btu/kWh

Attachment E: Market Penetration Estimates / Technical Transfer Activities
(Table and Narrative)

Technology Drivers

On the equipment side, recent technological developments have made this project much more feasible.

The very recent arrival (within the last year) of inexpensive, low voltage, small spot size (35 micron) x-ray generators has made it possible to illuminate the EPS material with the appropriate energy x-ray beam. The small spot size reduces the amount of blurring and allows for higher geometric magnification ratios.

In times past, radioactive sources were used for density and thickness measurement systems. However, x-ray systems are replacing radioactive sources for one simple reason: x-ray generators can be switched off at the end of the day and hauled to the metal recycler (legally) at the end of their lifetime.

The development of low price CMOS x-ray imaging plates is revolutionizing the entire x-ray radiography industry. The Rad-icon camera used in this project is less than 3 years out of prototype. It is also the only commercially available CMOS camera that is optimized for the 10 – 50 kV. x-ray energy range. Comparable CCD cameras are in the \$40,000 range, four times the cost of a CMOS camera.

Once the x-ray images are captured, there is a considerable amount of computer based image processing required in order to get to an accurate image. Computation of calibration coefficients for the over one million pixels on the camera required 75 hours of computer time on a 2.4GHz Pentium 4 computer. Calibration of individual images requires about 3 minutes per image. Disk storage of images requires about 5 MB for a raw image, intermediate files and a completed corrected image. This would have been very expensive 5 years ago and impossible 10 years ago.

On the application side, the primary focus of this project is the lost foam casting process. This process is driven by a desire to produce more complex, higher quality, stronger castings. As greater demands are put on the process, higher quality foam patterns are a necessity.

Over the last few years, foam density for demanding applications has decreased from 1.6 pounds per cubic foot (PCF) to 1.6 PCF. This has placed demands on the pattern making technology. Lower density foam requires more uniform bead fill, pattern density and percent connected void space. These are properties that can best be measured using x-ray technology.

Additional market areas include graphite foam density, archaeological applications, timber quality, and Civil Engineering applications. Graphite foams are currently under development at Oak Ridge National Laboratory and are now just entering commercialization. Density is an important issue in the manufacture of these foams.

Market Barriers

There are two major barriers to the introduction of the technology developed under this project. One barrier is price. The commercial cost of a system will be in the \$75 – 100 thousand range. In order to justify this expenditure, it is necessary to demonstrate that the use of this technology can create savings that more than offset the cost of test equipment.

The other barrier is that the demonstrated effectiveness of the technology in making better castings has not yet been widely accepted by the lost foam casting industry. We are addressing this issue through the Pattern Quantification Project.

Strategies for Deployment

Our primary strategy for the deployment of the technology is demonstration of the equipment as a part of our Pattern Quantification Program. Our goal is to sell the first unit in the lost foam casting industry to GM and for them to demonstrate the use of the equipment. This is a strategy that will require a year or so. Over a year was required for GM to master the use of the QMS machine sold to them by IAC. The current technology is much more complex and demanding; however, it shows foam properties that can be seen no other way.

We have demonstrated the use of our equipment to Oak Ridge National Laboratory for measuring carbon foam density. Our goal here is to connect with their commercial licensees as the process is commercialized.

We have captured x-ray images of Southeastern American Indian Pottery courtesy of the McClung Museum. The nondestructive analysis of pottery and other artifacts is of interest to them.

Another potential archaeology application is the x-ray imaging of old coins. These coins are sometimes so encrusted with other materials that it is impossible to identify the coin. We have done proof of concept work that shows that we can image copper coins and see the details of the coin, such as date and other embossed designs.

Channels for Distribution

Sales to the lost foam casting industry will be made through IAC directly. We have held preliminary discussions with Agfa NDT regarding sales through their distribution network.

Assumptions of Market Study

In the United States there are about 10 locations that are potential immediate customers in the lost foam casting industry for the technology developed under this program. These customers must be convinced that the technology works and then they must allocate budget for the capital expenditure. Budgets in Metal Casting are tight and slow

to move. Therefore, we assume one customer order during the latter half of 2003.

We estimate that there are another 10 commercial customers that are potential customers for the technology once it has been accepted by the industry leaders.

After these 20 potential customers, the industry will be saturated and further sales will be on the order of one or two per year. (Market saturation occurred on another DOE funded development, the Matrix Air Gauge; they sold well until everyone who wanted one had one. Then there were no more new sales to the lost foam industry.)

The graphite foam technology is now going to commercialization. There is now one commercial licensee. We estimate that there will be a total of three licensees during the next 5 years, and each of them will have our technology in place.

The below table includes the two machines at IAC and one additional machine that will be built in 2004.

Commercialization Table

Category	U. S. Market				
	Project Completion Year	5 Years after Completion	10 Years after Completion	15 Years after Completion	20 Years after Completion
(A) Total Number of Units in U.S. Market (Addressable Market)	3	16	30	30	Equipment obsolete
(B) Total Number Installed Units Using Your Technology (Capturable Market)	3	16	30	30	Equipment obsolete
(C) Market Penetration = $B/A \times 100\%$	100%	100%	100%	100%	0%

Attachment F: Cost Sharing

Final Cost Sharing

#	Company Name	Company Type*	In-Kind Contribution	Cash Contribution	Total
1	IAC	Small Business	\$179,728.84	\$0.00	\$179,728.84
	DOE			\$110,100.00	\$110,100.00
	Total				\$289,828.84

Attachment G: Partners and Contractors

#	Company Contact	Address	City	ST	Zip	Phone / Fax / e:mail
1	Oxford Instruments X-Ray Technologies, Inc.	275 Technology Circle	Scotts Valley	CA	95066	831 438 5742 / 831 438 5629 / sales@oxfordxtg.com
2	Rad-icon Imaging Corp.	3193 Bellick Street	Santa Clara	CA	95054-2404	408 486 0886 / 408 486 0882 / tgraeve@rad-icon.com
3	National Instruments	11500 N. Mopac Expressway	Austin	TX	78759-3504	800 433 3488 / 512 683 9300 / info@ni.com
4	Imgenation Corporation	PO Box 276	Beaverton	OR	97075-0267	503 495 2200 / / cssupport@cyberoptics.com
5	Rusty Ramsey		Knoxville	TN		865 256 2878 / / rusty.ramsey@tds.net
6	Ken Thomas		Knoxville	TN		865 691 2549 / / kgt@utk.edu
7	Nathan Pulcifer		Knoxville	TN		865 405 6492 / 865 882-8143 /
5	General Motors Jerry Barendreght		Saginaw	MI		989 757 0810 / 989 757 0373 / jerry.a.barendreght@gm.com

List all companies involved in the project (equipment vendors, consultants, subcontractors, customers etc. and provide a brief narrative discussing the role of each partner.)

- 1) Oxford supplied the x-ray tubes for the project. They provided extensive technical assistance in installing and starting up the x-ray generation system.
- 2) Rad-icon Imaging supplied the cameras. They provided extensive technical assistance in installing and starting up the cameras. They also provided much valuable insight into how to design the calibration algorithms used in the system.
- 3) National Instruments supplied the PCI bus controller cards and the Lab Windows CVI development tools. The NI web site has been very useful in providing example software and technical support.
- 4) Imegnation Provided the frame grabber cards for use with the x-ray cameras. Their software development help desk was very useful to me.
- 5) Rusty Ramsey is an electronics consultant who designed and built the photodiode amplifiers for the original optical and single channel x-ray sensors.
- 6) Ken Thomas is a mechanical consultant who designed and built the framework for both systems. This includes camera and moveable stage mounts, a back plane, and system shielding.
- 7) Nathan Pulsifer is an electronics consultant who builds x-ray systems for Quintek Measurement Systems in Knoxville. Nathan did most of the detail design and construction for the second system.
- 8) Jerry Barendrecht of General Motors has provided much advice and sample materials for use in this program. We are currently collaborating with Jerry in a test program to demonstrate the effectiveness of our system.

Note: This list includes only major suppliers. There were many other vendors involved to a lesser degree in this project.

Supplemental Information

Visual Aids (Photos, Videos, Samples, etc.)

Presentations:

AFS_03-113.doc	Paper Presented at the 2002 AFS CastExpo
Digital Imaging VI Paper.doc	Paper to be presented at ASNT Digital Imaging VI
RM_June_02.ppt	Presentation to IOF Sponsors Meeting* June 2002
RM_Oct_02.ppt	Presentation to IOF Sponsors Meeting* Oct 2002
RM_Feb03.ppt	Presentation to IOF Sponsors Meeting* Feb. 2003
RM_June_03.ppt	Presentation to IOF Sponsors Meeting* June 2003

Presentations are submitted in machine readable format on CD.

* Sponsors Meetings for: DOE IOF DE-FC07-02ID14235 Quantification and Standardization of Pattern Properties for the Control of the Lost Foam Metal Casting Process