09:32:23 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 06/10/93

Active

Project #: E-25-606 Cost share #: Rev #: 12
Center # : 10/24-6-R6796-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: DDM-8957848 Mod #: AMENDMENT 05 Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: 47.041
Main project #: PE #: N/A

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
COLTON J S MECH ENGR (404)894-7407

Sponsor/division names: NATL SCIENCE FOUNDATION / GENERAL
Sponsor/division codes: 107 / 000

Award period: 890815 to 950131 (performance) 950430 (reports)

Sponsor amount	New this change	Total to date
Contract value	62,500.00	312,000.00
Funded	62,500.00	312,000.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: PYI - INTELLIGENT DESIGN AND MANUFACTURING SYSTEMS

PROJECT ADMINISTRATION DATA

OCA contact: Jacquelyn L. Tyndall 894-4820

Sponsor technical contact

LALLIT ANAND
(202)357-7676

NATIONAL SCIENCE FOUNDATION
1800 G STREET, N.W.
WASHINGTON, D.C. 20550

Sponsor issuing office

DENISE YOUNG
(202)357-9602

NATIONAL SCIENCE FOUNDATION
DIVISION OF GRANTS AND CONTRACTS
1800 G STREET, NW
WASHINGTON, DC 20550

Security class (U,C,S,TS) : U
Defense priority rating : N/A
Equipment title vests with: Sponsor GIT X

ONR resident rep. is ACO (Y/N): N
NSF supplemental sheet

Administrative comments -
AMENDMENT 05 ADDS $62,500 TO PROJECT. THIS AWARD INCLUDES FUNDS FOR THE 5TH YEAR BASE AMOUNT OF $25,000 AND 5TH YEAR MATCH AMOUNT OF $37,500.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 01/31/95
Original Closeout Started 01/13/95

Project No. E-25-606   Center No. 10/24-6-R6796-0A0

Project Director COLTON J S   School/Lab MECH ENGR

Sponsor NATL SCIENCE FOUNDATION/GENERAL

Contract/Grant No. DDM-8957848   Contract Entity GTRC

Prime Contract No.

Title PYI - INTELLIGENT DESIGN AND MANUFACTURING SYSTEMS

Effective Completion Date 950131 (Performance) 950430 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments
LETTER OF CREDIT APPLIES. 98A SATISFIES PATENT REQUIREMENT.

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NATIONAL SCIENCE FOUNDATION

E-25-606

FOR CONSIDERATION BY NSF ORGANIZATIONAL UNIT (Indicate the most specific unit known, i.e. program, division, etc.)	PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE
	DDM-8957848

SUBMITTING INSTITUTION CODE (If known)	FOR RENEWAL ☐ CONTINUING AWARD ☐ ACCOMPLISHMENT BASED RENEWAL ☐ REQUEST, LIST PREVIOUS AWARD NO.:	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? Yes___ No X. IF YES, LIST ACRONYM(S)
0015693000		

NAME OF SUBMITTING ORGANIZATION TO WHICH AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS)
GEORGIA TECH RESEARCH CORPORATION

ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE) GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332-0420

IS SUBMITTING ORGANIZATION: ☐ For-Profit Organization; ☐ Small Business; ☐ Minority Business; ☐ Woman-Owned Business

TITLE OF PROPOSED PROJECT
Presidential Young Investigators Award: Intelligent Design and Manufacturing Systems

REQUESTED AMOUNT	PROPOSED DURATION	DESIRED STARTING DATE
$37,500	1 year	Aug 15, 1989

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW:

- ☐ Animal Welfare
- ☐ Endangered Species
- ☐ Human Subjects
- ☐ Marine Mammal Protection
- ☐ Pollution Control
- ☐ National Environmental Policy Act
- ☐ Research Involving Recombinant DNA Molecules
- ☐ Historical Sites
- ☐ Interdisciplinary
- ☐ International Cooperative Activity
- ☐ Research Opportunity Award
- ☐ Facilitation Award for Handicapped
- ☐ Proprietary and Privileged Information

PI/PD DEPARTMENT	PI/PD ORGANIZATION	PI/PD PHONE NO. & ELECTRONIC MAIL
Mechanical Engineering	GEORGIA INSTITUTE OF TECHNOLOGY	404-894-7407 JCOLTON @ GTRI01.Bitnet

PI/PD NAME/TITLE	SOCIAL SECURITY NO.*	HIGHEST DEGREE & YEAR	SIGNATURE
Jonathan Colton/ Asst. Prof	023-38-4429	PhD 1986	
ADDITIONAL PI/PD (TYPED)			
ADDITIONAL PI/PD (TYPED)			
ADDITIONAL PI/PD (TYPED)			
ADDITIONAL PI/PD (TYPED)			

For NSF Use:

TO BE COMPLETED BY THE AUTHORIZED ORGANIZATIONAL REPRESENTATIVE. By signing and submitting this proposal, the prospective grantee is providing the certifications set forth in (1) *Grants for Research and Education in Science and Engineering*, NSF 83-57 (rev. 11/87), and (2) Appendix C, 45CFR 620, Subpart F (Requirements for a Drug-Free Workplace).

(If answering yes to either, please provide explanation.)	YES	NO
Is the organization delinquent on any Federal Debt?		X
Is the organization presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency?		X

AUTHORIZED ORGANIZATIONAL REP. NAME/TITLE (TYPED)	SIGNATURE	DATE	TELEPHONE NO.
LYNN BOYD, CONTRACTING OFFICER		8/24/89	404/894-4817
OTHER ENDORSEMENT (optional) NAME/TITLE (TYPED)			

*Submission of social security numbers is voluntary and will not affect the organization's eligibility for an award. However, they are an integral part of the NSF information system and assist in processing the proposal. SSN solicited under NSF Act of 1950, as amended.

NSF Form 1207 (3/89)

PRESIDENTIAL YOUNG INVESTIGATOR AWARDS
REQUEST FOR NSF BASE AWARD AND/OR MATCHING FUNDS

Note: See reverse for instructions and definitions
Use separate form for each activity year

PYI Name: Jonathan S. Colton   Date of Request: 8/22/89

NSF Award #: DDM-8957848   Year PYI Awarded: 1989

==

NSF BASE AWARD REQUEST   Yes ___   No x   (Check one)

Amount: $ 25,000

Activity Year: 1 2 3 4 5 (Circle only one)
From month __ year ____ to month __ year ____

==

MATCHING FUNDS REQUEST   Yes x   No ___   (Check one)

Amount: $ 37,500 (Maximum $37,500 per activity year)

Activity Year: 1 2 3 4 5 (Circle only one)

Sources (List Individually)	Inst. Address (City, State, Zip)	P.O. Code	Cash Donation ($)	Equipment Donation ($)
(See sample on reverse side)				
1. Ford Motor Co.	Dearborn, MI 48121	F30	37,500	
2.				
3.				
4.				
5.				
6.				

SEE INSTRUCTIONS ON REVERSE BEFORE COMPLETING)

SUMMARY PROPOSAL BUDGET

APPENDIX IV

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
AWARD NO.		

ORGANIZATION: Georgia Tech Research Corporation

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Jonathan S. Colton

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	NSF FUNDED PERSON-MOS. CAL.	ACAD	SUMR	FUNDS REQUESTED BY PROPOSER	Matching FUNDS
1. Jonathan S. Colton				$	$
2.					
3.					
4.					
5. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
6. (1) TOTAL SENIOR PERSONNEL (1-5)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES					
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (3) GRADUATE STUDENTS				24,000	12,000
4. (3) UNDERGRADUATE STUDENTS				8,000	4,000
5. ( ) SECRETARIAL-CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				32,000	16,000
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				32,000	16,000
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000:) Microcomputer and peripherals					16,500
TOTAL PERMANENT EQUIPMENT					16,500
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				2,091	3,000
2. FOREIGN					
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER					
TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES					2,000
2. PUBLICATION COSTS/PAGE CHARGES					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS					2,000
H. TOTAL DIRECT COSTS (A THROUGH G)				34,091	37,500
I. INDIRECT COSTS (SPECIFY) 10% administrative costs in lieu of indirect costs					
TOTAL INDIRECT COSTS				3,409	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				37,500	37,500
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPM 252 AND 253)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 37,500	$ 37,500

PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION		
INST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - DGC / Program

NSF Form 1030 (1-87) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPM 233)

E-25-606
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Annual Report

to the

National Science Foundation

Division of Design and Manufacturing Systems
Directorate for Engineering

PYIA: Intelligent Design and Manufacturing Systems

Grant No. DDM-8957848

PI: Jonathan S. Colton
Georgia Institute of Technology
School of Mechanical Engineering
Atlanta, GA 30332-0405

First Year Annual Report
May 16, 1990

Introduction

Research on this grant is occurring in two major thrust areas: Composites Manufacturing and Intelligent Design Systems. Research in the first area is developing a science base for the processing of polymer matrix composites. The second area is studying the theories, methodologies, and tools needed to concurrently develop a product and its manufacturing process so that it can be manufactured right the first time.

Composite Manufacturing Research

Research in the processing of polymer matrix composites is developing a science base as well as prototype manufacturing processes. The consolidation of a novel, flexible tow-preg material is being studied to develop models appropriate for use in process design and control. A Ph.D. candidate is working on this project and is studying the effect of the flexibility of the fibers (as compared to the stiffness of most pre-pregs) effect the consolidation and shaping of parts made from these materials. A M.S. student is investigating the use of these materials for filament winding experimentally and theoretically. Sensors are a critical area of research for any process. Non-contact methods, such as optical fiber based sensors, as well as the traditional contact methods, such as thermocouples, will be studied for application in consolidation, molding, and filament winding in the next year by a visiting researcher on his sabbatical. Research is performed in the 3,000 square foot Composites Manufacturing Laboratory. Over the next year, three students (1 Ph.D. and 2 M.S.) will be joining the program. Their research will focus on sensor development and use in manufacturing processes. Thrust areas for the latter include filament winding, resin transfer molding, and reinforced reaction injection molding. Approximately three undergraduates will also be assisting in the laboratory in the next year. Matching funds from Ford have been obtained for this activity.

Intelligent Design Systems Research

This research is developing design theories and methodologies in the area of conceptual design. The approach taken is to develop generic functions that artifacts perform and to couple them to the needs of the customer. These functions are then translated into geometric and material specifications for a product. The interaction of the manufacturing function with the design process is being studied so that products are designed and manufactured right the first time. The feedback and incorporation of manufacturing knowledge is accomplished through the integration of CAD, artificial intelligence and database management systems. Three M.S. candidates have graduated after having completed theses in this area. Three undergraduates have also worked on this project integrating the various software and hardware systems that comprise the Intelligent Design System. Currently there are two M.S. working closely with GM on this project. This summer an undergraduate will work on the project and a Ph.D. candidate will be starting his research in the area of conceptual level functional design and the function/form interface. This fall a M.S. candidate will also be joining the project in the area of integrating manufacturing knowledge into the design process. Matching funds from GM and Ford have been obtained to support this work.

Summary

This project is developing a science base for the manufacturing of polymer matrix composites, well as investigating the techniques and tools required for the concurrent design of products and processes at the conceptual level. A large number of graduate and undergraduate students are being sponsored either directly on the NSF funds or by the matching funds obtained. A visiting researcher will be joining the project to spend his sabbatical year in the area of composites.

Projections for the next year point to an increase in the number of graduate and undergraduates to a steady state level. All of them are performing quality research in areas of critical needs to the U.S.

E-25-606

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Annual Report to the

National Science Foundation

Division of Design and Manufacturing Systems
Engineering Directorate

Grant No. DDM-8957848

PYIA: Intelligent Design and Manufacturing Systems

PI: Jonathan S. Colton
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405

Second Year Annual Report
May 10, 1991

Summary of this Year's Research

Introduction

This grant continues to support in research in two major areas: Composites Manufacture and Intelligent Design Systems. Research in composites continues to build a scientific base in the areas of consolidation and resin flow, and its application to filament winding and resin transfer molding. Research in intelligent design systems is exploring the methodologies for the design of complex systems using systems engineering approaches.

Composites Processing

This work is researching the fundamental aspects of polymer-matrix composites processing. A Ph.D. student is studying the consolidation of thermoplastic, continuous fiber reinforced materials. The model being developed will take into consideration the fact that the fibers are not typically perfectly aligned. This is not included in current models. The thermal aspects of the process, including heating and cooling and any possible crystallization of the matrix also will be included. The model will then be tested experimentally. Two M.S. students are studying filament winding of thermoplastic composites with the goal being the production of on-line, fully consolidated products, without the need for further processing, such as autoclaving. Their work is focussed on modeling the heat transfer and deformation processes that occur in rapidly heating and cooling the material as it is laid down on the mandrel. Theoretical models are being developed that predict the consolidation as a function of the processing parameters, in conjunction with the Ph.D. student's work. They are also studying alternative consolidation mechanisms to replace the roller, which provides a single line-contact, with flexible devices to provide a greater area for pressure. Another M.S. student is studying the spreading of fibers by air knife mechanisms. This work is modelling the fluid-fiber interactions, allowing the degree of spreading to be predicted. Spreading is important in the production of fiber prepregs to assure uniform polymer coatings. Another M.S. student, with the aid of an undergraduate, is studying the production of resin transfer molded parts from high performance epoxies and carbon fibers. They are trying to determine if precoating the fibers with a power-fusion coating of the epoxy prior to injection of the liquid resin improves mechanical properties.

Intelligent Design Systems

This portion of the research is studying the top level (conceptual) design of complex systems, such as automobiles, from a systems engineering standpoint. Top level design of products is not well understood. Most design research focuses on sub-systems or individual parts. This work looks at the relation of the customer's desires to the design and production of a product. The translation of the "voice of the customer" to the functional requirements of the vehicle and the translation of these functions into forms that can be manufactured efficiently is the focus of this work. A Ph.D. student is developing a model for the translations from the "voice of the customer" to the function and to the forms. Another Ph.D. student is looking at how the top level requirements become lower level requirements and in doing so affect other requirements. Two M.S. students are looking at the functional and form hierarchies of an automobile. Another M.S. student is studying the information technologies that will allow the integration of these various models into an intelligent design tool that will allow the testing of the completed system. The longer term goal of this work is to see if a systems engineering approach can be applied to complex product design, such as for an automobile, which has many competing and conflicting goals. The integration of the many design tools that are used for their design is a concurrent goal. Currently, there are no available tools, or even paradigms to direct the development of these tools, available. This work addresses these needs.

Matching Funds and Related Proposals

Matching funds for this research have been obtained in the form of grants from the Ford Motor Company and the General Motors Corporation. A proposal has been submitted to the National Institute of Standards and Technology in the area of composites processing to build upon the research funded by this PYIA. A grant has been awarded by the NSF to upgrade an undergraduate lab in composites processing, through the purchase of a filament winder, a resin transfer molding machine, and an upgrade to a C-scan ultrasonic testing device. This award was a direct outgrowth of the research sponsored by this PYIA. Another proposal has been submitted to NSF for additional equipment to support this PYIA research.

Next Year's Research Plan

In the composites processing program, research will continue to develop the consolidation and resin permeation models. The next year should see the integration of the various portions of the models into a complete whole, which can predict product properties as a function of processing parameters. Experimental testing of the models, will be performed on the filament winder and resin transfer molding apparati.

The various models and translations for the design of a complex systems, using the automobile as the test vehicle, will be integrated over the next year into a software prototype. This will allow the testing of the hypotheses of this research and of the various models. The test results will be used to modify the model, if necessary, and to point out future research directions.

E25-606
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Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405

April 20 1992

Mrs. Carol Guido, Administrative Officer
DDM, Room 1128
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

Dear Ms. Guido:

I am requesting my continuing grant increment for my PYIA grant No. DDM-8957848. Enclosed please find the third year annual report for my PYIA, as well as the budget and the request for base and/or matching funds. I would appreciate if you would process the paperwork so that I may obtain the increment. If you have any questions, please feel free to call me at 404-894-7407.

Thank you for your assistance in this matter.

Sincerely,

Jonathan Colton
Associate Professor

Enclosures

Annual Report to the

National Science Foundation

Division of Design and Manufacturing Systems
Engineering Directorate

Grant No. DDM-8957848

PYIA: Intelligent Design and Manufacturing Systems

PI: Jonathan S. Colton
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405

Third Year Annual Report
April 20, 1992

Summary of Third Year's Research

Introduction

This grant continues to support in research in two major areas: Composites Manufacture and Intelligent Design Systems. Research in composites continues to build a scientific base in the areas of consolidation and resin flow, and its application to filament winding and resin transfer molding. Research in intelligent design systems is exploring the methodologies for the design of complex systems using systems engineering principles.

Composites Processing

This work is researching the fundamental aspects of polymer-matrix composites processing. A Ph.D. student is completing his thesis on the consolidation of thermoplastic, continuous fiber reinforced materials. The model he developed takes into consideration the facts that the fibers are not typically perfectly aligned and that they move during processing. These are not included in current models. The thermal aspects of the process, including heating and cooling and any possible crystallization of the matrix also are included. The model has been tested experimentally and the agreement is very good. Two M.S. students finished theses on the filament winding of thermoplastic composites with the goal being the production of on-line, fully consolidated products, without the need for further processing, such as autoclaving. Their work focused on modeling the heat transfer and deformation processes that occur in rapidly heating and cooling the material as it is laid down on the mandrel. Theoretical/empirical models were developed that predict the consolidation as a function of the processing parameters. Another M.S. student completed her thesis on the spreading of fibers by air knife mechanisms. This work modeled the fluid-fiber interactions, allowing the degree of spreading to be predicted knowing the flow characteristics and spreader geometry. Spreading is important in the production of fiber prepregs to assure uniform polymer coatings. Another M.S. student is studying the production of resin transfer molded parts from high performance epoxies and carbon fibers. She is trying to determine if precoating the fibers with a power-fusion coating of the epoxy prior to injection of the liquid resin improves mechanical properties.

Intelligent Design Systems

This portion of the research is studying the top level (conceptual) design of complex systems, such as automobiles, from a systems engineering standpoint. Top level design of products is not well understood. Most design research focuses on sub-systems or individual parts. This work looks at the relation of the customer's desires to the design and production of a product. The translation of the "voice of the customer" to the functional requirements of the vehicle and the translation of these functions into forms that can be manufactured efficiently is the focus of this work. A Ph.D. student is developing a model for the translations from the "voice of the customer" to the functions and to the forms. An M.S.

special problems student studied how the top level requirements become lower level requirements and in doing so affect other requirements. One M.S. student completed his thesis on the functional and form hierarchies for automobile design and the integration of the required information technologies (such as databases, parametric design tools, and blackboards) to implement and test the models. The integrated tool allowed the voice of the customer to be translated into a form (drawing) that allowed the designer to check for geometric compatibilities (such as interferences) and the overall design during the conceptual design stage. This allowed the quality of the design to be determined at an early stage, thereby saving time and money as compared to having to check the design later, after much more work has been performed. Currently, there are no tools, or even paradigms to direct the development of these tools, available. This work addresses these needs.

Matching Funds and Related Proposals

Matching funds for this research have been obtained in the form of grants from the Ford Motor Company and the General Motors Corporation. A proposal was funded by the National Institute of Standards and Technology in the area of composites processing to build upon the research funded by this PYIA. A grant has been awarded by the NSF to upgrade an undergraduate lab in composites processing, through the purchase of a filament winder, a resin transfer molding machine, and an upgrade to a C-scan ultrasonic testing device. This award was a direct outgrowth of the research sponsored by this PYIA. Another proposal has been submitted to NSF for additional equipment to support this PYIA research.

Next Year's Research Plan

In the composites processing program, research will continue to develop the consolidation model. The next year will see the use of the model to study continuous processing techniques, such as filament winding, and the processing of flexible, prepreg preforms into net shape parts by matched die molding and resin transfer molding.

The various models and translations for the design of a complex systems, using the automobile as the test vehicle, will be further integrated over the next year into the software prototype. This will allow the testing of the hypotheses of this research and of the various models. The test results will be used to modify the model, if necessary, and to point out future research directions.

To NSF Program: DDM/ MPE

E-25-606

APPENDIX VIII

Annual NSF Grant Progress Report

4

PI Name: Jonathan S. Colton

NSF Award Number: DDM-8957848

PI Institution: Georgia Institute of Technology

PI Address: School of Mechanical Engineering
Atlanta GA 30332-0405

Date: 12/16/92

I certify that to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I understand that the willful provision of false information or concealing a material fact in this report or any other communication submitted to NSF ~~is~~ a criminal offense (U.S.Code, Title 18, Section 1001.)

Signature: ______________________

Please include the following information:

1. A brief summary of overall progress, including results obtained to date, their relationship to the general goals of the award and their significance to science;
2. an indication of any current problems or favorable or unusual developments;
3. a brief summary of work to be performed during the next year of support if changed from the original proposal; and
4. any other information pertinent to the type of project supported by NSF or as specified by the terms and conditions of the grant, including a statement describing the contribution of the research in the area of education and human resources development.

If applicable, please attach a copy of any updated human subject or animal subject certification.
[Attach additonal sheets as necessary.]

1. Summary of Fourth Year's Research

1.1 Introduction

This grant continues to support in research in two major areas: Composites Processing and Intelligent Design Systems. Research in composites continues to build a scientific base in the areas of consolidation and resin flow, and its application to compression molding, filament winding and resin transfer molding. Research in intelligent design systems is exploring the methodologies for the design of complex systems using systems engineering and TQM/CQI principles.

1.2 Composites Processing

This work is researching the fundamental aspects of polymer-matrix composites processing. A Ph.D. student completed his thesis on the consolidation of thermoplastic, continuous fiber reinforced materials. The model he developed takes into consideration the fact that the fibers are not typically perfectly aligned. This is not included in current models. New aspects of this work are the prediction of permeability and thermal properties based on the microstructure of the composites. New digital image processing techniques were developed that greatly reduce the computing needs and errors due to image quality and size. The thermal aspects of the process, including heating and cooling and any possible crystallization of the matrix also are included. The model has been tested experimentally and the agreement is very good.

An M.S. student completed her thesis on the production of resin transfer molded parts from high performance epoxies and carbon fibers. She determined that precoating the fibers with a power-fusion coating of the epoxy prior to injection of the liquid resin reduced the void content and improved the surface finish of the parts and did not adversely affect their mechanical properties.

Another student is working on his M.S. thesis in the area of filament winding. He is studying how different types of thermoplastic prepregs process and how the processing relates to final product quality. The types of prepregs studied include powder-coated towpregs, tapes made form powder-coated towpregs, and melt impregnated tapes.

Four undergraduates worked on projects in filament winding, compression molding, thermoplastic pultrusion, and in C-scan, ultrasonic, non-destructive testing.

A senior elective laboratory course in Composites Manufacturing is being offered. One half the class are undergraduates and one half are graduate students. The students experience hands-on manufacturing with industrial scale and grade equipment. This is one of the few courses in the country that so teaches.

1.3 Intelligent Design Systems

This portion of the research is studying the top level (conceptual) design of complex systems, such as automobiles, from a systems engineering standpoint. Top level design of products is not well understood. Most design research focuses on sub-systems or individual parts. This work looks at the relation of the customer's desires to the design and production of a product through the integration of Total Quality Management (TQM) and Continuous Quality Improvement (CQI) techniques.

One Ph.D. student is working on the transformations of the VoC into a functional representation and then into a form representation. This work is developing a "dynamic specification" that will allow the designer to develop competing designs for future selection. It is important not to delete designs at too early a stage, before the complete specification is developed.

Another Ph.D. student is focusing on optimization applied to the underhood packaging of a car. This requires the inclusion of geometric (the parts must fit), spatial (the parts must be in the right orientation), connectivity (the parts must be attached to each other in the correct manner), mass (the center of gravity must be low), and thermal (the engine must be cooled and hot parts should not be near parts that must remain cool) information.

An M.S. student is working on including "noise" in design. The designer may consider the customer, the management, the stylist, and a plethora of other sources "noise" in the system. This noise must *not* be filtered out. It must be used to develop a set of alternative designs for the "team" to study for the trade-offs in any design. In this manner, decision making can be enhanced.

Automobile design, as well as that of any complex system, requires that resources (cost and weight, for example) be allocated to the different design teams as a starting point for their work. The teams are well versed in their particular area and can optimize their designs. Unfortunately, no one is typically keeping track of the entire systems and a sub-optimized product results when the optimized sub-assemblies are integrated. Another M.S. student is studying the allocation of these resources at the beginning of the design process to assure the most economic and efficient product.

Object oriented information technology provides the opportunity to provide a relatively neutral environment for the design of complex systems. For example, a tire is a toroid (geometry); is made from rubber, metal, and polymer (material); is a suspension element (function); and is a friction element (function). The development of a complete object-oriented model of a car should allow one to determine if it is well designed (and to develop a well-designed car) by comparing the model with the model of the car's functions. A Ph.D. is studying this paradigm.

2. Matching Funds and Related Proposals

NASA, McDonnell Air, and Great Lakes Composites Corporation also is sponsoring the composites research. GE also is sponsoring the educational effort in composites. General Motors also is sponsoring the design-related work.

3. Next Year's Research Plan

In the composites processing program, research will test the consolidation model on continuous processing techniques, such as filament winding.

Design research will focus on developing the object-oriented paradigm and its inclusion in the tools being developed.

4. Next Year's Educational Plan

Two experiments in the undergraduate course in composites will be revised to include new equipment - a five axis filament winder and a color C-scan.

OMB Number 3145-0058

NATIONAL SCIENCE FOUNDATION
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E-25-606
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PI/PD Name and Address

Dr. Jonathan S. Colton
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NATIONAL SCIENCE FOUNDATION
FINAL PROJECT REPORT

PART I - PROJECT IDENTIFICATION INFORMATION

1. Program Official/Org. Dr. Bruce Kramer DMII

2. Program Name Materials Processing and Manufacturing

3. Award Dates (MM/YY) **From:** 8/89 **To:** 1/95

4. Institution and Address
Georgia Tech Research Corporation
Georgia Institute of Technology
Atlanta, Georgia 30332-0420

5. Award Number DDM-8957848

6. Project Title
Presidential Young Investigator Award:
Intelligent Design and Manufacturing Systems

NSF Grant Conditions (Article 17, GC-1, and Article 8, FDP-11) require submission of a Final Project Report (NSF Form 98A) to the NSF program officer no later than 90 days after the expiration of the award. Final Project Reports for expired awards must be received before new awards can be made (NSF Grants Policy Manual Section 677).

Below, or on a separate page attached to this form, provide a summary of the completed projects and technical information. Be sure to include your name and award number on each separate page. See below for more instructions.

PART II - SUMMARY OF COMPLETED PROJECT (for public use)

The summary (about 200 words) must be self-contained and intelligible to a scientifically or technically literate reader. Without restating the project title, it should begin with a topic sentence stating the project's major thesis. The summary should include, if pertinent to the project being described, the following items:

- The primary objectives and scope of the project
- The techniques or approaches used only to the degree necessary for comprehension
- The findings and implications stated as concisely and informatively as possible

Please see attached.

PART III - TECHNICAL INFORMATION (for program management use)

List references to publications resulting from this award and briefly describe primary data, samples, physical collections, inventions, software, etc. created or gathered in the course of the research and, if appropriate, how they are being made available to the research community. Provide the NSF Invention Disclosure number for any invention.

Please see attached.

I certify to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinion) are true and complete, and (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or of individuals working under their supervision. I understand that willfully making a false statement or concealing a material fact in this report or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001).

	1/15/95
Principal Investigator/Project Director Signature	Date

IMPORTANT:
MAILING INSTRUCTIONS
Return this *entire* packet plus all attachments in the envelope attached to the back of this form. Please copy the information from Part I, Block I to the *Attention block* on the envelope.

NSF Form 98A (Rev. 1/94)

PART IV — FINAL PROJECT REPORT — SUMMARY DATA ON PROJECT PERSONNEL

(To be submitted to cognizant Program Officer upon completion of project)

The data requested below are important for the development of a statistical profile on the personnel supported by Federal grants. The information on this part is solicited in resonse to Public Law 99-383 and 42 USC 1885C. All information provided will be treated as confidential and will be safeguarded in accordance with the provisions of the Privacy Act of 1974. You should submit a single copy of this part with each final project report. However, submission of the requested information is not mandatory and is not a precondition of future award(s). Check the "Decline to Provide Information" box below if you do not wish to provide the nformation.

Please enter the numbers of individuals supported under this grant.
Do not enter information for individuals working less than 40 hours in any calendar year.

	Senior Staff		Post-Doctorals		Graduate Students		Under-Graduates		Other Participants[1]	
	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.	Male	Fem.
A. Total, U.S. Citizens	1				14	5	5	3		
B. Total, Permanent Residents										
U.S. Citizens or Permanent Residents[2]:										
American Indian or Alaskan Native										
Asian.					1					
Black, Not of Hispanic Origin.					1		2			
Hispanic										
Pacific Islander										
White, Not of Hispanic Origin	1				12	5	3	3		
C. Total, Other Non-U.S. Citizens										
Specify Country 1. Norway Holland Korea					- - 1		1 1 -			
2. India					1		1			
3. Israel			2							
D. Total, All participants (A + B + C)	1		2		16	5	8	3		
Disabled[3]										

☐ Decline to Provide Information: Check box if you do not wish to provide this information (you are still required to return this page along with Parts I-III).

[1] Category includes, for example, college and precollege teachers, conference and workshop participants.

[2] Use the category that best describes the ethnic/racial status fo all U.S. Citizens and Non-citizens with Permanent Residency. *(If more than one category applies, use the one category that most closely reflects the person's recognition in the community.)*

[3] A person having a physical or mental impairment that substantially limits one or more major life activities; who has a record of such impairment; or who is regarded as having such impairment. *(Disabled individuals also should be counted under the appropriate ethnic/racial group unless they are classified as "Other Non-U.S. Citizens.")*

AMERICAN INDIAN OR ALASKAN NATIVE: A person having origins in any of the original peoples of North America and who maintains cultural identification through tribal affiliation or community recognition.

ASIAN: A person having origins in any of the original peoples of East Asia, Southeast Asia or the Indian subcontinent. This area includes, for example, China, India, Indonesia, Japan, Korea and Vietnam.

BLACK, NOT OF HISPANIC ORIGIN: A person having origins in any of the black racial groups of Africa.

HISPANIC: A person of Mexican, Puerto Rican, Cuban, Central or South American or other Spanish culture or origin, regardless of race.

PACIFIC ISLANDER: A person having origins in any of the orignal peoples of Hawaii; the U.S. Pacific territories of Guam, American Samoa, and the Northern Marinas; the U.S. Trust Territory of Palau; the islands of Micronesia and Melanesia; or the Philippines.

WHITE, NOT OF HISPANIC ORIGIN: A person having origins in any of the original peoples of Europe, North Africa, or the Middle East.

PART II. Summary of Completed Project

This research project focused on two areas: composites processing, and conceptual design theory and methodology.

Composites research developed theoretical models for the processing of high performance composites and tested them experimentally. These models can be used to determine the response of matrix-fiber networks to process parameters, such as temperature, pressure, and time, and to the initial material geometry and type. This allows the processing conditions needed to produce fully consolidated products to be determined a priori. Examples of the processes studied include filament winding, resin transfer molding, pultrusion, and bladder molding. Experiments on flat panels and actual parts validated the models. In conjunction, a new material form, a flexible powder-fusion coated towpreg, was studied as the prepreg for these processes.

Design research focused on conceptual design, studying the relations of forms and functions during the early stages of design, when only qualitative data is available. Unified, yet customizable strategies were developed that aid designers and were instantiated in software. They start with the translation of customer requirements into engineering data, assuring a desirable product and continue with the allocation of cost, weight, and space, in addition to function. Object-oriented strategies for design information management and mechanical packaging strategies that take into account the behavior of the components in addition to their geometries also were included. The product then is simulated to determine if it meets the customer's requirements and is produceable.

PART III - Technical Information

This research project focused on two areas: composites processing, and conceptual design theory and methodology.

Composites research developed theoretical models for the processing of high performance composites and tested them experimentally. These models can be used to determine the response of matrix-fiber networks to process parameters, such as temperature, pressure, and time, and to the initial material geometry and type. This allows the processing conditions needed to produce fully consolidated products to be determined a priori. Examples of the processes studied include filament winding, resin transfer molding, pultrusion, and bladder molding. Experiments on flat panels and actual parts validated the models. In conjunction, a new material form, a flexible powder-fusion coated towpreg, was studied as the prepreg for these processes.

Specific projects developed and experimentally verified models for the consolidation of high performance thermoplastic continuous fiber composites, such as PEEK/ carbon fiber. Models included the matrix characteristics, such as resin flow and solidification, as well the waviness of the fibers on a micro-scale. Most models lump the latter into the permeability and do not attempt to model its actual geometry. The inclusion of the waviness represents a key advance in improving the accuracy of these types of models. They were tested using flat, compression molded plaques as well as filament wound parts. The results agreed nicely. To process thermoplastic composite tape and towpreg prepregs into filament wound parts, machine components and equipment were designed, built, and tested using hot air guns and pultrusion dies. Similar commercial systems can cost $250,000, and include robotic devices. The lab scale device used approximately $1,500 worth of parts and relied on the filament winding machine for control and positioning. The research results and equipment were noted with approval by the AMRF at NIST. They provided further funding to develop the theory and equipment to suit their specific needs.

Another area of research studied the production and use of powder-fusion coated towpregs. These are flexible materials that were developed with a NASA grant to allow the combination of high viscosity thermoplastics, which are difficult to melt process, with continuous fiber reinforcement. Three patents have been issued on this material, its use and method of manufacture using some of the results of the NSF-funded research. A start-up company in the Atlanta area has been commercializing the process and product for the past two years. The use of this material for filament winding, as a preform for resin transfer molding (RTM), and for bladder molding has been studied under this grant. Key results have been models of how the material processes with the different techniques, which highlight the similarities and differences to melt coated materials. Results have allowed the production of RTM parts with a reduced void content and the on-line consolidation of filament wound parts using a consolidation roller. Another area has been the bladder molding of hollow parts, such as tennis racquets and bicycle tubes. There has been much industrial interaction on this project. The start-up company Custom Composite Materials, Inc. (CCMI), is the most obvious. Others include Johnson

Controls, on bladder molding, the Great Lake Composites Corporation, on pultrusion of the towpreg, 3M, on RTM, NASA, on towpreg production and conversion, and the U.S. Navy. The results from the NSF work were used to attract further funding from these companies and agencies. Commercial products under development include automobile parts, golf club shafts, bicycle tubes, tennis racquets, and medical items, such as shoe instep inserts.

This grant was leveraged by an ILI equipment grant which aided in the purchase of a filament winding machine, a resin transfer molding machine, and ultrasonic non-destructive testing equipment for use in the senior elective, Laboratory in Composites Manufacture and Testing. This class is part of an undergraduate curriculum in composites engineering and provides the hands-on portion of the sequence. Students make and test parts using industrial grade equipment. The availability of the equipment makes the transfer of the research results to undergraduate, and even graduate, students taking the class much more tangible and meaningful.

The research in composites processing has developed valuable models and knowledge concerning continuous fiber composites processing, has developed new materials and the techniques for their processing, including equipment, and has transferred these results to industry and government. The results have attracted additional funding to further the work and its commercialization.

Design research focused on conceptual design, studying the relations of forms and functions during the early stages of design, when only qualitative data is available. Unified, yet customizable strategies were developed that aid designers and were instantiated in software. They start with the translation of customer requirements into engineering data, assuring a desirable product and continue with the allocation of cost, weight, and space, in addition to function. Object-oriented strategies for design information management and mechanical packaging strategies that take into account the behavior of the components in addition to their geometries also were included. The product then is simulated to determine if it meets the customer's requirements and is produceable.

Specific projects have addressed the issues of Design for Manufacture (DFM) of mechanical systems, such as power transmissions. This work studied how the information associated with components and systems, such as behavior and geometry, as well as their methods of manufacture, can be combined within a computerized system to design a produceable product. Expert systems and object oriented programming techniques were used to handle the knowledge required to make design decisions. Information management systems, specifically those based on the relational and the object-oriented paradigms, were studied to determine the best way to handle the plethora of information. While object-oriented systems provide a more natural way to view the data, they are somewhat difficult to use and are somewhat less efficient than relational databases. A combination was deemed most effective. The NSF funded results were used to attract additional funding from Ford and GM. These projects continued the DFM work (Ford), focusing on how to interface expert systems and databases with other modeling and analysis systems to provide a unified design environment. Work with GM looked at the hierarchical decomposition design methods for automobiles and the development, implementation and testing of an object oriented vehicle model for conceptual design.

These interactions led to further projects under this NSF grant. These included the translation of the Voice of the Customer (the customer's desires) into engineering specifications. Until this work, much of the use of the House of Quality (within Quality Function Development) has been qualitative in nature, with designers only having a qualitative, non-mathematical feel for the relation between the customer's desires and the engineering characteristic of the design. Using the automobile as an example of a complex system, work has developed high level models of the behavior of a car in relation to the customer's desires, allowing the car's performance to be prototyped in software before detail design is performed. These models are integrated to provide the designer with the high level specifications needed to start the design process. The models assure that nothing is left out of the specifications and that the car is feasible. This method could lead to reduced design time as less iterations are needed because the customer's wishes have been captured in the proper format and in enough detail. Another area is the packaging of electro-mechanical systems, using the car engine as an example. In the past, most work on packaging has been developed for two dimensional problems, such as sheet metal stamping, or three dimensional problems, such as loading a truck or airplane, and has been based solely on geometric constraints. The work here has gone beyond this to include functions and behavior. For example, the fan belt must transmit torque (function) by connecting a number of pulleys within a given volume (geometry). Both primary behavior (desired) and secondary behavior was included. For example, the battery must not be placed near the engine block, lest it melt, as a secondary behavior of the engine is to produce a lot of heat. The inclusion of secondary behaviors in addition to the primary behaviors represents a large step forward in addressing packaging issues. Grammars were developed to allow this type of packaging strategy to be applied generically. Genetic algorithms, simulated annealing and object-oriented programming are a few of the techniques used in these works.

Research in design has focused on the representation and use of knowledge that encompasses customer requirements, manufacturing capabilities, product behavior and information management and unify them in to a support structure for the design of produceable and desirable products.

Jonathan S. Colton DDM-8957848

Publications Resulting from the NSF Award

Journal Papers:

1. Wade, J. and Colton, J.S., "A Framework for Feature-based Representation of the Design Process," Engineering with Computers, Vol. 6, 185-192, (1990).

2. Muzzy, J.D., Wu, X., and Colton, J.S., "Thermoforming of High Performance Thermoplastic Composites," Polymer Composites, Vol. 11, No. 5, 280-285 (1990).

3. Colton, J.S. and Dascanio, J.D., "An Integrated, Intelligent Design Environment," Engineering with Computers, Vol. 7, 11-22 (1991).

4. Colton, J.S. and Pun, R.C., "Information Frameworks for Conceptual Engineering Design," Engineering with Computers, Vol. 10, 22-33 (1994).

5. Miller, G.S. and Colton, J.S., "The Complementary Roles of Expert Systems and Database Management Systems in a Design for Manufacture Environment," Engineering with Computers, Vol. 8, 139-149 (1992).

6. Colton, J., and Leach, D., "Processing Parameters for Filament Winding Thick Section PEEK/ Carbon Fiber Composites," Polymer Composites, Vol. 13, No. 6, 421-426 (1992).

7. Colton, J., Muzzy, J., Birger, S., Yang, H., and Norpoth, L., "Processing Parameters for Consolidating PEEK/ Carbon Fiber (APC-2) Composites," Polymer Composites, Vol. 13, No. 6, 427-434 (1992).

8. Shields, K. and Colton, J. "Resin Transfer Molding with Powder-Coated Preforms," Polymer Composites, Vol. 14, No. 4, 341-348 (1993).

9. Carpenter, C.E. and Colton, J.S., "On-Line Consolidation Mechanisms in Thermoplastic Filament Winding," Polymer Composites, Vol. 15, No. 1, 55-63 (1994).

10. Yang, H. and Colton, J.S., "Microstructure-Based Processing Parameters of Thermoplastic Composite Materials. Part I: Theoretical Models," Polymer Composites, Vol. 15, No. 1, 34-41 (1994).

11. Yang, H. and Colton, J.S., "Microstructure-Based Processing Parameters of Thermoplastic Composite Materials. Part II: Experimental Results," Polymer Composites, Vol. 15, No. 1, 42-45 (1994).

12. Yang, H. and Colton, J.S., "Quantitative Image Processing Analysis of Composite Materials," Polymer Composites, Vol. 15, No. 1, 46-54 (1994).

13. Colton, J.S., and Ouellette, M.P., "A Form Verification System for the Conceptual Design of Complex Mechanical Systems," Engineering with Computers, Vol. 10, 33-44 (1994).

14. Muzzy, J.D. and Colton, J.S., "The Processing Science of Thermoplastic Composites," Engineering Analysis of Composites Manufacturing, Chapter 3, (T.G. Gutowski, Ed.), New York: Butterworth-Heinemann (199X).

15. Wagner, P. and Colton, J.S., "On-Line Consolidation of Thermoplastic Towpreg Composites in Filament Winding," Polymer Composites, in press (1994).

16. Yang, H. and Colton, J.S., "Thermal Analysis of Thermoplastic Composites during Processing," Polymer Composites, in press (1994).

17. Nunes, N. and Colton, J.S., "Characterization of Adhesion between Polymer Layers during Insert Overmolding," Polymer Engineering and Science, submitted for publication (1994).

18. Colton, J.S. and Staples, J.W., "Optimizing the Allocation of Resources during Preliminary Automobile Design," Engineering with Computers, submitted for publication, (1994).

Conference Presentations

1. Wade, J. and Colton, J.S., "A Framework for Feature-based Representation of the Design Process," Proceedings: Engineering Database Management: Leadership Key for the 90's, Computers in Engineering Conference, American Society of Mechanical Engineers, Anaheim, 3, 97-102, July 30 - August 3, 1989.

2. Wu, X., Muzzy, J. and Colton, J.S., "Rheological Studies of Thermoforming APC-2, An Aromatic Polymer Composite," 2nd Topical Conference on Emerging Technologies in Materials, American Institute of Chemical Engineers, San Francisco, November 6-9, 1989.

3. Wade, J. and Colton, J.S., "The Development of a Design for Manufacture Expert System," Proceedings: Advances in Manufacturing Systems, Manufacturing International '90, American Society of Mechanical Engineers, Atlanta, 4, 69-75, March 25-28, 1990.

4. Wu, X., Muzzy, J. and Colton, J.S., "Thermoforming of Thermoplastic Composites: Rheological Characterization," 199th National Conference, American Chemical Society, Boston, April 22-27, 1990.

5. Dascanio, J.L. and Colton, J.S., "An Integrated, Intelligent Design Environment," Proceedings, Computers in Engineering Conference, American Society of Mechanical Engineers, Boston, 1, 9-15, August 6-8, 1990.

6. Pun, R.C. and Colton, J.S., "A Framework for Conceptual Engineering Design," Proceedings: Advances in Integrated Product Design and Manufacturing, Winter Annual Meeting, American Society of Mechanical Engineers, Dallas, PED-Vol. 47, 1-15, November 25-30, 1990.

7. Miller, G.S. and Colton, J.S., "The Complementary Roles of Expert Systems and Database Management Systems in a Design for Manufacture Environment," Proceedings: Advances in Integrated Product Design and Manufacturing, Winter Annual Meeting, American Society of Mechanical Engineers, Dallas, PED-Vol. 47, 39-51, November 25-30, 1990.

8. Colton, J.S., "Advanced Fiber Resin Systems for Automotive Applications," Proceedings, Future of High Performance Fabrics Conference, Industrial Fabrics Association International, Atlanta, 46-58, December 4-5, 1990.

9. Colton, J.S., "Intelligent Design and Manufacturing Systems," Proceedings, 17th Annual NSF Conference on Design and Manufacturing, Austin, 657-666, January 9-11, 1991.

10. Leach, D. and Colton, J.S., "Processing Parameters for Filament Winding Thick Section PEEK/ Carbon Fiber Composites," Proceedings, 49th Annual Technical Conference, Society of Plastics Engineers, Montreal, 2058-2061, May 6-10, 1991.

11. Colton, J.S., Muzzy, J., Birger, S., Yang, H., and Norpoth, L., "Processing Parameters for Consolidating PEEK/ Carbon Fiber (APC-2) Composites," Proceedings, 49th Annual Technical Conference, Society of Plastics Engineers, Montreal, 2013-2017, May 6-10, 1991.

12. Wu, X, Muzzy, J. and Colton, J.S., "Buckling as a Constraint in Thermoforming PEEK/ Carbon Fiber (APC2) Composites," Proceedings, 49th Annual Technical Conference, Society of Plastics Engineers, Montreal, 2053-2057, May 6-10, 1991.

13. Wu, X, Muzzy, J. and Colton, J.S., "Quantitative Characterization of Forming Properties in PEEK/ Carbon Fiber Composites," Proceedings, International Conference on Composite Materials VIII, Honolulu, 10-H-1 - 10-H-12, July 15-19, 1991.

14. Leach, D. and Colton, J.S., "Processing Parameters for Thermoplastic Filament Winding," Proceedings: Processing and Manufacturing of Composites Materials, Winter Annual Meeting, American Society of Mechanical Engineers, Atlanta, PED-Vol. 49, 231-246, December 1-6, 1991.

15. Colton, J.S., "Modeling of Processing of Advanced Composites," Proceedings, 1992 NSF Design and Manufacturing Systems Conference, Atlanta, 49-52, January 8-10, 1992.

16. Colton, J.S., and Birger, S., "Characterization of APC-2 and PEEK/AS-4 Commingled Yarn Composites for Processing," Proceedings, 37th International

SAMPE Symposium, Society for the Advancement of Material and Process Engineering, Anaheim, 1291-1300, March 9-12, 1992.

17. Muzzy, J.D. and Colton, J.S., "The Processing Science of Thermoplastic Composites," 1992 Society of Plastics Engineers Annual Technical Conference, Detroit, May 3-7,1992.

18. Muzzy, J.D. and Colton, J.S., "The Processing Science of Thermoplastic Composites," Conference on Science and Innovation in Polymer Composites Processing, MIT, Cambridge, MA, July 16-17, 1992.

19. Colton, J.S., "PYIA: Intelligent Design and Manufacturing Systems: Advanced Composites Processing," Proceedings, 1993 NSF Design and Manufacturing Systems Conference, Charlotte, 79-82, January 6-8, 1993.

20. Colton, J.S., "Advanced Polymer Matrix Composites Manufacturing," Proceedings, US/Taiwan Joint Symposium on Advanced Manufacturing Processes, Atlanta, 199-209, February 10-12, 1993.

21. Shields, K. and Colton, J.S., "Resin Transfer Molding with Powder-Coated Preforms," Proceedings, 38th International SAMPE Symposium, Society for the Advancement of Material and Process Engineering, Anaheim, 477-487, May 10-13, 1993, (with K. Shields).

22. Carpenter, C.E. and Colton, J.S., "On-Line Consolidation Mechanisms in Thermoplastic Filament Winding (Tape Laying)," Proceedings, 38th International SAMPE Symposium, Society for the Advancement of Material and Process Engineering, Anaheim, 205-216, May 10-13, 1993, (with C.E. Carpenter).

23. Shields, K. and Colton, J.S., "Resin Transfer Molding with Powder-Coated Preforms," Proceedings: Composites Modeling and Processing Science, 9th International Conference on Composite Materials, Madrid, III, 505-512, July 12-16, 1993.

24. Carpenter, C.E. and Colton, J.S., "On-Line Consolidation Mechanisms in Thermoplastic Filament Winding (Tape Laying)," Proceedings: Composites Modeling and Processing Science, 9th International Conference on Composite Materials, Madrid, III, 430-437, July 12-16, 1993.

25. Ouellette, M.P. and Colton, J.S., "A Form Verification System for the Conceptual Design of Complex Mechanical Systems," Proceedings: Advances in Design Automation - Volume 1, Design Automation Conference, American Society of Mechanical Engineers, Albuquerque, DE-Vol. 65-1, 97-108, September 19-22, 1993.

26. Yang, Y. and Colton, J.S., "Microstructure-Based Processing Parameters of Thermoplastic Composite Materials," Proceedings: Use of Plastics and Plastic Composites, Winter Annual Meeting, American Society of Mechanical Engineers, New Orleans, MD-Vol. 46, 609-631, Nov. 28 - Dec. 3, 1993.

27. Ouellette, M.P. and Colton, J.S., "A Form Verification System for the Conceptual Design of Complex Mechanical Systems," Proceedings: Intelligent Concurrent Design, Winter Annual Meeting, American Society of Mechanical Engineers, New Orleans, DE-Vol. 66, 55-66, Nov. 28 - Dec. 3, 1993.

28. Colton, J.S., "Microstructure-Based Processing Parameters of Thermoplastic Composite Materials," Proceedings, 1994 NSF Design and Manufacturing Grantees Conference, Cambridge, 527-528, January 5-7, 1994.

29. Wagner, P. and Colton, J.S., "On-Line Consolidation of Thermoplastic Towpreg Composites in Filament Winding," Proceedings, 39th International SAMPE Symposium, Society for the Advancement of Material and Process Engineering, Anaheim, 1536-1545, April 11-14, 1994.

30. Colton, J.S., "Development of the Laboratory in Composites Manufacture and Testing: Filament Winding, Resin Transfer Molding, and Ultrasonic Non-Destructive Evaluation," Proceedings, ASEE Conference, American Society for Engineering Education, Edmonton, 535-539, June 26-28, 1994.

Patents:

1. "Non-woven Flexible Multiply Towpreg Fabric," 5,198,281, with J.D. Muzzy (March 30, 1993).

2. "Flexible Multiply Towpreg, Products Therefrom, and Methods of Production Therefor," Taiwanese Patent #211,542 with J.D. Muzzy and B. Varughese (1994).

3. "Flexible Multiply Towpreg Tape from Powder Fusion Coated Towpreg and Method for Production Thereof," 5,296,064, with J.D. Muzzy (March 22, 1994).

Theses:

PhD

1. Heechun Yang, "Modeling the Processing Science of Thermoplastic Composite Materials for Tow Prepregs," graduated Fall 1992.

2. Susan Carlson, "Component Selection Optimization using Genetic Algorithms," graduated Summer 1993.

3. Paul Lomangino, "Optimizing Component Placement during the Packaging of Mechanical Systems, anticipated graduation Winter 1995.

4. M. Patricia Brackin," Developing Feasible Design Specifications for Complex Systems," anticipated graduation Spring 1995.

MS

1. John Wade, "The Development of a Design for Manufacture Expert System," graduated Winter 1989.

2. John Dascanio, "The Development of an Integrated Intelligent Design Environment," graduated Summer 1989.

3. Raymond Pun, "A Decision Framework for Conceptual Engineering Design," graduated Spring 1990.

4. Garth Miller, "The Complementary Roles of Expert Systems and Database Management Systems in a Design for Manufacture Environment," graduated Winter 1990.

5. David Leach, "A Study of the Process Parameters in Thermoplastic Filament Winding, graduated Summer 1991.

6. Holly Perkins, "Air Knife Fiber Spreading in Composites Manufacturing," graduated Spring 1992.

7. Charles Carpenter, "On-Line Consolidation Mechanisms for Thermoplastic Composites," graduated Spring 1992.

8. Mark Ouellette, "Form Verification for the Conceptual Design of Complex Mechanical Systems," graduated Spring 1992.

9. Karen Shields, "Resin Transfer Molding with Powder-Coated Preforms," graduated Spring 1992.

10. Philip Wagner, "On-Line Consolidation of Thermoplastic Towpreg Composites in Thermoplastic Filament Winding," graduated Fall 1993.

11. Nikhil Nunes, "Insert Overmolding for Hand-held Applications, graduated Winter 1994.

12. Judd Staples, "Optimizing the Allocation of Resources during Preliminary Automobile Design," graduated Spring 1994.

13. Paul Vallis, "A Method of Information Management for Layout Design," graduated Summer 1994.

14. Amy Graham, "Manufacturing and Environmental Considerations in Conceptual Design," anticipated graduation Winter 1995.