Melissa Green, United Negro College Fund Special Programs Corp
Melissa C. Green, Ph.D. Acting Director, Division of Science and Technology Programs United Negro College Fund Special Programs Corporation (UNCFSP) 2750 Prosperity Avenue, Suite 600 Fairfax, VA 22031

Dr. Green currently serves as the Director of the Division of Science and Technology Programs at the UNCFSP. In this position, she provides expert leadership in areas of effective project and grant management, strategic resource development and capacity building. A former research scientist, she has effectively coordinated numerous workshops on graduate education for underrepresented STEM students. The Maryland native received her B.S. degree in Chemistry from Claflin College (Orangeburg, SC) and her Ph.D. in Biochemistry and Molecular Biology from the Indiana University School of Medicine (Indianapolis, IN). Prior to coming to UNCFSP, she acquired extensive knowledge and expertise in cancer biology, virology and reproductive medicine through her research appointments at Eli Lilly and Company, Kansas State University and Morehouse School of Medicine.

Maria Jackson Hittle, UNCF SP
Maria Jackson Hittle is an employee of the United Negro College Fund Special Programs (UNCFSP) Corporation. She has served as the Project Assistant for the NASA Administrator's Fellowship Program for the past 4 years. Ms. Jackson Hittle possesses an A.S. in Computer Aided Drafting and Design and a B.S. in Engineering Design Technology.

Gholam Ali Shaykhian, NASA
GHOLAM ALI SHAYKHIAN Gholam Ali Shaykhian is a software engineer with National Aeronautics and Space Administration (NASA), Kennedy Space Center (KSC), Shuttle Processing Directorate. He is NASA Administrator Fellow (Cohort 7). He served his fellowships at Bethune Cookman College (B-CC) in Daytona Beach, Florida, teaching and conducting research in computer science and software engineering. Ali has received a Master of Science (M.S.) degree in Computer Systems from University of Central Florida in 1985 and a second M.S. degree in Operations Research from the same university in 1997. His research interests include Object-Oriented methodologies and design patterns. He is currently teaching graduate courses in computer science and software engineering at Florida Institute of Technology (FIT) and teaches (as volunteer) an online course in software engineering for B-CC. Mr. Shaykhian is a senior member of Institute of Electrical and Electronics Engineering (IEEE) and is Vice-Chair (2005) and Education Chair (2003-2005) of IEEE Canaveral section.

Jianping Yue, Essex County College
Robert Singleterry, NASA
Victor Obot, Texas Southern University
Premkumar Saganti, Prairie View A&M University
Marc Mendez, Texas A&M University-Corpus Christi
Jack Esparza, Texas A&M University-Corpus Christi
Rafic Bachnak, Texas A&M University-Corpus Christi
Ken Fernandez, NASA
Pamela Denkins, NASA
Dr. Pamela Denkins is NASA Administrator Fellow (Cohort 4).
2006-306: A NAFP Research Project with the Participation of Community College Students

Jianping Yue, Essex County College

Jianping Yue is a Professor and Coordinator of the Manufacturing and Mechanical Engineering Technology program in the Division of Engineering Technologies and Computer Sciences at Essex County College, Newark, New Jersey. He is a NASA Administrator’s Fellow, and a Certified Senior Industrial Technologist by the National Association of Industrial Technology. Dr. Yue received his B.S. and M.S. degrees in Hydraulic and Coastal Engineering from Wuhan University, China in 1977 and 1982, and a Ph.D. degree in Civil Engineering from the University of Memphis, Tennessee in 1990.
A NAFP Research Project with the Participation of Community College Students

Abstract

The NASA Administrator’s Fellowship Program (NAFP) research grant is awarded to faculty fellows upon the completion of their one-year resident research at a NASA center. The award provided a unique research opportunity, which is rarely available for faculty and students at community college level, for the author to conduct a research project at a community college. With the support of the NAFP faculty research award, the author was able to not only continue the NASA related research on optimum machining parameters, but also get students involved in the research project. In this paper, the author presents the research project and experimental results. In addition, he shares his experiences of how to engage and supervise community college students in research as well as lessons learned from the process.

1. Introduction

Machining by metal cutting is one of the most popular manufacturing techniques. The U.S. spends over $100 billion annually on machining operations. High material removal rate (MMR) and surface quality are always the primary objectives of machining. Since the industrial revolution in the 19th century, continuous improvements have been made in machine tools and cutting tools. New materials and designs have significantly improved the hardness and life of cutting tools. High-speed machining centers can now operate at a spindle speed that is as high as half a million revolutions per minute (RPM). In order to utilize the power and capacity of these new machine tools and cutting tools, and to achieve potential high MMR and desired surface quality, the optimization of machining parameters is necessary.

As a faculty fellow in the NASA Administrator’s Fellowship Program (NAFP), the author did one year resident research at NASA Langley Research Center. The research topic, optimum machining parameters, was part of a long-term project at the center on “lights-out manufacturing,” where the objective is to achieve unattended automatic machining that will efficiently produce high precision one-of-a-kind aerodynamic models for wind tunnel experiments. NAFP faculty fellows also receive a research grant after coming back to their colleges and universities. The NAFP faculty research award enables the faculty fellows to continue NASA related research and strengthen the research and curriculum of minority-serving colleges and universities. With the support of the award, the author conducted an experimental research project on optimum machining parameters at Essex County College.

To encourage junior college students to go beyond classroom learning, the author sought the participation of interested students in the research. The concepts and theories of the research topic are included in curriculum and discussed in the related manufacturing and computer numerical control (CNC) courses. The student applicants are then selected from these classes. They worked as research assistants and received intensive training on how to follow the protocols of research, carrying out experiments on the CNC machines in the college’s manufacturing laboratory during the summer. They investigated machine chattering under
various spindle speeds, feed rates, and depths of cut. Through participating in research, students had a better understanding of the purpose of research, enhanced their knowledge of the research topic by the hands-on experiments, and increased their interests in manufacturing engineering technology. They reported that the research better prepared them for advanced level engineering education and inspired them to pursue a career in the field.

2. NAFP Program

In order to promote the success of minority students and faculty in Science, Technology, Engineering, and Mathematics (STEM) programs and ensure the diversity of its workforce, National Aeronautics and Space Administration (NASA) offers several special programs for minority institutions through the United Negro College Fund Special Programs Corporation (UNCFSP). These programs include the Jenkins Predoctoral Fellowship Program (JPFP), the NASA Administrator’s Fellowship Program (NAFP), the Curriculum Improvement Partnership Awards (CIPA), and the University Research Centers (URC). The minority institutions (MIs) include Historically Black Colleges and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), Tribal Colleges and Universities (TCUs), and other minority institutions (OMIs). Among the MIs, the enrollment of underrepresented minority groups (single or combined) must exceed 50% of the total student enrollment in OMIs, at least 25% student enrollment is Hispanic and 50% or more of the Hispanic students are low-income individuals for HSIs, and 50% or more of student enrollment is American Indians for TCUs. A list of minority institutions is published by the U. S. Department of Education.

The NASA Administrator’s Fellowship Program (NAFP) provides professional development opportunities for both NASA scientists and STEM faculty of minority institutions. Each year, the program awards up to six NASA scientists to teach or enhance curricula at minority institutions, and up to six STEM faculties to do one-year research at NASA centers. NASA compensates the faculty fellows’ salary and benefits through their home institutions. Since the inception of the program from 1997 to 2005, NAFP has awarded a total of 30 faculties (11 women) from 24 minority institutions (1 community college). The faculty fellows came from 22 HBCUs, 5 HSIs, and 3 OMIs, and they have done research at the NASA headquarters and 8 NASA research centers. There have been 40 NASA scientists (8 women) from 9 NASA research centers awarded the fellowship. They taught at 27 minority institutions, including 13 HBCUs, 10 HSIs, 3 TCUs, and 1 OMIs. A summary of NAFP fellows from NASA and minority institutions is listed in Table 1.
Table 1 NAFP Fellows from NASA and Minority Institutions

<table>
<thead>
<tr>
<th>Year</th>
<th>NASA Fellows</th>
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<tr>
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<tr>
<td>2005</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>30</td>
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</table>

3. NAFP Faculty Research Award

After NAFP faculty fellows complete their one year resident research at NASA centers, they have the opportunity to receive a NAFP faculty research award of at least $25,000 for another year to do research at their institutions. The award enables the faculty fellows to continue NASA related research, advance the research capability, and improve the STEM curricula at minority universities and colleges.

With the support of the NAFP research award, the author was able to not only conduct research at a community college, but also get students involved in the research project. The research topic, “optimum machining parameters,” has been included in the curriculum of the Manufacturing and Mechanical Engineering Technology Program, including the courses of MET 202 Modern Manufacturing Systems and Robotics and MET 225 Computer Numerical Control. Students learn the topic from lectures and through laboratory experiments.

4. Support to the NAFP Research Project

The NAFP research project received full support from UNCFSP and Essex County College.

4.1 Faculty development and students activities at Essex County College

A project cannot be successful without the support of the institution’s administrators. Essex County College has established a system for professional development through a Faculty Development Committee. The college administrators strongly encourage faculty development and closely advise the committee. The committee has organized various faculty development activities and provided opportunities for faculty to attend professional conferences, training workshops, and various seminars. For example, the committee organized several workshops to introduce NASA’s educational programs and research opportunities. It was Dr. Yamba, the President of the College, who sent faculty to attend the NAFP Awareness Workshop held at Delaware State University in January 2003, through which the author got to know about the NAFP program, applied for it, and became a NAFP Fellow in 2003.
Essex County College is an urban two-year community college with a student body of 53% African-American, 19% Hispanic-American, 12% Caucasian, and 3% Asian/Pacific [4]. Essex County College has a tradition to encourage, support, and provide opportunities for students, especially minority students, to participate in educational and community activities and achieve high academic expectations. The College’s student chapter of Phi Theta Kappa, the International Honor Society of the Two Year College, has actively recruited students and received many awards. Two of the past presidents of the chapter, Susan Stepney, an African American woman student, and Claudia Ordonez, a Hispanic woman student, have been named by the USA Today to the prestigious All-USA Community and Junior College Academic First Team in 2001 and 2005. Essex County College hosts many extracurricular programs to help the students including Mathematics, Engineering and Science Achievement (MESA), Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP), and Graduation Really Achieves Dreams (GRAD). The recruitment of students to participate in the NAFP research project also received strong support from the College.

4.2 Support to the NAFP research project

Mr. Gilbert Knowles, NAFP Program Manager at UNCFSP, visited Essex County College on October 6, 2004 to present the NAFP research award. Mr. Knowles met with the College President, Vice President, Dean of Faculty, Department Chair, faculty, and students during the visit. He also frequently kept in touch with the author to offer help and monitor the progress of the project during the 2004-2005 academic year.

The administrators at Essex County College provided their full support and resources for the NAFP research project. The President of the College assigned Professor Ladylease White, Dean of Faculty, as the Technical Monitor (TM) for the project. The author must submit a monthly report to the TM. Then the report, signed by both the author and TM, was submitted to the NAFP Manager as required.

The NAFP research activities have drawn media attention in the college community and statewide. Essex County College held an award ceremony when Mr. Gilbert Knowles, NAFP Program Manager at UNCFSP, visited the College on October 6, 2004 to present the award. The College’s E-Newsletter reported the event [5, 6]. The Star-Ledger, the largest newspaper in New Jersey, interviewed the author and featured an article on him and his research [7]. The Division of Engineering Technologies and Computer Sciences at Essex County College also reported the research activities and students participations in the Division’s newsletter [8, 9].

5. Participation of Community College Students in the NAFP Research Project

Participation of community college students in NASA related research is one of the major objectives of the NAFP research project. Two year community college students rarely have opportunities to participate in scientific research activities. The NAFP research project provided an opportunity for students’ participation.

Community college students made up a majority of U.S. college freshmen [10]. Many of them will continue their education at four-year universities and become future engineers and scientists.
NASA has recognized the importance of community college students and included them in NASA’s education pipeline. NASA’s mission is “to understand and protect our planet, to explore the universe and search for life, to inspire the next generation of explorers …as only NASA can.” We should inspire students at all levels of education to be interested in science, technology, engineering, and mathematics (STEM), so that they will carry on NASA’s mission in the future.

The research project was well planned and prepared. The recruitment of students focused on sophomores in the manufacturing and mechanical engineering technology program who have taken related courses with adequate knowledge of the topic and skills to operate CNC machines. The theory of machine chattering was developed in late 1950’s. But it has not been included in most manufacturing textbooks until recently. For example, the chatter theory and stability lobe diagram was not included in the popular textbook by DeGarmo et al. until its ninth edition in 2003. The author first added the topic in the manufacturing and mechanical engineering technology curriculum. The chatter theory was discussed in the MET 202 Modern Manufacturing Systems and Robotics course to provide students with theoretical knowledge. Then, in the MET 225 Computer Numerical Control course, students obtained hands-on experiences in programming and operating CNC milling and turning machines in laboratory. It has been emphasized that the stability lobe diagram can be applied to obtain optimum machining parameters, such as cutting speed, feed rate, and depth of cut. Students did a literature review and wrote a technical essay on machine chattering. They also designed and machined parts on the CNC machines in several projects, as well as handed-in lab reports and made presentations. These curriculum activities not only provided updated knowledge and necessary skills for all students in the major, but also helped them to develop interest in the topic so that some of them may want to learn more about the topic and take the opportunity to apply for the NAFP research project.

The research project was scheduled to take place during the summer of 2005. Many students showed interest in the project, but preference was given to the students majoring in manufacturing or mechanical engineering technology who had taken the related manufacturing and machining courses of MET 202 and MET 225. Because most of our engineering technology students have to work full-time, especially during summer, many of them were unable to participate even though they were interested. Finally, two students were selected. They worked together with the author intensively in the College’s manufacturing laboratory six hours a day from Monday to Thursday for three weeks. One student conducted experiments on a CNC milling machine, and another on CNC turning machines. With each cutting process consisting of a different set of cutting speed, feed rate, and depth of cut, a total of 202 sets of milling and 406 sets of turning process data were collected. Through the research project, the two students gained valuable experiences in fundamental research techniques, including the design of experiments, the selection of cutting tools and workpiece materials, and data collection and analysis. In his report, Cristian Alvarado wrote, “The most I like about the project is the hands-on experience that I am getting…In this research, I had the opportunity to work with the porLIGHT 3000 and spectraLIGHT 0400 turning machines [to] investigate the effects on the material when cut at different speeds with different feed rates…[Through] the research, I learned a great amount of knowledge in regards to how materials react to different [machining] environments, and different results that can be obtained when we use different speeds, feed rates
and depth of cut.” Carl Diaz wrote, “[through] this project, I have learned new things [such as] taking data and pictures in details to ensure the accuracy of our final statements. Doing this research project has greatly improved my studies in manufacturing engineering.” In addition, the students became more aware of the educational programs and opportunities available at NASA during the recruitment and application process and through the participation in the NAFP research project.

6. Preliminary Results of the Research

High material removal rate (MMR) and surface quality are primary objectives of machining operations. This research project investigated the improvement of material removal rate and surface quality through the use of optimum machining parameters and control of machine tool chatter. The machine chatter theory was developed by Tobias & Fishwick \cite{12} in late 1950’s. For half a century, the chatter theory has been improved and applied by many researchers including Tlusty & Smith \cite{14, 15, 16}, Merritt \cite{17}, Altintas & Budak \cite{18}, et al. The chatter theory creates a relationship between the critical chip width or depth of cut and spindle speed, and makes it possible to achieve the highest material removal rate.

6.1 Machine chatter theory

The governing equations of machine chattering can be derived from the general equation of vibration and the regenerative chatter theory as follows.

\[
\frac{b}{b_{\min}} = \frac{(1 - r^2)^2 + (2\zeta r)^2}{4\zeta(1 + \zeta)(1 - r^2)}
\]  

(1)

\[
\frac{f}{f_t} = n + 1 + \frac{1}{\pi} \tan^{-1} \frac{2\zeta r}{1 - r^2}
\]  

(2)

where

\(b\) = chip width or depth of cut
\(b_{\min}\) = the minimum chip width for chattering,
\(f\) = chatter frequency
\(f_t\) = cutting frequency or tooth-stroke frequency
\(n\) = the number of surface waves between subsequent cutter teeth (also called the lobe number. \(n = 0, 1, 2, \ldots\))
\(r\) = ratio of chatter frequency to natural frequency \((r = f / f_n)\)
\(\zeta\) = ratio of damping coefficient to critical damping coefficient \((\zeta = c / c_c)\)

From equations 1 and 2, we can create a theoretical stability lobe diagram, which shows the relationship between the dimensionless \(b / b_{\min}\) and \(f / f_t\), or between chip width \(b\) and spindle speed \(N\) (Figure 1).
The minimum chip width $b_{\text{min}}$ occurs when $r = \sqrt{1 + 2\zeta}$, which is independent of chatter frequency or spindle speed. In Figure 1, $b_{\text{min}}$ is the lowest point on each lobe and has the same value for all lobes. The constant of $b_{\text{min}}$ forms a horizontal lower borderline, below which the cutting process is unconditionally stable. An upper borderline can also be created by connecting the intersections of adjacent lobes, and it is unconditionally unstable above this line. In between the two boundary lines, chatter does not exist below the lobes and occurs above the lobes.

6.2 Discussions of the stability lobe diagram

Machining is a very complicated process. There are many parameters that contribute to the interactions of machine tool, cutting tool, and workpiece. Cutting force is a major factor in machine chattering. The force is determined primarily by three parameters, cutting speed, feed rate, and depth of cut, in the order of importance, among many machining parameters. In deriving the chatter equations, cutting speed and feed rate are indirectly considered by spindle speed and chip load. However, the final result as represented by the stability lobe diagram only shows the relationship between the depth of cut and spindle speed. Cutting speed is not only a function of spindle speed, but also depends on the cutter diameter for milling or workpiece diameter for turning. Could machine chatter relationship be directly represented by cutting speed rather than spindle speed? Furthermore, could feed rate be included as an explicit parameter in chatter equations or stability lobe diagram?

Tobias & Fishwick[^12] theoretically proved that at low spindle speed, chatter could not happen, the machining system is unconditionally stable, and the depth of cut could reach infinite. Practically, with enough machine power, is there a limit for depth of cut at low spindle speed? If there is a limit, what relationships exist?

Most chattering data in the literature were obtained from heavy and high-speed machines. This research project performed experiments on and collected data from tabletop and portable...
machines that are common in small machine shops and laboratories. It sought the answers to the questions of improved chatter equations and machine chattering at lower speeds.

6.3 Apparatus for the experiments

The experiments were conducted on three CNC machines in the College’s manufacturing laboratory. The machines are the spectraLIGHT 0400 Turning Center (Figure 2a), proLIGHT 3000 Turning Center (Figure 2b), and TMC-1000 Machining Center (Figure 2c) manufactured by Light Machines - a subsidiary of intelitek. The TMC-1000 Machining Center is a three-axis vertical CNC mill that has an industrial standard R8 spindle taper and a quick-change tool holder with a maximum spindle speed of 5,000 RPM. The maximum spindle speeds for the spectrLIGHT 0400 and proLIGHT 3000 are 2,500 RPM and 1,200 RPM respectively.

Figure 2a spectraLIGHT 0400 CNC turning center  Figure 2b proLIGHT 3000 CNC turning center  Figure 2c TMC-1000 CNC milling center

The cutting tools are high speed steel end mills with 0.125, 0.250, and 0.375 inches diameters for milling, and carbide tool bits and inserts for turning. The workpieces are 3 × 2 × 1.5 inches rectangular 6061 aluminum blocks for milling, and 0.75 and 1.00 inches diameter and 3 inches long 6061 aluminum rods for turning.

For milling operations, the workpieces were held in the vise in the position of 2 × 3 × 1.5 (x × y × z) inches. The cutter was fed into the workpiece in the positive x-axis at a preset spindle speed, feed rate, and depth of cut. Most runs were slot milling (the width of cut equals the cutter diameter) and conventional or up milling, where the width of cut equals half of the cutter diameter. Some climb or down millings were also performed for comparisons. Each run of the turning operations consisted of a straight turning of 0.50 inches in length with preset spindle speed, feed rate, and depth of cut. Since the overall length of the workpiece was only 3 inches, tail stock was not used. The workpieces and their machined surfaces for the milling and turning operations are shown in Figures 3a and 3b respectively.
6.4 Results and discussion

There were a total of 202 sets of milling runs and 406 sets of turning runs recorded. A thorough analysis of the data has not been completed. However, a preliminary analysis of the experimental results has shown some interesting findings, which need further investigation. Additional experiments have been planned to collect more data in the near future.

6.4.1 Experimental stability diagram

The experimental data collected from the TMC-1000 milling machine with a 0.375 inch diameter end mill cutter are plotted into a stability diagram as shown in Figure 4.

The stable, chattering, and transition zone are not clear with the limited data shown in Figure 4. However, the measured data already displayed the trend of the upper borderline, by connecting the border points, for the unconditionally unstable or chattering zone.
6.4.2 Chip melting

In a number of experimental runs on the milling processes, it was observed that chips were melted and stuck on the side walls of the cutting slots (Figure 5). Further investigation and analysis are necessary to explain the phenomenon.

![Figure 5 Chip melting in milling](image)

6.4.3 Depth of cut at low speed

In the turning experiments, the depth of cut or chip width reached 0.2 inches at a spindle speed as low as 600 RPM and feed rate of 1.0 ipm. The cutting process was a little rough but the surface was still relatively smooth without severe chattering. Figures 6a and 6b show this turning process and the finished surface. This seems to confirm Tobias & Fishwick’s [12] theory that a machining system tends to be unconditionally stable at very low cutting speed.

![Figure 6a A turning process](image)

![Figure 6b The finished surface](image)
7. Comments on the NAFP Research Project

Additional comments on the NAFP research project are as follows.

7.1 Encouraging community college students to participate in extra-curricula activities

Many students at Essex County College work while attending school. Some of them have full-time jobs, and others have their own family and children to support. At the same time, they also take a full-time course load of twelve or more credit hours per semester. Many have to go to work during the day, and come to school in the evening. This leaves practically no time for anything else.

In the process of recruitment for the research project, many students showed strong interest, but only a few were able to find time for it. For example, one student could only come on Friday evenings and on weekends. Four students were selected for the project, but only two of them finally managed their schedules to participate in the project.

Encouraging and recruiting community college students to participate in extra-curricula activities is a challenging task for faculty and staff. But because extra-curricula activities open the doors for students to succeed, we must continue to provide academic opportunities for minority students and stimulate their interests in science, technology, engineering, and mathematics. With hard work and opportunities, minority students will achieve their educational and career goals and excel in the future.

7.2 A unique research opportunity for community college faculty

Community college faculty usually have a heavy teaching load and teaching is their primary duty. For example, at Essex County College, a faculty member is required to have at least 15 contact hours of classroom and laboratory teaching, 1/3 of the contact hours as office hours for advising students, 1/5 of the contact hours as additional office hours by appointment for advisement and other duties. Two-year community colleges provide only fundamental curricula. The laboratory equipments are usually not suitable for research. Even though continuous professional development is also important for community college faculty, there is little time and resource for them to do research.

The NAFP faculty research award provides a unique research opportunity for community college faculty. This award has enabled the author to acquire necessary cutting tools and workpiece materials to carry out experiments in the laboratory at Essex County College, and continue the research he conducted at NASA Langley Research Center in the precious year.

7.3 Longer period for the research project

The NAFP faculty research award is for a one year period. It will make a better use of the research budget if the period of the research award could be extended for a longer period of time. It will provide more time for the faculty to analyze the experimental data, and prepare papers...
reporting the research results for publication in professional journals and for presentations at conferences.

8. Conclusion

The NASA Administrator’s Fellowship Program (NAFP) provides a unique opportunity for faculty at minority institutions and in the fields of science, technology, engineering, and mathematics (STEM) to participate in NASA related researches. This opportunity is especially valuable for the author as a two-year community college faculty with little time for research because of a heavy teaching load. The NAFP research award enabled the author to conduct an experimental research on optimum machining parameters at Essex County College (ECC). The project received strong supports from ECC, and recruited two students to participate as research assistants. The students were excited to have the opportunity to participate in NASA related research as community college students. They conducted intensive hands-on experiments by operating CNC machines to cut aluminum workpieces and investigating the effects of machining parameters including spindle speeds, feed rates, and depths of cut. Through the research project, the two students gained valuable experiences in fundamental research techniques, and further developed and strengthened their interest in manufacturing technology. The experimental investigations have revealed some interesting results. Further experiments and analyses are planned to carry on the research.

9. Acknowledgements

I would like to thank NASA for funding this research project through the NAFP Faculty Research Award. I also would like to thank UNCFSP and Essex County College, especially Mr. Gilbert Knowles, NAFP Program Manager, and Prof. Ladylease White, Dean of Faculty, for their supports to the project. Finally, I would like to thank Carl Diaz and Cristian Alvarado, students in the Manufacturing Engineering Technology Program at Essex County College, for their participation in the research project and their assistants in conducting the experiments.

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