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Final Technical Report

NASA/OAI RESEARCH ASSOCIATES PROGRAM

NASA Cooperative Agreement
NCC3-169

March 19, 1990 to December 31,1992

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NASA/OAI Research Associates Program

NCC3-169

Summary

The intent of this activity was the development of a cooperative program between the Ohio Aerospace Institute and the NASA Lewis Research Center with the objective of better preparing recent university graduates for careers in government aerospace research laboratories. The selected individuals were given the title of Research Associates.

To accomplish the aims of this effort: (1) the research associates were introduced the NASA Lewis Research Center and its mission/programs, (2) the research associates directly participated in NASA R&D programs, and (3) the research associates were given continuing educational opportunities in specialized areas

A number of individuals participated in this project during the discourse of this cooperative agreement. Attached are the research summaries of eight of the Research Associates. These reports give a very good picture of the research activities that were conducted by the associates.

NASA-OAI COLLABORATIVE AEROSPACE RESARCH ASSOCIATES PROGRAM: FINAL REPORT

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September 1992

INTRODUCTION

The purpose of this report is to outline the author's accomplishments during a tenure as a research associate participating in the NASA-OAI Collaborative Aerospace Research Program. This participation contributed to the research efforts of the Advanced Controls Technology Branch of the Instrumentation and Controls Division at the NASA Lewis Research Center. The Advanced Controls Technology Branch develops and implements advanced controls concepts for various applications. Presently, the branch is involved with developing control systems for advanced systems such as High Altitude Aircraft, Short Take-off and Vertical Landing (STOVL) aircraft and the Space Shuttle Main Engine (SSME). The author's main focus has been participation in this last project, the development of an intelligent control system (ICS) for the SSME. Specifically, the implementation of a simulation testbed used to demonstrate the feasibility of the ICS concept. Other work included the setup and system administration of a Sun workstation, the testing and evaluation of a reflective shared memory fiber-optic network system as well as contributing to papers and presentations.

INTELLIGENT CONTROL SYSTEM

The Intelligent Control System (ICS) is under development in the Advanced Controls Technology Branch with the objective of improving the operation and durabililty of the reusable Space Shuttle Main Engine. The ICS is composed of various subsystems such as model-based failure detection, rule-based or expert system fault detection, sensor validation and diagnostics, all working in conjunction with a reconfigurable controller. To demonstrate the validity of the ICS concept, a simulation testbed has been assembled. This testbed will provide an environment for researching and developing the various functionalities of the ICS. Because of the diverse nature of these components a distributed architecture was chosen for the testbed consisting of specialized hardware and software.

A large part of the author's work has been his involvement in the implementation and validation of the ICS simulation testbed. The type of work involved was diverse and included hardware integration and testing, software development, neural network implementation and controls simulation and data collection. The following is a description of the author's contributions to the ICS testbed.

Controls Computer

The controls computer is referred to as the Control, Interface and Monitoring (CIM) Unit and was fabricated in-house at NASA Lewis Research Center. The CIM Unit is used to implement and evaluate digital control designs in closed-loop with an external plant. This external plant may either be a simulation or actual hardware. This flexibility is made possible due to the fact that the components of the CIM Unit were built into a portable test rack and all I/O is achieved through analog interface hardware.

The components of the CIM Unit consists of an 80486 microprocessor board running the Intel iRMX real-time operating system. The capabilities offered by this operating system are necessary for the successful scheduling in real-time of the control algorithm, the fault detection algorithm, the I/O routines and the data collection utilities. The CIM Unit's interface hardware consists of analog I/O boards that can be patched to external cables. This allows the controls computer to send command outputs to and receive feedback signals from either a plant simulation or actual hardware. Also, the CIM Unit is equipped with front panel indicator lights and input switches that can be programmed to show controller status and to send operator input to the controller. In addition, the CIM Unit is equipped with a monitoring system that allows the transient collection of data during simulation runs.

Integration of the CIM Unit into the ICS testbed involved implementing and testing various communication channels to the other computers in this distributed environment. The CIM Unit's base connectors were attached to trunk lines running from the AD100 simulation computer which will be executing the SSME engine simulation. The engine simulation will provide sensor feedback to the controller via analog signals generated by D/A hardware. Similiarly, the controller will be sending command signals to the engine simulation through these cables. Other I/O hardware installed onto the CIM Unit includes a DR11 digital interface for communication to the diagnostic computer and an ethernet link for communication to the user interface computer.

Software developed for the CIM Unit include the Multivariable Reconfigurable controller and the Model-Based Failure Detection (MBFD) algorithm. The control design is first developed and tested on a development system using MatrixX. Once this design has been varified, it is converted into a FORTRAN program using Autocode. This piece of code was then transferred to the CIM Unit, compiled and executed. Also, additional code was included to implement the logic for initiating failure modes on the AD100 engine simulation through front panel buttons on the CIM Unit.

The Model Based Failure Detection algorithm was originally written to be a standalone program. Some modifications were required to convert the code for execution on the CIM Unit in conjunction with the ICS controller code. Required modifications included adding code for I/O with the controller code and the MINDS data collection utility, resolving variable conflicts between the controller code and the MBFD code, and changing the initialization logic of the MBFD procedures to match the logic used by the executive on the CIM unit. Once all the modifications were performed and the remaining bugs were corrected, execution of the code revealed that the algorithm functioned incorrectly. Running the algorithm with the controller in closed-loop with the AD100 engine yielded invalid results. The algorithm was not able to consistently detect a valve failure during a down-thrust transient. After some examination of the code, some parameter values used by the algorithm were adjusted. These modifications were implemented and the results were much improved. The algorithm was successful in the detection of valve failures.

PC Neural Network Implementation System

The sensor validation functionality of the ICS system is realized through a neural network design. In order to incorporate this component into the testbed, a hardware neural net capability was developed in the form of the PC neural network implementation system. This system is composed of specialized hardware to provide the necessary computational power to "implement" neural network designs and the I/O links to provide communication to the other components of the testbed. In addition, software was developed to schedule the operation of the various hardware components.

The hardware consists of an 80286 AT/PC cabled to a separate expansion chassis which essentially extends the PC bus and provides additional expansion slots. This chassis connection was necessary, because of the large number of peripheral boards required. Installed onto this setup is an ANZA Plus neural processor board from Hecht-Nielson Corporation. It should be noted that this board does not actually contain true neural network devices; such neural net hardware is just now beginning to appear on the market and does not yet possess the necessary sophistication. Rather, the ANZA Plus is an accelerator board which utilizes the Intel i860 reduced instruction set computing (RISC) processor chip. This processor has the ability to multiply and accumulate in a single cycle, thus allowing it to speed up interconnect calculations and other neural computations. System communication was provided by installing appropriate I/O hardware. Installed were two DASH-16 A/D convertor boards to provide external inputs to the Anza board and two DDA-06 D/A convertor boards to allow outside access to the neural net outputs. This hardware provides the system with an I/O capability consisting of 16 inputs and 12 analog outputs. Since the system interface consists of analog signals, the neural network implementation has the appearance of a true analog neural net to the other components of the testbed.

The software developed for the PC neural network implementation system consists of a main executive program, which schedules the operation of the Anza neural processor and the I/O boards, as well as various procedures grouped into functional modules. This main executive performs the required declarations and definitions and initializes the hardware. It then schedules the conversion of analog signals into neural net inputs, the iteration of network computations on the Anza board, the conversion of computed net outputs into analog signals and the updating of the display screen. These operations are performed by the executive through procedure calls.

These procedures are grouped by function into the following modules: I/O procedures, neural net procedures, display procedures and timing procedures. The I/O routines provide an interface to the A/D and D/A boards. They initialize conversions, access control and data registers on the boards and perform the appropriate scaling of input and output data. The display routines initialize the screen and provide continual display updates of the network input and output states in the form of a plotted graph. The timing routines provide a means of measuring the cycle update times for benchmarking purposes, even though the system is configured to execute as fast as possible and is not sychronized to any other components of the testbed. The neural network procedures are used to

initialize the Anza board, initialize a network structure, load pre-trained weights, put input data into the board, initiate net iterations and get computed states from the board. It should be mentioned that these procedures interface with the Anza processor board via the HNC User Interface Subroutine Library (UISL) which is a set of commands used to control processor operations.

As previously mentioned, the neural network implementation system was developed to implement the sensor validation component of the ICS. The next step was then to program the neural net design onto this system via a C language programs. In order to implement the neural network, the C code had to specify the network structure and paradigm. Once this was accomplished, predefined weights associated with all neural interconnections were loaded. These existing weights were obtained previously by training a software simulation of the sensor validation network. In addition to the neural net, the sensor validation requires some additional logic to detect any sensor failures and disconnect the corresponding input to the net. This logic is handled in software by the C program. Once the code loads the network structure and weights onto the Anza board, it then controls the network cycling as well as provide input data to the network and access output data from the network. These network outputs can then be sent externally as analog signals through the D/A convertor boards once they have been appropriately scaled. In addition, the output data is used by display routines to plot the output signals to the screen. The code written to program the Anza board was designed in a modular fashion. This consideration facilitates the addition of other neural networks into the system.

It was determined that additional communication was required between the Neural Net PC and the Controls Computer. Data about the sensor states needed to be relayed to the the controller and is used to provide indicators for sensor failures as determined by the neural net. To achieve this I/O a digital link was implemented. This link involved some hardware design and low-level programming to connect the parallel ports between the PC and the processor board on the CIM Unit via a flat parallel cable. The operation of the link has been verified.

Extended Kalman Filter

An additional project in which the author participated, involved work with a summer researcher. The researcher was working on a joint investigation between NASA Lewis and the University of Cincinatti into an implementation of nonlinear parameter estimation for the Space Shuttle Main Engine. The work involved implementing an existing extended Kalman filter algorithm onto the ICS simulation testbed. The algorithm program was converted to execute on the CIM Unit so that the Unit's analog I/O capability could be used to interface the Extended Kalman filter with the engine simulation running on the AD100. This involved setting up an executive and utility programs to interface with the Kalman filter and to modify CIM unit I/O routines to provide the correct analog inputs.

It turned out that the Kalman filter code required a great deal of time to execute due to its utilization of a variable time-step numerical integration scheme and a great deal

of matrix computation. As a result, the executive needed to be slowed down. However, the executive program updated on a hardware interrupt tied to a timer on the processor board, which limited the maximum length of the update interval. This limitation was circumvented by setting up a counter which counts up to a specified number of interrupts then triggers a lower level interrupt which in turn initiates the algorithm, effectively yielding a long update interval.

Executions of the algorithm operating in conjunction with the engine simulation were made to gather data. The CIM Units data collection capability was very useful in this regard. The results obtained allowed the research team to gain insight into the feasibility of real-time implemention of this algorithm in future work.

SCRAMNET

SCRAMNet is a shared-memory fiber-optic networking system that is being considered for purchase by the Advanced Controls Technology Branch. The author was a member of an evaluation team which installed and tested several boards loaned by the manufacturer. Three boards were installed onto separate computer chassis and connected by fiber-optic cables. These boards were used to evaluate the feasibility and effectiveness of a multiprocessing approach to computationally intensive simulations. Timing studies were performed on partitioned and unpartitioned versions of an engine simulation and the results compared to determine the relative performance increase.

SUN WORKSTATION

To provide the branch with additional computational and analytical capability, a Sun SPARCStation 4/330 workstation was purchased. The author was given the task of setting up the workstation, installing the operating system, connecting to the Lewis labwide network (DESNET) and serving as system administrator. An advantage to connecting to the network is that the workstation will have access to the Epoch fileserver which contains a great deal of software licensed to Lewis. In addition, it allows the workstation access to other computers for remote connection, file transfer and electronic mail.

PUBLICATIONS AND PRESENTATIONS

Since NASA is a research organization, publications and presentations are important avenues for disseminating research results. Additionally, it is important to stay abreast of the latest technology through further training. The author's efforts in this regard are outlined below.

a.   Co-authored a paper presented at the Advanced Earth To Orbit Conference (ETOC) in May. The paper presents the implementation of the simulation testbed for the Intelligent Control System.

b.   A demonstration of the PC neural network system was prepared and presented to a group of visitors from Allen-Bradley on April 28, 1992.

c.   Attended the Advanced Earth-To-Orbit Conference held at NASA Marshall Flight Center on May 20, 1992.

d.   Member of a review committee to review a paper authored by colleagues in the Advanced Controls Technology Branch entitled "Implementation of a Model Based Failure Detection and Diagnosis Technique for Actuation Faults of the SSME."

e.   A progress demonstration of the ICS testbed given to the Division Chief. The demonstration consisted of running the controller (on the CIM unit) in closed-loop with the engine simulation (on the AD100). It was shown that when an engine fault was initiated, the Model-Based Failure Detector could detect a failure and inform the controller, which in turn was able to successfully identify and accommodate the failure in its control of the engine.

f.   Attended a training course on system administration of the Sun Workstation offered by Sun Microsystems. The course presented the concepts and procedures required for administering a network of Sun workstations. The topics discussed included disk partitioning and formatting, software installation, kernel configuration, maintaining user accounts, maintaining and backing up the file system, maintaining system security, hardware configuration and maintaining a network. In addition to lectures, the course offered hands-on lab sessions which reinforced the lecture material.

g.   Attended a training course on neural network applications offered by Hecht-Nielson Corporation (HNC). The course provided some basic theory on neural network architecture, most notably, multi-layer back propagation. A rather general procedure to solving problems utilizing neural networks was presented along with some rule-of-thumb hints that HNC has developed. Several application example problems were presented and their neural net solutions were discussed. In addition, some hands-on experience was provided in building and running a neural net simulation utilizing Explorenet 3000, the company's neural network development environment. Also, the company's user interface software was discussed.

CONCLUSION

Presently, the ICS testbed has nearly reached it's final configuration. However, work has already begun on the testing and validation of the various control and diagnostic capabilities of the Intelligent Control System. The development and refinement of these capabilities will continue to prove challenging. The PC Neural Network Implementation

System is fully integrated with the ICS testbed and has been successfully verified. This work performed during the author's tenure as an OAI research associate in the Advanced Controls Technology Branch has been both interesting and challenging. The author hopes to have made an important contribution to the research efforts of NASA Lewis.

Biographical Information

Name: EDMOND WONG

Title: Research Engineer

Work: Advanced Controls Technology Branch (Org. 2550)   8/91 - Present

NASA Lewis Research Center
21000 Brookpark Road, Mail Stop 77-1
Cleveland, Ohio 44135

Education: Bachelors of Science (B.S.) in Electrical Engineering
Case Western Reserve University   1988

Masters of Science (M.S.) in Electrical Engineering
Case Western Reserve University   1992

Interests: Include controls design and implementation, real-time systems, neural networks and microprocessors.

Current Activities: Include the implementation of an Intelligent Control System for the Space Shuttle Main Engine (SSME) and the testing and validation of advanced controls designs. Current work also includes the implementation of systems for real-time neural network development.

9/92

FINAL REPORT
ON
RESEARCH ASSOCIATE TENURE

Prepared for the Ohio Aerospace Institute

by

Hal F. Weaver
Research Associate

September 15, 1992

INTRODUCTION

In the following informal report I will give a brief description of my job at Lewis Research Center and then the highlights of the projects and work I have done over the last 14 months while with OAI.

JOB OVERVIEW

My area of work at Lewis Research Center has been with the Engine Components Branch of the Aeropropulsion Facilities and Experiments Division. The basic function of the Engine Components Branch is the mechanical support of research projects being conducted in advanced gas turbine engine components: turbomachinery (compressors and turbines) and combustors.

More specifically, the branch operates in the following manner. After a research project has been decided upon, the research branch supporting that project will present a research requirements document to division and branch management. This document defines the specific conditions necessary to complete the research project. After all has been defined the project is then assigned to specific Operations Engineer(s) within the Engine Components Branch. It is then the responsibility of the Operations Engineer to have the mechanical components fabricated and/or procured, coordinate the assembly and supervise the checkout of the new rig, and, once the rig is operational,

troubleshoot any problems which arise with the rig and execute the continual modifications requested by the researchers.

A wide array of skills is necessary to be a successful Operations Engineer, among these are exceptional interpersonal skills, mechanical aptitude, organizational ability, and good old common sense.

WORK PROJECTS

I will now give a brief description of the main projects in which I have been involved during my 14 month tenure with OAI.

Large Low Speed Centrifugal Compressor

Begun in approximately 1982, the Large Low Speed Centrifugal Compressor (LSCC) was a scaled up version of a typical centrifugal compressor. The purpose of the research conducted was to verify the CFD modelling of the internal flows within such a machine. Hence the reason to scale up. In order to measure flow characteristics, flow passages had to be large enough to allow internal installation of instrumentation and access for laser anemometry.

We successfully mapped the flow field throughout the compressor and the results of the work were presented at the ASME International Gas Turbine Conference in Cologne in June 1992.

Obviously, I only became involved during the latter stages

of this project. I assisted one of the senior engineers with the management of this project. As an ongoing program, some of the responsibilities of an operations engineer were already completed, hardware design for example. However, troubleshooting was necessary on occasion, as well as a few small design modifications. For example, late in the program the shaft which opened and closed our throttle valve broke. I was part of the team which analyzed the causes for the break, came up with a temporary solution to complete the project on time, and recommended a permanent solution.

Piping Rework

In October 1991, it was decided by research that the old piping supplying pressurized air to the High Reynolds Number Heat Transfer Wind Tunnel in the Engine Research Building (ERB) was too small to obtain the flowrate necessary to obtain the research goal of this program.

Again, I assisted one of the senior engineers, with a much more prominent role, with the design, procurement, installation, and checkout of the new piping system.

This was a challenging project for me because it required a lot of learning on my part since I knew very little about piping and its associated standards, fittings, welding, NASA safety regulations, etc. (i.e. a lot of practical knowledge which they don't teach in a classroom).

Segments of the project which I completed myself included procurement of most of the piping components, design of the valve control system and procurement of the associated components, and writing the valve control procedures for the High Reynolds Number Wind Tunnel.

High Reynolds Number Heat Transfer Wind Tunnel

The High Reynolds Number Heat Transfer Wind Tunnel is a small (18" dia.) wind tunnel with a scaled up single airfoil contained in the test section. The purpose of the project is to gather heat transfer data from an airfoil at Reynolds number regimes not previously studied, up to 7 million. The data will then be used to develop CFD/heat transfer codes to aid in designing superior blades for the Space Shuttle Main Engine turbopumps, which have had to be replaced more often than originally thought.

I was given primary responsibility for this rig as the lead operations engineer (as much as was possible while I was a contractor) in January 1992. As such, I was responsible for the build-up, checkout, and operation of the tunnel. There was an August 28 deadline to complete the desired research. I am happy to report that we were successful in meeting this deadline (with much credit due to the other people involved with the project as well), despite an obstacle or two along the way. For example, the test section of the tunnel is covered by a 1-1/4" thick plexiglass window. We accidentally cracked our window upon installa-

tion. With no backup on hand we had only a few weeks to have a
new window manufactured off-site and certified safe via pressure
test. This was the most pressure I have endured while at Lewis.

Large Low Speed Axial Compressor

The Large Low Speed Axial Compressor (LSAC) is the companion
rig to the LSCC. After the LSCC program was completed in December
1991, the centrifugal compressor was removed and a 4 stage axial
compressor was installed in its place. Most components were not
changed (drive motor, piping, etc.) enabling a quick turn-around.
I was only superficially involved in the installation of the
axial compressor. The research goals of the axial are parallel to
those of the centrifugal, measurement of the flow field and flow
phenomena in the compressor for CFD code verification/ improve-
ment.

There are several specialists in rotating hardware within
our branch who handled the installation phase of the project.
However, starting with checkout in July 1992, I have been once
again involved with the facility. My role is similar to when I
was with the LSCC program, however, I have taken an increased
role in coordination between all participants in the program:
research, trades, and engineering. which has challenged my
interpersonal skills. Starting in September 1992, I have been
given the lead operations engineer role for this facility as
well. Currently I am working on several modifications to the

compressor: adding diffuser vanes to the collector and changes to the laser seeder system.

SUMMARY

In the preceding informal report I have given a brief description of my job at Lewis Research Center and the highlights of the projects and work I have done over the last 14 months while with OAI. I hope this has given a sufficient overview of my work. However, if more details are desired or any questions are raised, please contact me. I can be reached at Lewis Research Center MS 6-9 or (216) 433-8869.

On a concluding note I would like to take this opportunity to thank all the people at OAI who facilitated this transition period in my working career and helping me whenever I had a question or problem.

MEMO FOR RECORD

TO: Dr. T Keith
           Ms Sylvia Thompson

FROM: Carol M. Tolbert

DATE: October 8, 1992

SUBJECT: Work Description Overview

        As an OAI employee for one year I was assigned to NASA Lewis as a member
of the Solar Dynamics and Thermal Systems Branch. More specifically I worked
on the 2kWe Solar Dynamic Ground Test Demonstration Project (SD GTD).
Initially my role on the program was to help write the statement of work,
organize a team of participants to evaluate the proposals and work closely
with procurement to meet important procurement timelines for a streamlined
procurement approach. The streamlined procurement approach was successful and
the NASA participants will receive monetary recognition. As a contractor I
could not participate in the contractual evaluation of the proposals nor the
contract negotiations therefore, I do not qualify for the award.

        Another aspect of the SD GTD project included investigating a solar
simulator to provide simulated sunlight for the SD GTD.   I initiated the
solar simulator effort with a study to determine what types of simulators were
commercially available and whether they could meet the requirements of the SD
GTD.   The study was accomplished by Arnold Engineering Development Center,
(Calspan), Tullahoma, TN. As a result of the study we learned that commer-
cially available solar simulators could meet our project requirements but how
much would it really cost. I requested and funded a follow-on study to
provide NASA with a detailed Project Plan on the most appropriate solar
simulator for the ground test demonstration. At this point the solar simula-
tor was passed to the Engineering Directorate to manage and I became deputy
project manager for the SD GTD project.

        To provide you with a more detailed technical description of the 2kWe SD
GTD I have included a copy of the Research and Technology article I recently
wrote to be published in the NASA annual report. See attachment 1.

1992 R&T Article

ORG. CODE: 5490

TITLE: 2kWe Solar Dynamic Ground Test Demonstration Program

LEWIS CONTACT : Richard K. Shaltens (6138)/Carol M. Tolbert (6167)

HEADQUARTERS PROGRAM OFFICE: OAST - Platform Power & Thermal Systems

PERSON WHO WROTE ARTICLE: Carol M. Tolbert (6167)

FIGURE IDENTIFICATION: C-92-07348

TEXT OF ARTICLE (738 WORDS):

The development of Solar Dynamic (SD) power technologies for
space use has been underway for more than 25 years by NASA and other organiza
tions. Although these technologies have been around for many years, it
has never flown in space. Extensive studies have shown that SD technology has
the potential to become a power source for space which supports the selection
of this technology for ground system testing. This development has brought
SD power components/subsystems to a point where it is considered a leading
candidate power source. Selection of the SD power system is based on
studies and analyses which indicate significant savings in life cycle costs,
launch mass and Extra Vehicular Activity (EVA) requirements when compared with
the existing, more conventional photovoltaic/battery power system.

Any new or untested system proposed for space application raises issues
as to the performance of major SD components when used in an integrated power
system context. Addressing and resolving these issues can only be accom
plished in a system test of sufficient scale and fidelity to warrant confi
dence in the availability of this technology. For this reason on April 1,
1992 NASA Lewis awarded a 42 month, $18 million dollar contract to an aero
space contractor team lead by Allied-Signal Aerospace Company from Phoenix,

Arizona. The aerospace contractor team will design, develop and fabricate system components for a 2kWe SD System to be tested in a ground space facility with simulated solar energy at NASA Lewis.

Led by Allied-Signal, the contractor team includes Harris Corp. Elec tronic Systems Sector, Government Aerospace Systems Division, Melbourne, Fla., for the solar concentrator; Allied-Signal Aerospace Company, Airesearch Los Angeles Division, Torrance, Calif., for the heat receiver and gas cooler; Allied-Signal Aerospace Company, Garrett Fluid Systems Division, Tempe, Ariz., for the turbine/alternator/compressor assembly; Loral Vought Systems Corp., Dallas, Texas, for the radiator, while Rockwell International Corp., Rocketdyne Division, Canoga Park, Calif., is responsible for system integra tion. Work began April 1, 1992, at the prime contractor's plant in Tempe, Ariz.

Solar dynamic systems focus the sun's light into a chamber, heating a fluid that powers a turbine-alternator combination that produces electricity. The fluid is then cooled by a radiator that rejects waste heat to space. The major benefit of solar dynamic systems in space is their high efficiency about twice that of today's solar cell power systems. This lets them be more compact, which decreases atmospheric drag.

SOLAR DYNAMIC POWER SYSTEM CHARACTERISTICS

The basic features of a typical solar dynamic power system using a Closed Brayton Cycle (CBC) conversion include heat supplied to the system by means of a reflecting concentrator which focusses incident solar energy into a cavity-type heat receiver. The receiver includes heat exchanging tubes for transfer of thermal energy to the gaseous working fluid of the CBC heat engine. It also includes capsules containing a fluoride salt mixture sur

rounding the tubes. During the sunlit portion of an earth orbit, sufficient thermal energy is stored within these thermal energy storage (TES) capsules to maintain constant power out of the CBC alternator through the eclipse portion of the orbit. The heated gas is expanded through the CBC turbine, which converts thermal energy to mechanical energy by driving the CBC gas compressor and alternator. The alternator in turn converts mechanical energy into electrical energy which is distributed to the ultimate user. Excess electrical power is radiated to space by a parasitic load radiator. In order to maximize CBC efficiency , most of the thermal energy remaining in the gas exiting the turbine is recovered by a recuperator and used to preheat the gas entering the heat receiver. Thermal energy that cannot be recovered is radiated to space by means of a heat rejection system.

GROUND TEST DEMONSTRATION

This SD ground test demonstration program is based upon using existing CBC and concentrator components from previous programs. This approach maximizes program efficiency by minimizing component design, fabrication and development effort. NASA, with active participation from the contractor will conduct the major subsystem and integrated system tests at LeRC. The com completely assembled SD system will be installed in and tested in the NASA LeRC Tank 6 Space Vacuum Facility with simulated solar energy in FY 95.

A Summary of Work Done Under Tenure
With The Ohio Aerospace Institute

February 10 - September 11, 1992

prepared by
Andy Provenza
Aerospace Engineer
NASA Lewis Research Center
September 22, 1992

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<u>Summer SHARP Program Participation</u>

Part of my tenure with OAI was spent in the SHARP program as a mentor for a high school student. For eight weeks my student Santino Westfield from the Cleveland school of science and I worked on a project to assist the magnetic bearing research in the structural dynamics branch.

<u>Background</u>

One of the magnetic bearing topics which is being researched here at Lewis is the adaptability of magnetic bearings to rotating systems which function in a cryogenic environment. One vital application would be a liquid hydrogen turbopump not unlike the one used in the space shuttle propulsion system. The magnetic bearing being tested at Lewis for low temperature applications currently uses a permanent magnet ring to provide a constant magnetic flux (force) which levitates (centers) the shaft and linearizes the control. New nonlinear control techniques require this bias to be changeable, so the permanent magnet ring must be replace by an electromagnetic coil. An electromagnetic coil produces magnetic force potential with applied current whereas a permanent magnetic produces potential through its permanent magnetization.

<u>Description</u>

The official title for the project was "Evaluation of an electromagnetic bias coil for use in a cryogenic magnetic bearing." Replacing the permanent magnet with an electromagnet required testing of the coil's thermal characteristics. Will the coil reach a steady-state temperature for the required current inputs, and how long will it take to reach one? These are two questions that needed answering. The coil used in the testing, shown in figure [1], had a total of 532 windings on it. These windings of copper wire carried current, and the flow of this current through the wire creates a magnetic field. It also creates heat; and lots of it.
The experiments involved sending constant direct-current (DC) amperages into the coil while measuring the coil's resistance until a steady state resistance was reached. The temperature of the coil, which was our main concern, was directly calculated from the resistance using a well know conversion formula.

<u>Results</u>

One requirement of the electromagnetic coil was that it produce 1000 Ampere-Turns of magnetic flux. To achieve this amount, approximately 2 amps was required. During the tests, it was discovered that at any current over 1.5 amps, the coil would not reach an equilibrium temperature within a time span of 6 hours. Tests at 2.5 amps showed the coil's temperature rising dangerously close to the wire insulation curing temperature after 4 hours of constant applied current. This was a serious problem that led to the following recommendations:

1. Use square wire to increase the efficiency in coil channel space utilization.
2. Pot the coil with epoxy or some other adhesive to improve the heat conduction inside the coil.

3. Possibly use forced air convection to cool the outer coil surface.

Following up on the third recommendation, a test of the coil at 2 amps with and without forced air convection was done. The results are shown graphically in figure [2]. The forced convection significantly reduced the time it took the coil to approach steady-state, and the coil actually reached a steady state of 48.7 C after just 64 minutes. In most electrical machines or devices which require significant power input, you will find some type of forced convection system. It may be required for the magnetic bearing system to be redesigned to accommodate a small fan. It should be noted here that the bearing is being designed for a cryogenic application and would not require a fan, but a majority of the testing is currently done at room temperature where heat dissipation is more of a concern. The other two recommendations are currently being studied.

Wind Tunnel Testing of F39 Forward-Swept Counter-Rotating Unducted Fan Blades

The analytical and experimental aeroelastic analysis of rotating bladed systems is a major area of research in the structural dynamics branch. I was given the opportunity to gain experience in wind tunnel testing by assisting in the tests of a new counter-rotating fan system.

Background

In a counter-rotating fan system, there are two separated rows of propfan blades which spin in opposite directions. The front and back sets have traditionally been backward swept blades. The noise developed in the interaction of the blades sets with airflow is at present, unacceptably large. One way to possibly reduce the noise is to increase the distance between the tips of the fore and aft blade rows by replacing the leading backward swept blades with new forward swept blades.

Description

Our roll in these test was not to measure the sound being emitted by the system (that was someone elses job), but to monitor the deflections of the blades. If the blades were to flutter in the test operating regime, they would inevitably fail. General Electric fabricated these blades and predicted they would not flutter for the test rotational speeds.

My responsibilities were the following:

1. Assist Orel Mehmed in recording real-time strain amplitude measurements of the fan system at various rotational speeds and take notes on the characteristics of each test.

2. Input laser-measured blade displacement data into Xgraph running on a local Concurrent computer in the wind tunnel control room and then send the plots to the scivax so they could then be sent to a Talaris printer near by for pick up and immediate analysis. These plots typically determined the estimated rotational speed limit of the fan blades for the current test.

3. At times, make critical decisions as to whether or not the rotational speed of the blades

could be increased based on the real-time blade deflection amplitudes.

Results

To the contrary of GE's predictions, the blades fluttered before the operational rpm was reached. The flutter speed was never actually reached or passed, but approached - very carefully. A vast amount of valuable flutter data was as a result acquired and will be used to verify the flutter predictions made by our in-house flutter prediction codes. The blades were modified once by clipping their tips here at Lewis, and then eventually redesigned by GE and tested again. I did not participate in the tests of the redesigned blades, but understand that they too began to flutter.

Magnetic Bearings 101

I decided to include a section in this paper on some of the activities I partook in over the past seven months in learning about magnetic suspension technology. The reason for including the following information is that a large percentage of my time had been spent acquiring information from papers and books on magnets and electromagnetism, attending meetings with magnetic bearing investigators, and attending a conference and short course on magnetic bearings.

Industrial leaders in magnetic suspension such as Honeywell and Avcon have visited us to discuss their research in the area, to look at what we are doing, and to discuss future endeavors. I had the opportunity to attend these day long sessions and gain invaluable knowledge on what is being done in the field and what needs to be done. It also gave me an opportunity to personally meet the people who work in the field.

On a much larger scale, I attended the 3rd International Symposion on Magnetic Bearings in Alexandria Virginia. There I attended a one day short course on magnetic bearings and three days of technical presentations and discussions. As with the small meetings with industry at Lewis I gained immeasurable experience. I met a lot of key people in the field from all over the globe.

Assessment of Force vs. Gap and Current in a Magnetic Actuator

Background

The project I did most of my technical work to date in was the assessment of how force changes with gap and current in a single pole magnetic actuator. The limited force producing capabilities of magnetized ferrous metals and the force requirements of magnetic actuators has led to the need for operating magnetic actuators in their saturation regimes. This is quite challenging since the saturation regions of magnetic materials are nonlinear as is visible on any real B-H curve. Local saturation and fringing of magnetic flux are two phenomenon which determine the shape of the B-H curves for a given actuator, or in other words, the force-producing capabilities of the magnetic system over an applied current range. The applied current and the actuator gap size

(distance between rotating component and bearing) are two variables which affect the magnitude of attractive force developed in a magnetic bearing pole. The losses in such a actuator system due to saturation and fringing need to be quantified. I developed a test procedure for quantifying the losses in a single pole system and used it to develop force versus current plots for different measured gap sizes. An experimental apparatus was developed that allowed the measurement of the force in a magnetic actuator pole, the flux developed inside the pole, the applied voltage, and the size of the gap. A rough sketch of the apparatus is shown in figure [3].

Description

The gap size was first set at a known mil value with brass shims. Then a voltage was applied to the pole to produce an attractive force between the pole and the journal. The voltage and gap size were recorded and then the aluminum rectangular beam shown in the figure was used to transfer a moment applied to it by unscrewing the load cell screw to the pole-journal area. This force counteracted with the magnetic attractive force until the force generated manually at the load cell side was greater than the pole-journal force. At this point the gap "broke free". In the meantime, an analyzer was recording load cell force vs. time. The maximum force generated in the gap for a set applied voltage and gap size was obtained in this process repetitively. Figure [4] shows a resulting plot of the acquired data.

Results

One of the goals of this experiment was of achieve 200 psi of magnetic pressure. This converts to about 120 lbs. of force if you base the pressure on bearing quadrant area. The results show that this value was reached, but well within the saturated region of the system and at a very small gap of 3 mils or less. Operation of a full magnetic bearing at this level would be difficult. The gap is too small for operation given the control system accuracy that is currently available, and the prolonged application of the amount of voltage required to produce the required current would cause the bearing to overheat and possibly burn up. When the force converted from the measured flux traveling through the coils is compared to the measured pole force, a difference of almost 50% is sometimes apparent.

To develop a solution to eliminate some of the detected losses, more experimental and analytical work needs to be done. Future experimental work will entail locating the paths of flux leakage and points of saturation with probes and sensors. On the analytical side, the same information can be obtained from a finite element analysis of the actuator system. Most of the work in magnetic bearings here at Lewis has primarily been experimental in nature and the inclusion of some analytical work is now needed. This is where I hope to provide the most impact in the coming year.
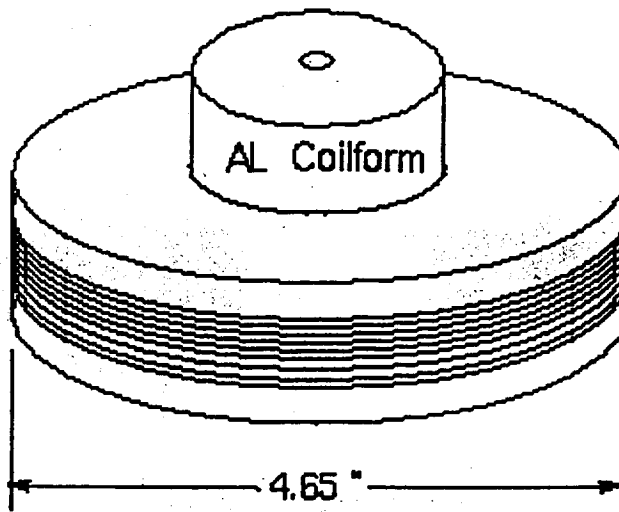
Figure [1]. An aluminum mock coilform used to test the thermal characteristics of the 532-turn electo-magnet coil.
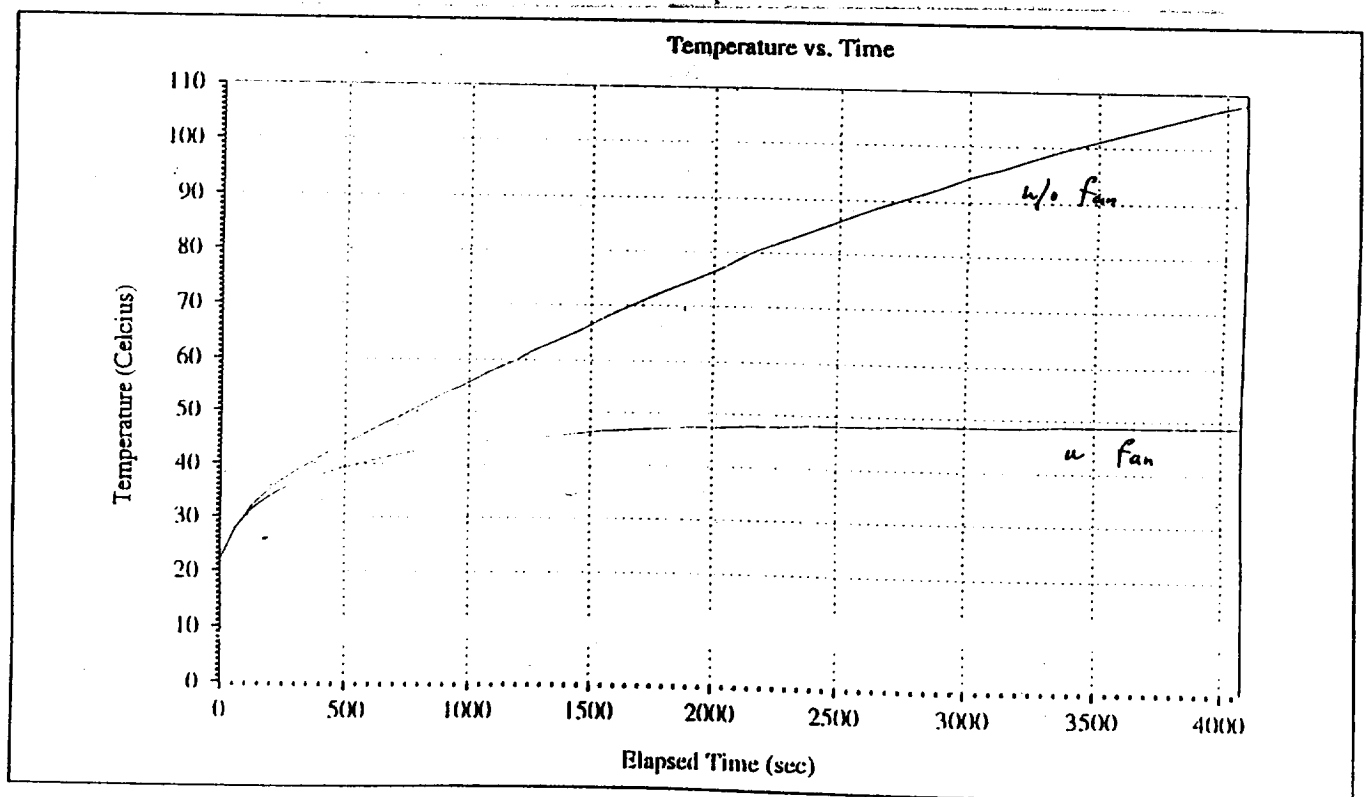

Figure [2]. A plot of computed temperature versus time with and without forced air convection.
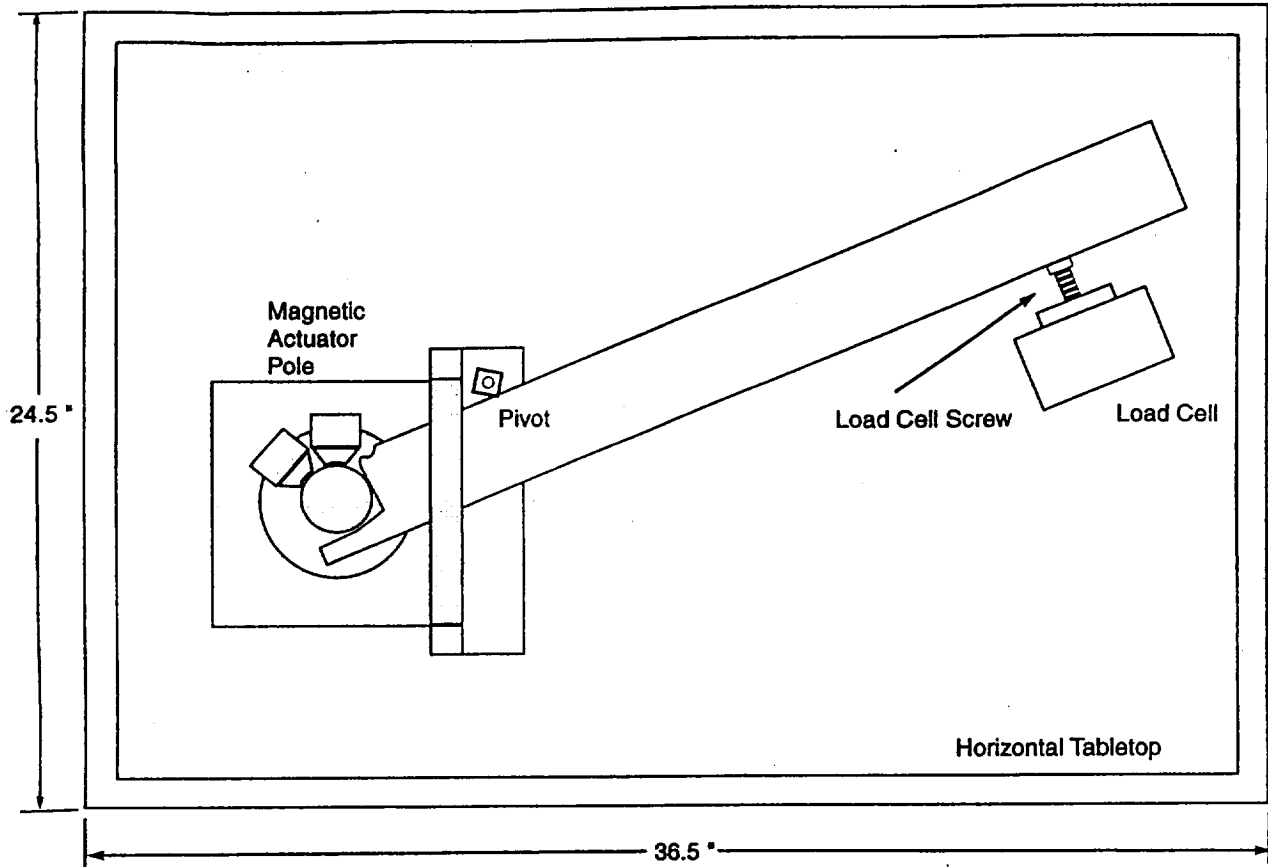
Figure [3]. Test apparatus used to gather magnetic breakaway
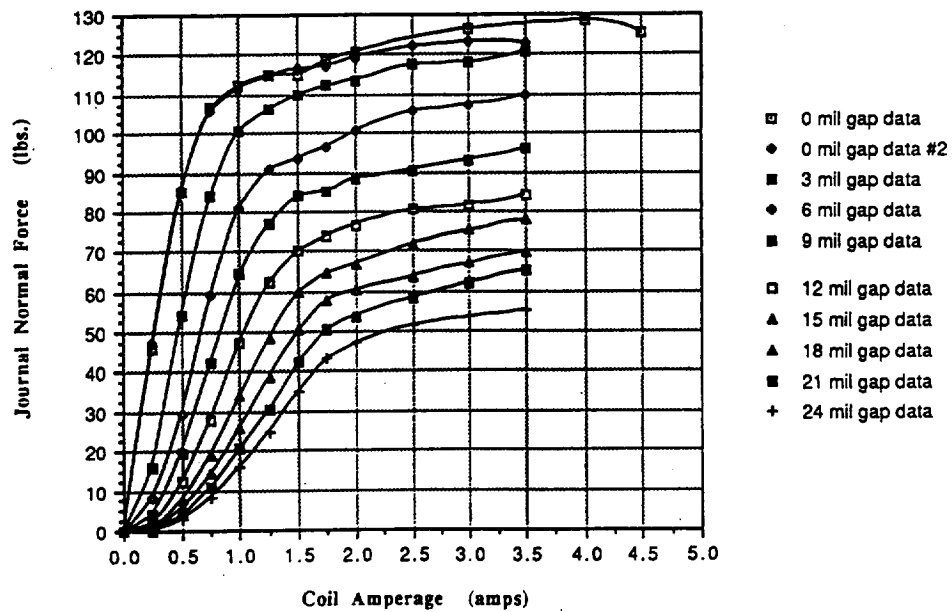force as a function of gap and coil current.

Figure [4]. Breakaway force vs. coil current plots for set gap
increments.

Ohio Aerospace Institute Research Associate Final Report

Dr. Philip G. Neudeck

Integrated High Temperature Electronic Sensors Program
Instrumentation and Control Technology Division

Period of OAI Research Associateship: July 1, 1991 through September 7, 1992

I. Background and Purpose of Research Work Undertaken:

The Integrated High Temperature Electronic Sensors (IHTES) Program within the Instrumentation and Control Technology Division at the Lewis Research Center is currently developing a new family of silicon carbide (SiC) semiconductor devices for use in high-temperature, high-power, and/or high-radiation conditions where conventional semiconductors (such as silicon) cannot operate. In addition to numerous important applications within the aerospace areas of propulsion control, power control, radar and communications, and rad-hard circuits, a family of hostile-environment integrated electronics and sensors would find numerous important spinoff applications in the earthbound commercial power and automobile industries.

Currently, jet aircraft and automobile engines rely extensively on control electronics that reside in "black boxes" well-away from the heat and vibration of the engines themselves. Considerable weight savings and performance enhancement could be achieved if high-temperature electronic instrumentation and control circuitry could be placed directly on the engines themselves. Much of the weight in satellites is dedicated to radiators which cool spacecraft electronics. By eliminating the need for cooling, the use of high-temperature electronics could drastically reduce spacecraft launch weights and/or greatly increase functional satellite capacity. Future space nuclear power systems will also require control and condition monitoring circuits for safe and optimum performance. In addition to the automobile industry, known Earth-based applications include deep-well drilling instrumentation, power electronics for motor and actuator control, and nuclear reactor instrumentation and control.

With such a broad-based range of applications and benefits, it should come as no surprise that Germany, Japan, and the United States are all working on the development of silicon carbide electronics technology. It is viewed as important to the future competitiveness of major industries within each country. Since 1982 the NASA Lewis IHTES research group, in partnership with several U.S. companies and universities, has played a major role in the advancement of SiC electronics, and it is recognized worldwide as one of the top pioneers in the field.

Work on simple SiC electronic devices has already progressed to the point where a small U.S. company (Cree Research, Inc., Duhram, NC) is producing and selling a half-million blue SiC light-emitting-diodes a month. However, there are many fundamental issues that remain to be addressed before more complex SiC electronics (i.e., transistors and integrated circuits) are ready for widespread reliable use in hostile aerospace propulsion environments. To date, several research groups (including the NASA Lewis IHTES group) have built very promising 6H-SiC prototype transistors, but their performance has been limited somewhat by the fundamental crystal growth and device processing issues. These fundamental performance-limiting issues are the focus of the IHTES research efforts.

Appropriate to the nature of the work and the expertise of the research scientists involved, the IHTES research group is loosely divided into a SiC crystal growth subgroup and a SiC electrical device subgroup. The crystal growth subgroup is focusing on improving the quality and electrical properties of the SiC semiconductor crystals, while the electrical device subgroup is working on

the procedures and techniques for turning the SiC crystals into worthwhile devices and circuits. As an electrical engineer, most of my contributions to the NASA IHTES SiC research program were in the electrical device area.

II. Summary of Work Performed

A. Buildup of Electrical Device Research Infrastructure

To support the expanding SiC electrical device research effort in the NASA IHTES program, I spent a non-trivial amount of time pursuing the purchase, installation, and/or upgrade of numerous items of laboratory equipment and supplies. These items, whether major or minor in price, have played and will continue to play a key role in the success of the device research program.

> Mask Alignment System - I was the lead technical person on the purchase of this vital piece of equipment. This system will enable the IHTES group to produce submicron patterns on its SiC wafers, resulting in the capability to produce state-of-the-art SiC Field-Effect Transistors.

> Installation and Customization of Capacitance-Voltage Equipment - I installed and customized the electrical characterization equipment that is carrying out all capacitance-voltage measurements done by the NASA IHTES group. **The rapid capacitance-voltage measurement capability that this equipment enabled has given the crystal growth subgroup immediate feedback on the electrical quality of the epitaxial SiC films they are producing. This capability played a critical role in the experiments that lead to the patent discoveries discussed in this document.**

> Installation and Customization of Current-Voltage Equipment - I installed and customized the electrical characterization equipment that is carrying most of the current-voltage measurements done by the NASA IHTES group. **This equipment was used to gather the ground-breaking SiC diode data outlined in this document.**

> Upgrade to Semiconductor Grade Chemicals - I instituted a badly-needed upgrade in the purity of all chemicals used in the instrumentation division clean room. This has substantially reduced contamination problems that have hindered our electrical device performance.

> Ion Implantation Contract - I set up a draw contract for the ion-implantation services that will become increasingly important as the SiC research effort pursues more complex semicondcutor device structures.

> Upgrade of Reactive Ion Etcher - I saw to the upgrade of the IHTES reactive ion etch (RIE) system. This upgrade has greatly enhanced our ability to etch SiC in a smooth and reproducible manner -- a capability needed to produce a large variety of prototype electrical device structures.

B. Research Accomplishments

While with OAI, my research work strongly contributed to 4 publications and a patent disclosure. The highlights and significance of my most important research contributions are

outlined in this section.

Silicon carbide occurs in many different crystal structures (called polytypes) with each crystal structure having its own unique electrical and optical properties. Of the two most common polytypes that have been grown on reproducible large-area substrates suitable for mass production, (6H-SiC and 3C-SiC), the 6H polytype has yielded far superior electrical device results. However, this is almost entirely due to the fact that growth techniques for producing substrates and epitaxial films in the 6H material are well advanced compared to 3C-SiC crystal growth methods.

Though the development of 6H-SiC semiconductor technology has progressed rapidly during the last several years, there are many fundamental issues that remain to be addressed before 6H-SiC electronic devices are ready for widespread reliable use in hostile environments. To date, several research groups (including ours) have built promising 6H-SiC prototype devices, but their performance has been limited somewhat by the fundamental crystal growth and device processing issues that the NASA IHTES group is attempting to address.

The purity and quality of the semiconductor crystal is naturally one such critical limiting factor in the performance and capabilities of silicon carbide devices. **I am one of four co-inventors on a new chemical vapor deposition (CVD) growth process (patent disclosure submitted) which consistently and reproducibly yields the highest purity silicon carbide epilayers (both 3C and 6H) reported to date. Using epilayers grown by this new technique, I directed the fabrication and electrical characterization of 6H-SiC PN junction diodes whose reverse breakdown voltage exceeds our 1100 V measurement capabilities (Figure 1). To the best of our knowledge, the 20 nA leakage current represents the lowest room-temperature leakage current density (< $50\mu A/cm^2$) ever reported in a semiconductor diode above 1 kV applied reverse bias.**
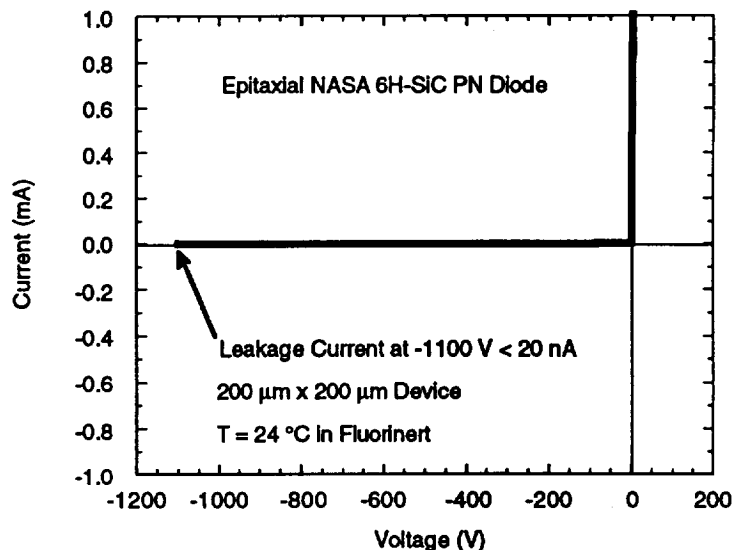

Figure 1. Record-breaking 6H-SiC PN Junction diode produced with my contributions as an Ohio Aerospace Institute Research Associate.

These excellent electrical characteristics are a reflection of the improved epitaxial material, which should similarly improve the operating characteristics and capabilities of most 6H-SiC electrical devices (e.g., transistors) and circuits. If the patent is awarded and licensed, both OAI and NASA could potentially profit from royalties and positive publicity arising from the invention. Several major American companies have already expressed interest in the capabilities offered by the patent. None of these accomplishments would have been possible without the unique collaborative arrangement between OAI and NASA that the Research Associates Program offers.

Despite the promising early success of prototype 6H-SiC devices, 3C-SiC has some important material property advantages over 6H-SiC (such as higher carrier mobilities) which could be exploited to produce superior devices and circuits in many applications. Because no technique had previously been developed for growing 3C-SiC of acceptable crystalline quality however, these property advantages have not been realized in any 3C-SiC electrical devices to date.

I also supervised the fabrication and electrical characterization of record-shattering 3C-SiC devices that represent a major step towards realizing high-quality 3C-SiC electrical devices. A previously-developed process for making 3C-SiC epilayers with fewer crystal defects was combined with the new high-purity SiC CVD growth process to produce record-shattering 3C-SiC PN junction diodes (Figure 2). Capable of blocking current at up to 200 V reverse bias at room temperature, these diodes represent a greater than 4-fold improvement in reported 3C-SiC PN junction rectification voltage. Reverse leakage current densities and forward saturation current densities have also been improved. When placed under sufficient forward bias, the diodes emit a bright green-yellow light, which to the best of our knowledge represents the first report of a significantly bright 3C-SiC light emitting diode. The substantial improvements made in the 3C-SiC material and diode characteristics should clearly enable vast improvements in the performance and capabilities of 3C-SiC transistors and circuits -- perhaps to the degree that experimental 3C-SiC devices might become superior to 6H-SiC devices in some applications.
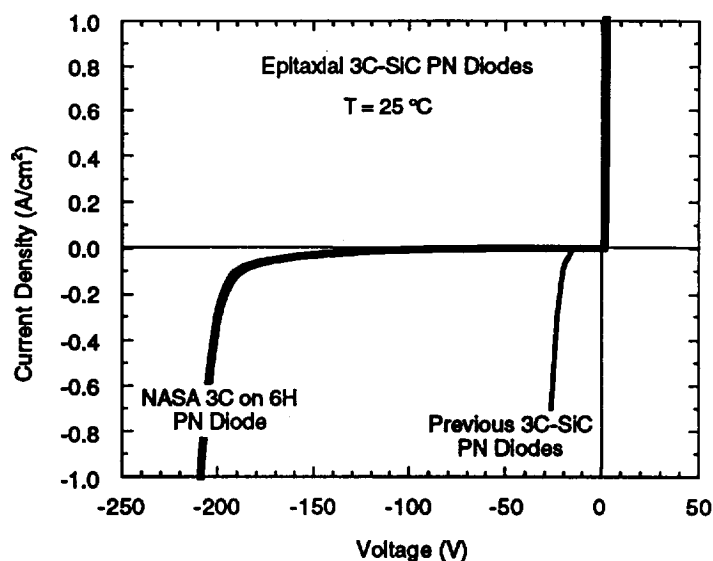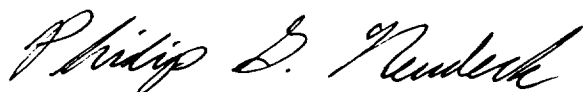

Figure 2. Improvement in 3C-SiC PN junction diode characteristics obtained with my contributions as an Ohio Aerospace Institute Research Associate.

As witnessed by the record-setting diode performances, the new growth techniques produce 3C- and 6H-SiC epitaxial films of previously unattainable quality on a consistent and reproducible basis. These advancements will enhance the electrical capabilities and performance of all devices and circuits produced in silicon carbide.

Most of the other research contributions I've made to the NASA Lewis IHTES program as an OAI Research Associate are outlined in the following publications which I've enclosed with this report:

1. J. B. Petit, P. G. Neudeck, L. G. Matus, and J. A. Powell, "Thermal Oxidation of Single-Crystal Silicon Carbide: Kinetic, Electrical, and Chemical Studies", To be published in Proceedings from the 4th International Conference on Amorphous and Crystalline Silicon Carbide and Other IV-IV Materials, Santa Clara, CA, October 10-11, 1991.

2. J. A. Powell, P. G. Neudeck, L. G. Matus, and J. B. Petit, "Progress in Silicon Carbide Semiconductor Technology", Materials Research Society Symposia Proceedings, Vol. 242, pp. 495-505, 1992.

3. Philip G. Neudeck and Lawrence G. Matus, "An Overview of Silicon Carbide Device Technology", American Institute of Physics Conference Proceedings 246, Proceedings of the 9th Symposium on Space Nuclear Power Systems, Part One, pp. 246-253, 1992

4. Gary W. Hunter, G. C. Madzsar, Philip G. Neudeck, C. C. Liu, and Q. H. Wu, "Hydrogen Sensor Technology at NASA Lewis Research Center", Advanced Earth-to-Orbit Propulsion Technology Conference, Huntsville, AL, May 19-21, 1992.

I would like to take this opportunity to express my sincere gratitude to the organization and people of OAI for a most rewarding and memorable tenure as a research associate. Based upon my experience, I feel strongly that the Research Associates Program is beneficial to OAI, NASA, and the associates themselves and should be continued. None of these accomplishments would have been possible without the unique collaborative arrangement between OAI and NASA that the Research Associates Program offers.

Dr. Philip G. Neudeck

Biography

Philip G. Neudeck received his doctorate in Electrical Engineering from Purdue University in May 1991. His dissertation dealt with III-V semiconductor devices for use in high-speed random-access memory applications. From July of 1991 through August of 1992 he worked as an Ohio Aerospace Institute Research Associate contributing to the Integrated High Temperature Electronic Sensors (IHTES) program at NASA Lewis Research Center in Cleveland, Ohio. In September of 1992, he joined the staff of the National Aeronautics and Space Administration (NASA) as a research electronics engineer in the Lewis IHTES program. Throughout his entire association with the NASA IHTES program, Dr. Neudeck has worked on silicon carbide semiconductor devices for use in hostile-environment electronic applications.

Final Report

Nelson Morales
Research Associateship Program
Ohio Aerospace Institute
September 15, 1992

Research Associateship Tenure Final Report

Nelson Morales
21000 Brookpark Rd. AAC-2
Cleveland, OH 44135
216 977-7050

I obtained my Bachelor of Science Degree from the University of Puerto Rico at Mayaguez in December, 1990. On July 15th, 1991, I started to work in the Systems Analysis and Engineering Branch (6830) at NASA Lewis Research Center as a Research Associate of the Ohio Aerospace Institute.

I performed photovoltaic space power systems analyses. I studied and learned the principles of photovoltaic (PV) power systems and their components (solar arrays and energy storage systems). I examined different type of solar cells including silicon (Si), gallium arsenide (Ga As), amorphous silicon (a-Si), indium phosphide (InP), thin films and multiband gap (MBG), as well as different types of energy storage systems such as nickel hydrogen (NiH_2), nickel cadmium (NiCd) and sodium sulfide (NaS) batteries, regenerative fuel cells (RFC), and flywheels.

During my first six months, I analyzed several photovoltaic power systems for a lunar base application using common power requirements (25kW during the lunar daytime and 12.5 kW during lunar nighttime). I based these analyses on the PV/RFC power system baselined in the NASA 90-Day Study. In these analyses, I examined the effect of cell type and energy storage system on the solar array area, energy storage mass and total system mass for Moon and Mars surface applications. I compared these results with the power systems presented in the NASA 90-Day Study. Following this, I delivered a presentation showing the results I obtained.

Later, I participated on a team examining photovoltaic power system options that could be used for various missions on the lunar surface, martian surface, low earth orbit and geosynchronous orbit. As part of these analyses, I developed a computer code that allowed me to calculate different characteristic of photovoltaic power systems, such as solar array area and mass, energy storage mass and total system mass, among others. The code calculated these

characteristic for several combinations of cell, array and energy storage subsystems.

Presently, I am working on some modifications of the code. I will use the results from this code to help determine the most appropriate photovoltaic power system for each of the above mentioned applications.

September 27, 1992

From   : Kenol Jules

To   : Sylvia Thompson

Subject : Final Report

The following is a condensed version of the technical work that I performed from June 3, 1991 up to September 8, 1992 as a Research Associate during my tenure at the Ohio Aerospace Institute.

My assignment was to work on the development of the airbreathing propulsion system for the Beta Two Stage To Orbit launch vehicle which is scheduled to enter into service by year 2005.
Beta system is a Two Stage To Orbit vehicle. Il comprises a carrier vehicle and an orbiter. Beta is being developed by NASA/BOEING/GE. Il will have the capability to put a 10,000 lb payload into a polar orbit. The system (carrier and orbit) will take off horizontally (airplane-like) and will land similarly. The orbiter (space shuttle-like) is tucked inside the carrier and is released at 100,000 ft at which point the orbiter fires its single rocket (SSME) to continue to orbit and the carrier turns around to come back to the landing site. The entire system is fully reusable.
The propulsion system for the BETA is a dual mode system. Both turbomachinery and ramjet are used to obtain the required thrust necessary to carry the mission. At one point the turbomachinery is shut down and only the ramjet is on. The present configuration of the propulsion system is an over/under (configuration).

My work was to come up with ways to improve the thrust margin for the BETA vehicle in the transonic since it's a well known fact that any supersonic/hypersonic vehicle using conventional airbreathing propulsion system has a thrust pinch in the transonic. Threrefore, I had the responsability of finding ways to increase the thrust margin in the transonic region and also maximize the propulsion performance in the high Mach number range to shorten the mission time.

I had used two main programs in carrying out my assignment. One calls NNEP which is a one dimensional thermodynamic analysis code. It 's used to model different engines cycle and can be used to optimize the cycle being considered for either thrust or fuel consumption based on the constraints put on the cycle . The other code is called Scramram which is a one dimension fluid dynamic analysis. It's used to model ramjet performance and can optimize the said performance as well within the realm of realism (engineering jugement).

Therefore, during my tenure at OAI, I used these two codes to find ways by applying engineering jugement to improve the performance of the Beta vehicle.

First, when I came on board the thrust margin in the transonic was almost none. That means the propulsion system was producing just as much thrust as the vehicle drag. Thus, there was almost no acceleration through transonic but Beta is an acceleration vehicle. I used the codes and find ways to control the engine cycle so as to increase the thrust margin in the transonic and obtained a converging solution. Also, the thrust at high Mach number was significantly improve. The total mission time a year ago (that is time from takeoff to release of the orbiter at 100,000 ft) was 716 secondes. The current time now is 493 secondes. This drastic reduction in mission time was due to better propulsion performan- ce, better inlet and better vehicle aero.

Besides the baseline thrust optimization for the BETA vehicle, I explored ways to increase the thrust in the transonic as well. One of them was to overspeed the engines in the transonic only in order to increase thrust. The result is very satisfactory. This increases the thrust in the transonic to as much as 50%!

Also I looked into the possibility of using different fuels, with higher heating value, in the transonic as a way of increasing thrust. That gives an increase of as much of 13%.

The last option that was being looked into before my resignation from OAI was the water injection to the engines in the transonic for thrust augmentation. This study is on a on-going status, thus, result is not available yet. But the consensus is it will increase thrus considerably in the transonic. As to how much , I don't know yet.

Other study I did was to take the baseline engine designed to operate up to Mach 2.4 and extend the operating range of the engine to Mach 3.0. Later on I did some more study and extend the engine operating range from Mach 3.0 up to 3.5. Thus, I had extended the engine operating range from Mach 2.4 up to Mach 3.5. This engine is an airbreathing engine.

Other study was done by me to optimize the system for minimum fuel consumption for a subsonic ferry mission and the normal flying back of the carrier after releasing the orbiter. This study was satisfactory as well.

I gave Several presentations of the results of my work as an OAI Research Associate.

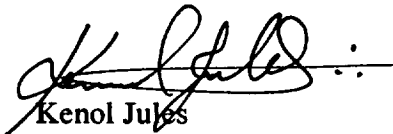A presentation was given to General Electric (GE) on May 5, 1992 in Cincinnati.
A presentation was given for the management yearly review on July 11, 1992 at NASA (AAO)
Another presentation was given to GE/NASA/BOEING/WRIGHT PATT LAB AFB on September 9, 1992.

A paper is currently being written for the Joint Propulsion Conference & exhibit to present the result of the diverse studies that were done to improve the thrust capability of the propulsion system for the BETA vehicle.

Biographical Sketch

Kenol Jules was born in Port-au-Prince, Capital of Haiti. He received his High School in 1984. He entered Junior College in May 1985. He received his Associate in Art in May 1987 from Miami Dade College. In august 1987 he entered Parks College of Saint Louis University and obtained his Bachelor of Engineering Science in Aerospace Engineering from Parks College in July 1989. He entered the University of Tennessee Space Institute in September 1989 to pursue a Master of Science degree in Aerospace Engineering and was awarded the same in May 1991. Currently he has 42 credits hours towards his Ph.D. at the same university. He came to the Ohio Aerospace Institute in June 1991 as a Research Associate to do post-graduate research work. He finished his tenure at the OAI as a Research Associate in September 1992. He is currently working for NASA Lewis Research Center in the office of Aerospace Analysis Center as an Aerospace Engineer.

Kenol Jules

Research Associate at OAI

FINAL REPORT

OHIO AEROSPACE INSTITUTE

RESEARCH ASSOCIATE TENURE

JANUARY 28, 1992 - SEPTEMBER 7, 1992

JUAN C ETHERIDGE

TABLE OF CONTENTS

Biography

I was raised in Columbia, South Carolina where I attended school until high school graduation in June 1986. I then successfully completed one year at the University of South Carolina before transferring to North Carolina A &T State University. I received my Baccalaureate of Science in Electrical Engineering from North Carolina A & T State University in December of 1991 with a GPA of 3.3. During my time as an undergraduate student I worked as a summer co-op student with Naval UnderWater Systems Center (NUSC) presently referred to as Naval Underwater Warfare Center (NUWC). I began my co-op term as a GS-4 civil servant and concluded as a GS-5. My area of work was in the Launcher Division which was mainly responsible for the research and design of submarine launcher equipment. This entailed torpedo launching systems as well as communication buoy launchers. One of the projects with which I was involved was the design of a flowmeter to be used to measure the flow through a test model of torpedo launcher designed by Dr. Paul Lefebve. This meter along with several other measurement devices was used to collect data from actual launches of a dummy torpedo in the scaled launching model. I also was involved in the implementation of a infrared image processing system to detect for cavitation in the turbine pumps used in the system. Another, and not final,project with which I was involved was assisting in the construction and testing of a since patented balloon launcher design which was intended to abate noise made by flow pumps which could be used in the detection of submarines. My work term

concluded with the beginning of my tenure as a Research Associate.

Report

During the period of January 28 through September 7, 1992 I was assigned to work in the Controls Engineering Branch/7310 as an OAI Research Associate . All the work performed during this tenure was to assist in the implementation, design and construction of a Distributed Control System (DCS) to an existing Supervisory Control and Data Acquisition (SCADA) system. My first project towards this goal was verification of configuration drawings in attempt to assist in configuration control during the design and construction of the new SCADA system. This task involved using a database printout to verify revisions and identifying baseline drawings. The results were then handed over to the drafting contractor, Sverdrup, for corrections to be officially added to the database.

The next project with which I was involved was installation of inverter systems in the NASA Substations. The purpose of these inverter systems were to take 125 volts DC off of a battery source and convert it to the neccessary AC power to the be used as a backup AC power source for the new Process Control Units (PCU's) of the Bailey DCS. My Primary task was to gather information from several sources on the power loads associated with each inverter model and perspective substation RTU's. This information was to then be tabulated with its corresponding substation so it could be used by the contractor (EDG) assigned to the inverter installation

to insure proper matching of inverter power loads(see enclosure 1).

In order to properly perform my duties with the new SCADA & DCS systems it was necessary that I take several training courses, both off and on site. The first of these was the Bailey Infi-90 training course taken at the Bailey Training Center in Wickliffe,Ohio (SEE ENCLOSURE 2). In this course I was given an overview of the DCS configuration and an introduction of the Engineering Work Stations with its trending and Computer Aided Design (CAD) features. The next session of training was also given at Bailey and entailed an overview of the Bailey Operator Interface Stations (OIS) - more specifically the OIS-40 systems. In this course I learned how to perform a proper shutdown of the OIS-40 systems. I also learned how to create various graphics and alarm screens. The last course that I took in this series was the maintenance courses for both the Infi-90 modules and the OIS-40 stations. In these courses I learned the various errors that may occur in both systems and a systematic way of troubleshooting them. The on site courses taken which were completed at The Learning Center comprised of the Modicon 984 PLC Training, Electric Drive Systems, and self tutorials in Word Perfect 5.1 and Lotus 123. Several personnel development courses was taken through the Training and Development Branch including Time Management and Effective Listening.

My tenure in the Control Engineering Branch also required that

I participate in several group efforts towards the successful completion of the SCADA/DCS project. These include participation in the factory acceptance testing in the areas of Electrical Distribution and all SCADA project meetings. During the installation of the bailey equipment at various sites I assisted in tagout of necessary equipment by pulling drawings and locating points for power isolation and using Lotus 123 to tabulate the information so it could be used by the responsible individuals. I also traveled to Detroit Michigan, Toronto Canada and various other instate sites to visit instrument control shows and demonstrations to become more familiar with the various manufacturers and new technology in instrument controls. As can be seen my tenure as an OAI Research Associate has served as a convenient start towards my future career in the NASA Controls Engineering Branch.

ENCLOSURE 1

COPY - INVERTER POWER LOAD

TABLE

MODEL A31 SERIES

U.L. FILE #E48647

OPTIONAL ACCESSORIES

Code	Description
03J	2 ms. Static Switch (Fast) **
164	20 ms. Static Switch (Slow) Prime
165	20 ms. Static Switch (Slow) Standby
132	Inverter Available Relay (1 form "c")
CF	50 Hertz Output* (Not UL Listed)
CF	240 VAC Output
06L	A.C. Ammeter (STD IKVA and Larger)
06M	A.C. Voltmeter (STD IKVA and Larger)
06C	D.C. Ammeter
06D	D.C. Voltmeter
012	D.C. Breakers(24 and 48V input units only, requires 12A option)
12A	Manual PreCharge Push Button
129	Isolated Duplex Receptacles (Not UL Listed)

* May require larger case
** Available on IKVA and larger only

D.C. to A.C. Inverter
Sine Wave Output

GENERAL DESCRIPTION

The LaMarche model A31 inverter is designed for small computers, CRT's, and printers.

The A31 are low cost, compact and supply a sine wave output. High reliability is provided by transistor switching and a ferroresonant transformer which has inherent voltage regulation, output filtering, and overload protection.

The A31 is self-protected for a.c.-d.c. shorts and undervoltage. Battery protection is supplied by low voltage shutdown and d.c. input fusing. An input reverse polarity indicator and input filter precharge circuit with indicator are provided as standard.

Typical applications for the A31 are: Telecommunications, Burglar and fire alarm systems, Telemetering and Supervisory control, Nuclear and missile installations and Data processing point of sale terminals.

DESIGN FEATURES
- Reliable, Ferroresonant Design
- Quartz Time Base
- Voltage Regulated and Current Limited
- Adjustable D.C. Undervoltage Turn-off
- Overload Protected
- Reverse Polarity Indicator/Filter Precharge Circuit
- Available for 24,48 and 120 VDC Batteries
- Inverter On/Off Switch
- A.C. Circuit Breaker
- 60 Hertz Operation (50 Hz Optional)
- Class H (180 C) Insulation
- Convection Cooled (4KVA and 5KVA are Fan Assisted)
- 32 DBRN `c' Input Noise Filtering (24 and 48 VDC Only)
- Line Synchronization
- Reverse Polarity Protection

OUTPUT SPECIFICATIONS

A.C. Output Voltage: 120 Volts Nominal (240 Volts Optional)
Output Power: Rated Volt-Amps Continuous for Unity to .8 Lagging P.F.
Line Regulation: ±3% for over D.C. Battery Range
Load Regulation: ±4%,
Frequency: 60 Hertz (50 Hertz Optional)
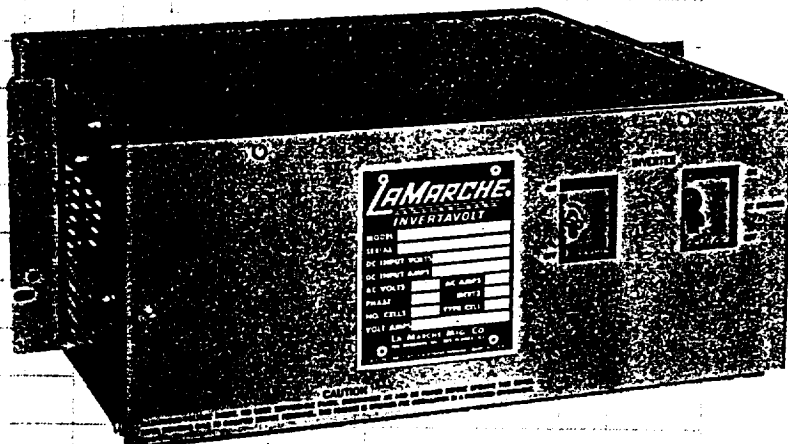**Frequency Regulation:** ±.05% (Quartz Clock)
Total Harmonic Distortion (THD): Approximately 5% at Nominal D.C. Input and Full Load. Less than 3% for any single harmonic
D.C. Undervoltage Shutdown: Adjustable
Current Limit: Approximately 150% of Rated Load. Protected by A.C. Breaker
Input: Reverse Polarity Protection Indicator/Filter Precharge Circuit. Protected by D.C. Fuse
D.C. Overvoltage Shutdown: Adjustable

POWER REFERENCE TABLE FOR SUBSTATION INVERTERS

| SUBSTATION | MODEL NUMBER | RTI | INVERTER POWER | | SINGLE (120VDC INPUT) | | | CABINET | |
| | | | D.C. INPUT AMPS | | | | | POWER LOADS | |
			NO LOAD	FULL LOAD	VA	VOLTS	AMPS	PEAK AMPS	VA
SUB A & L	A31 -750 -120V-A6	R24	0.8	7.5	750	120	6.25	5.47	656.86
SUB B	A31 -750 -120V-A6	R28	0.8	7.5	750	120	6.25	4.97	596.78
SUB C	A31 -750 -120V-A6	R19	0.8	7.5	750	120	6.25	4.86	583.20
SUB D	A31 -500 -120V-A6	R29	0.7	5	500	120	4.17	2.58	309.76
SUB E	A31 -750 -120V-A6	R17	0.8	7.5	750	120	6.25	4.97	596.78
SUB F	A31 -1K -120V-A6	R20	1	9	1000	120	8.33	6.42	769.90
SUB G	A31 -1.5K -120V-A6	R25	1.5	14	1500	120	12.5	9.14	1096.46
SUB H	A31 -1K -120V-A6	R21	1	9	1000	120	8.33	5.77	691.82
SUB J	A31 -1.5K -120V-A6	R18	1.5	14	1500	120	12.5	8.48	1017.17
SUB K	A31 -750 -120V-A6	R27	0.8	7.5	750	120	6.25	5.31	637.51
SUB M	A31 -1K -120V-A6	R22	1	9	1000	120	8.33	5.77	691.82
SUB N	A31 -500 -48V-A6	R23	1.5	13	500	120	4.17	1.62	194.85

PREPARED BY: 7310/ JUAN C. ETHERIDGE

THE TABLE ABOVE CONTAINS ALL CHANGES REFERENCED IN THE EDG LETTER DATED JULY 7, 1992 TO THE SUBSTATION INVERTER SIZES INSTALLED. IT SHOULD BE NOTED THAT COLUMNS 4-8 CONTAIN SPECIFICATIONS TAKEN FROM THE MANUFACTURING COMPANY'S SPECIFICATION SHEET FOR THE MODEL A31 SERIES. COLUMNS 9-10 ARE THE CABINET POWER LOADS TAKEN FROM THE EDG HEAT AND POWER CALCULTIONS DATED 3/10/92.

ENCLOSURE 2

BAILEY TRAINING

Certificate of Successful Completion

Is Awarded To

JUAN C. ETHERIDGE

for

SPECIAL INFI 90 MAINTENANCE COURSE

Wayne Lg. Smith
MANAGER, TRAINING SERVICES

Dale Perez
TRAINING INSTRUCTOR

DATE _JUNE 1-12, 1992_

Bailey Controls Company

TRAINING

Certificate of Successful Completion

Is Awarded To

JUAN C. ETHERIDGE

for

INFI 90 SPECIAL ENGINEERING COURSE

Wayne D. Conlor
MANAGER, GLOBAL TRAINING

DATE ___MARCH 2-13, 1992___

John Knaszen
TRAINING INSTRUCTOR

Bailey Controls Company

Bailey TRAINING

Certificate of Successful Completion

Is Awarded To

JUAN C. ETHERIDGE

for

OPERATOR INTERFACE STATION
SERIES 40 COURSE

Wayne W. Lambo
MANAGER, GLOBAL TRAINING

DATE __MARCH 23-27, 1992__

[signature]
TRAINING INSTRUCTOR

Bailey Controls Company

Final Report

Anthony Chan

September 2, 1992

During my last fourteen months at the Lewis Research Center, I was assigned to the Electronic Systems Branch of the Aeropropulsion Facilities and Experiments Division. The specific facility in which I worked is the 10x10 Supersonic Wind Tunnel. I worked with other engineers from the same division to support the test programs at this tunnel as well as other facility-related matters.

When I first arrived fourteen months ago, the tunnel had just gone through a major upgrade. A new distributed control system by Westinghouse was installed. The idea behind the distributed control system is that several control units located throughout the facility can communicate with each other on a fiber optic highway. This allows commands given in the control room to go to the individual units where they are processed. The outputs from the units will in turn energize relays to start motors, move tunnel valves, or talk to other control units.

One of the first things I did was to verify that all the inputs and outputs (I/O's) and correct. Each I/O point is given an unique point name in the system. By calling up a point, I can find out its hardware address (and bit position if it is a digital point). I also had a listing of these points and where they are wired. Therefore, by calling up the points and checking against the list, I was able to determine that all the points are in the system and are wired correctly. When I find a mismatch, then I had to check the wiring to see what was wrong. After this process was done, I updated the list of I/O points. This list is now our means of keeping track of all the I/O's and where we can add new points.

Next, I updated old sketches of thermocouples in the tunnel near the compressors and coolers. I identified the device and determined where they are wired as an input to the Westinghouse system. This helped to verify that we are reading what we think we are reading. The sketches will also provide an expedient means of locating the thermocouples if any problems should arise in the future.

I then worked with the other engineers to prepare for the Mach 5 Inlet Test. This model is very complicated. It has over a thousand tubes for pressure data and many movable parts. The moving parts include fourteen translating probes, sixteen bleed plugs, a main mass flow plug, and three movable ramps to change the dimensions of the inlet. I was involved in the calibrations of the moving parts and assisted in setting up their controls as well.

After the calibrations, I worked on making the probes all move at once in small steps (0.003" to 0.009") over a 2-inch span by using the Test Matrix Sequencer. The sequencer is interfaced to a computer. The user has to enter a matrix of set points. In my case, I had to enter a matrix of voltages to position the probes, give a command to record the data, and go to the next

position. After the probes have reach their last positions and recorded their data, they will all return to their starting places. Once I entered the matrix, the computer did all the work to output the right voltages to position the probes where I told them. In addition to the probes, I also helped in setting up the controls for the other moving parts. This involves setting up the servo valve controls and adjusting the feedback to read 0 to 5 volts. This was not as easy because there are four pairs of bleed plug that move together. It took a long time to set the bias and gains on the controllers so that they move together and at the same rate. Sometimes I stayed for the runs to help make sure all the controls function properly. On those occasions, the day seemed long, but the time went by rapidly. This is mainly because after fifteen hours at work and four hours of commuting, all I have time for was sleep when I got time.

During the Mach 5 program, I was also working on facility-related tasks. One such item is the installation of new model strut controls. This is needed to give the model some kind of angle of attack change. I worked with another engineer in making it work. We checked the wiring and the control logic after it was installed to make sure all the electrical work is completed as requested. We also worked on setting the controller for optimal speed and response. I also designed a operator's panel for the model operator to control the model's angle of attack. This strut control system is currently in used at the facility.

Another task I performed in this period was the documentation of the patchboards. The patchboards are used as a means of connecting the various transducers, potentiometers, and other signals from the model to the signal conditioners, amplifiers, and other data acquisition devices in the control room. I made block diagrams of the entire patchboard network. I also made drawings on how the signal conditioners, amplifiers, etc. are connected to the patchboards. These sketches were given to Sverdrup for the production of full-size drawings. By doing this documentation, I have a better understanding of how a signal gets conditioned, amplified, and ultimately recorded.

A month or so ago, I was given the task of documenting the facility's alarms and interlocks. This involved examining the ladder logic of the Westinghouse system. By studying the ladders, I was able to identify the various conditions that would cause an alarm condition. I then wrote down what they were, and what action to take in the event of an alarm. If the alarm can not be fixed, the tunnel may have to be shut down because the tunnel can not be operated without the drive motors and certain valves. In a similar fashion, I also documented the various interlocks and what cause them. The interlocks are designed to prevent the operation of some part of the tunnel for safety reasons, and are therefore, very important. By identifying the interlocks, we can also check on only those items that make up the interlock should something failed and we can not get the interlock or remove it. By working with the logic behind the controls, I have gained

familiarity with what goes into making a facility of this size work both during a tunnel run, and on a day-to-day basis.

Currently, with a two-month facility shutdown, I am working on the installation of two new hydraulic stations for the control of tunnel valves. I am responsible for the control of the pump motors as well as the instrumentations used to monitor the oil temperature and the level of fluid in the reservoirs. Since we are going from a single motor to a dual motor hydraulic pump setup, a lot have to be redone. New breakers and thicker wires have to be used to satisfy the current drawn by the motors. After rewiring the motors, some time will also be needed for checking the control logic when it is programmed into the Westinghouse system.

We are also preparing for the next test to arrive at the tunnel. This will be a Variable Diameter Centerbody test. I was asked to design an unstart sensor for the model. This sensor will detect an unstart and take action to recover the model. Hopefully, it will help to minimize damage done to the model. The sensor will involve the use of pressure transducers and an analog divider to determine a pressure ratio in terms of volts (i.e. 5V equals a ratio of 5). This ratio will be compared to an adjustable voltage above which would be analogous to an unstart. This in turn will actuate the necessary model components to recover it.

Overall, the past fourteen months at Lewis have been both enjoyable and educational. This is because the engineers I work with, Tim McCartney and Joe Panek allow me the opportunity to work on my own. However, if I have any problems or questions, they are always there to help. They also provide me with a starting point when they ask me to do something instead of letting me find things out the hard way.

FINAL REPORT

OHIO AEROSPACE INSTITUTE TENURE

by

Jean Bianco
Research Associate

September 14, 1992

I was employed as a Research Associate with Ohio Aerospace Institute from the period of May 20, 1991 to September 7, 1992. During my tenure, I worked at NASA Lewis Research Center in the Aeropropulsion Facilities and Experiments Division. More specifically, I worked as an Operations Engineer for the Engine Components Branch of AFED.

In this capacity I was assigned to work in test cell CE5 of the Engine Research Building. This test cell houses two high pressure/high temperature combustor rigs for experimentation as part of NASA's High Speed Research Program(HSR). In a nutshell, the HSR program is addressing some of the technologies that may be used to design economically viable, environmentally compatible, supersonic airliners of the future. Due to the recent concerns over the ozone layer depletion, the emissions of any future aircraft, more specifically the NOx emissions, become a major focusing point. It is the goal of the High Speed Research program to achieve a 90% reduction of the NOx emissions levels of current aircraft. Both combustor concepts being tested have been shown to meet this goal.

The two combustor concepts being tested in CE5 are the Rich Burn/Quick Quench/Lean Burn, or RQL, Combustor; and the Lean Premixed Prevaporized, or LPP, Combustor. In addition, testing of a Lean Direct Injection, or LDI, Combustor being evaluated in place of the LPP test rig. These combustor concepts are derived around the premise of burning at either fuel lean or fuel rich conditions. Burning fuel lean or fuel rich will reduce the amount of NOx produced. The basic operation of the test rigs is as follows: 1)high pressure air(450 PSIG; 3-15 lb/sec), preheated to elevated temperatures(1000-1100F), is passed through the test section; 2)jet fuel is injected into the heated airstream and the mixture is ignited through the use of a Hydrogen torch; 3)different test conditions are set and the gaseous emissions are then analyzed.

In addition to the basic operation and data gathering of the two test rigs, measurements using advanced diagnostic techniques were employed. Various measurements were made on the LPP test rig using a focused Schlieren system and a Malvern droplet analyzer. These techniques measured the fuel droplet size and degree of vaporization within the mixing section of the LPP test rig. Laser measurements will be made on both test rigs in both the mixing and combustion sections. Although not scheduled until late this year, installation of the laser system has already begun.

During the first 6 months of my tenure, I assisted the lead Operations Engineers on the operation and maintenance of the two test rigs. In addition, I worked along with the cell mechanics to organize both inside and outside storage of CE5. After this initial training period, and due to the position availability, I became the lead Operations Engineer of the LPP, and subsequent LDI Combustor Test Rig.

In general, some various tasks/responsibilities I had as an Operations Engineer are as follows:

I became familiar with the various power systems available at NASA, and their interaction in the CE5 test cell. Also, I became familiar with the two test rigs and subsystems within CE5.

I participated in the weekly operation of the test rig and prepared the pre-op checklists for operation of the test rigs.

I worked along with various NASA facilities/departments in preparing the test rig for operation(ie. Machine Shop and Fabrication Shop for rework/original fabrication of hardware, etc).

I procured needed hardware/equipment to 1)maintain the weekly run schedules, 2)satisfy the research req'ts, etc.

I assisted in prioritizing the workload placed on the limited manpower available within the test cell.

I reported on the results of the research testing and test rig operation after each run; and I reported on the monthly status of the test rigs and their operation.

I participated in design reviews of modifications to existing hardware or of future test hardware.

I obtained the safety approval for the operation of the test rigs and supporting systems in the test cell; and I renewed the safety permits as required.

I gave guided tours and discussions on the test rigs in CE5.

I organized and arranged the conversion from the LPP testing to the LDI testing in a timely manner to enable testing to be performed before the 2 month lab shutdown.

In addition to these general tasks, I was able to do the following:

I co-authored a technical paper with the Research Engineer on "Predicting NOx emissions in a Lean Premixed Prevaporized Combustor" based on the research testing performed.

I organized the fuel tank/gas cylinder storage outside of the test cell meeting the research requirements as well as following lab safety standards.

I volunteered for various labwide activities such as
1)assisting in the decorations for the NASA 50th anniversary
picnic, 2)manning the NASA tent for the Cleveland National
Airshow in both '91 and '92; and 3)manning the NASA exhibit
at the indoor amusement park at the IX center.

I completed a series of training tapes at the Learning
Center on "Instrumentation and Measurements".

I attended a week long course in "Project Management".

I attended the High Speed Research Program Semi-Annual
Review with NASA, industry, and university personnel.

I visited vendors as well as companies participating in the
HSR program.

Also, it is worth noting that I, along with several co-workers,
received a NASA group award for the efforts put in towards the
HSR program combustion testing.

RESEARCH ASSOCIATE BIOGRAPHICAL SKETCH

NAME: Jean Bianco

ADDRESS: 651 Vineyard Drive #204
Broadview Heights, OH 44147

PHONE: (216) 237-1045

BIRTH DATE/LOCATION: June 10, 1962/Indiana, PA

PREVIOUS/CURRENT ADDRESSES: Clymer, PA   6/62 - 2/72

Seven Hills, OH 7/72 - 2/90

Broadview Hts, OH 2/90 - Present

SEX: Female

MARITAL STATUS: Single

EDUCATION: John Glenn Elementary, Seven Hills, Ohio
1972-1974

Shiloh Junior High School, Parma, Ohio
1974-1976

Hillside Junior High School, Parma, Ohio
1976-1977

Normandy High School, Parma, Ohio
1977-1980
Major: College Prep/Mathematics

Cleveland State University, Cleveland, Ohio
1980-1985
Bachelor of Science in Mechanical Engineering
Graduated Cum Laude

Cleveland State University, Cleveland, Ohio
1987-1990
Graduate courses in Computer and Information
Sciences

PERTINENT JOB HISTORY:

City of Akron Civil Engineering Dept, 1981
Worked in the bridge and road repair section

Parker Hannifin Corporation, 1982-1985
Co-op Engineer
Worked on computerized tooling inventory
and various fuel nozzle design sub-projects
Parker Hannifin Corporation, 1985-1991
Engineer - Senior Design Engineer
Involved in the design of fuel nozzles for jet
engines. Worked on fuel nozzles for Rolls Royce
RB211-535, RB211-524, Tay engines; Garrett GTC
131-3 Auxiliary Power Units; Pratt & Whitney
ATF engine.

HOBBIES: Golf, Snow skiing, Reading, Cooking, Pets, Volunteering