PL-TR-96-1059, Vol. II

PL-TR-
96-1059
Vol. II

LOW-COST SPACE STRUCTURE (LCSS) EXPERIMENT

Volume II of II

David DeYoung
Lawrence Robertson, III

SVS R&D Systems Inc.
6207 Pan American Freeway NE
Albuquerque, NM 87109

June 1996

Final Report

Distribution authorized to DoD components only; Proprietary Information; June 1996. Other requests for this document shall be referred to AFMC/STI.

WARNING - This document contains technical data whose export is restricted by the Arms Export Control Act (Title 22, U.S.C., Sec 2751 et seq.) or The Export Administration Act of 1979, as amended (Title 50, U.S.C., App. 2401, et seq.). Violations of these export laws are subject to severe criminal penalties. Disseminate IAW the provisions of DoD Directive 5230.25 and AFI 61-204.

DESTRUCTION NOTICE - For classified documents, follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX. For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

PHILLIPS LABORATORY
Space and Missiles Technology Directorate
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776

UNCLASSIFIED

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

AD NUMBER

AD-B214 764

NEW LIMITATION CHANGE

TO

DISTRIBUTION STATEMENT A -
Approved for public release; Distribution unlimited.

Limitation Code: 1

FROM

DISTRIBUTION STATEMENT -

Limitation Code:

AUTHORITY

Janet E. Mosher; Phillips Lab/CA, Kirtland AFB, N.M.

THIS PAGE IS UNCLASSIFIED

PL-TR-96-1059

This report contains proprietary information and shall not be either released outside the government, or used, duplicated or disclosed in whole or in part for manufacture or procurement, without the written permission of the contractor. This legend shall be marked on any reproduction hereof in whole or in part.

This report has been approved for publication.

RICHARD COBB, Capt, USAF
Project Manager

FOR THE COMMANDER

L. KEVIN SLIMAK, GM-15
Chief, Structures and Controls Division

CHRISTINE M. ANDERSON, SES, DAF
Director, Space and Missiles Technology
Directorate

The following notice applies to any unclassified (including originally classified and now declassified) technical reports released to "qualified U.S. contractors" under the provisions of DoD Directive 5230.25, Withholding of Unclassified Technical Data From Public Disclosure.

NOTICE TO ACCOMPANY THE DISSEMINATION OF EXPORT-CONTROLLED TECHNICAL DATA

1. Export of information contained herein, which includes, in some circumstances, release to foreign nationals within the United States, without first obtaining approval or license from the Department of State for items controlled by the International Traffic in Arms Regulations (ITAR), or the Department of Commerce for items controlled by the Export Administration Regulations (EAR), may constitute a violation of law.

2. Under 22 U.S.C. 2778 the penalty for unlawful export of items or information controlled under the ITAR is up to two years imprisonment, or a fine of $100,000, or both. Under 50 U.S.C., Appendix 2410, the penalty for unlawful export of items or information controlled under the EAR is a fine of up to $1,000,000, or five times the value of the exports, whichever is greater; or for an individual, imprisonment of up to 10 years, or a fine of up to $250,000, or both.

3. In accordance with your certification that establishes you as a "qualified U.S. Contractor", unauthorized dissemination of this information is prohibited and may result in disqualification as a qualified U.S. contractor, and may be considered in determining your eligibility for future contracts with the Department of Defense.

4. The U.S. Government assumes no liability for direct patent infringement, or contributory patent infringement or misuse of technical data.

5. The U.S. Government does not warrant the adequacy, accuracy, currency, or completeness of the technical data.

6. The U.S. Government assumes no liability for loss, damage, or injury resulting from manufacture or use for any purpose of any product, article, system, or material involving reliance upon any or all technical data furnished in response to the request for technical data.

7. If the technical data furnished by the Government will be used for commercial manufacturing or other profit potential, a license for such use may be necessary. Any payments made in support of the request for data do not include or involve any license rights.

8. A copy of this notice shall be provided with any partial or complete reproduction of these data that are provided to qualified U.S. contractors.

DESTRUCTION NOTICE

For classified documents, follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX. For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

DRAFT SF 298

1. Report Date (dd-mm-yy)
June 1996

2. Report Type
Final

3. Dates covered (from... to)
04/95 to 06/96

4. Title & subtitle
Low-Cost Space Structure (LCSS) Experiment, Volume II

5a. Contract or Grant #
F29601-93-C-0205

5b. Program Element # 62601F

6. Author(s)
David DeYoung
Lawrence Robertson, III

5c. Project # 3005

5d. Task # C0

5e. Work Unit # DL

7. Performing Organization Name & Address
SVS R&D Systems Inc.
6207 Pan American Freeway NE
Albuquerque, NM 87109

8. Performing Organization Report #

9. Sponsoring/Monitoring Agency Name & Address
Phillips Laboratory
3550 Aberdeen Ave SE
Kirtland AFB, NM 87117-5776

10. Monitor Acronym

11. Monitor Report #
PL-TR-96-1059 Vol II of II

12. Distribution/Availability Statement
Distribution authorized to DoD components only; Proprietary Information: June 1996. Other requests for this document shall be referred to AFMC/STI

13. Supplementary Notes

14. Abstract The INSPECT program was a subset of the Low-Cost Space Structure (LCSS) experiment described in Volume I of this technical report. Under this program, a helicopter mounted pointing and tracking system was designed, fabricated, tested, and used to collect high-resolution images of power transmission equipment. The heart of the system was a precision stabilized gimbal to which narrow-field and wide-field digital cameras were mounted. Track algorithms capable of operating on power poles, high voltage conductors and various types of insulators were developed for the track processor. Further, processing algorithms were developed to facilitate automatic and rapid recognition of selected faults in the power transmission system. The INSPECT system was demonstrated on selected power lines belonging to the Tennessee Valley Authority (TVA) through a series of flight test in November 1995.

15. Subject Terms Airborne inspection, power transmission fault detection, stabilized imagery

Security Classification of					
16. Report unclassified	17. Abstract unclassified	18. This Page unclassified	19. Limitation of Abstract Limited	20. # of Pages 26	21. Responsible Person (Name and Telephone #) Capt Richard Cobb (505) 846-8255

SBIR Rights Notice

These SBIR data are furnished with SBIR rights under USAF/PL Contract No. F29601-93-C-0205. For a period of four (4) years after acceptance of all items to be delivered under this contract, the Government agrees to use these data for Government purposes only, and they shall not be disclosed outside the Government (including disclosure for procurement purposes) during such period without permission of the Contractor, except that, subject to the foregoing use and disclosure prohibitions, such data may be disclosed for use by support Contractors. After the aforesaid four (4) year period, the Government has a royalty free license to use, and to authorize others to use on its behalf, these data for Government purposes, but it is relieved of all disclosure prohibitions and assumes no liability for unauthorized use of these data by third parties. This notice shall be affixed to any reproductions of this data, in whole or in part.

1 INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION

This report is intended to document the activities and accomplishments of the INSPECT program. The INSPECT program is a Small Business Innovative Research (SBIR) cooperative effort undertaken by SVS R&D Systems and jointly funded by the Philips Laboratory, USAF and the Tennessee Valley Authority.

1.2 PROGRAM OBJECTIVES

The INSPECT program objectives are summarized to apply advanced image stabilization and pattern recognition technologies to the routine maintenance inspection tasks of commercial power transmission lines and components to:

1. Perform the inspection tasks with greater speed and precision in a cost effective manner.
2. Operate in an airborne, helicopter mounted environment.
3. Provide inspection equipment that is easily operable by commercial power company technician personnel.
4. Support recognition of a diverse set of transmission line configurations and operate with a range of background scenes and lighting conditions.

1.3 EXECUTIVE OVERVIEW

The INSPECT program began in September, 1994 and was successfully completed in December, 1995. The program used a combination of wide and narrow field visible waveband cameras to obtain images of power line components. The cameras were mounted in a four axis mechanical gimbal system which was attached to the forward bottom fuselage of a TVA supplied, Jet Ranger II helicopter. Electronics associated with the cameras and gimbals, video recorders for collecting the inspection images, computer processing and operator controls were mounted in an electronic rack located in the rear passenger section of the helicopter.

The outer two axes of the gimbal are used to provide wide field of regard coverage (± 120 ° in pan and +15, -60 ° in pitch) for the inspection cameras while the inner two axes provide a limited (±1° pan and pitch) but highly stabilized field of regard in order to isolate the cameras from helicopter and aerodynamically induced vibrations.

The wide field (16x16 degrees) camera is used view the transmission towers, lines and components allowing the operator to observe and select objects of interest as the helicopter flies along side the transmission right of way. The narrow field (variable from 10x10 to 1x1 degrees) camera is used for the high resolution, magnified imaging inspection of the selected object. The operator views the camera video on a computer controlled monitor screen that is part of the electronics console. The monitor also displays operational information and various gate structures used in the acquisition and tracking process. Line-of-sight pointing of the gimbal and cameras is accomplished by the operator with a two axis manual joy stick. Once an inspection component has been selected and centered in the acquisition reference gate, the operator commands a transition to track mode, and the line of sight to the selected component is automatically maintained by an edge-correlation tracking processor in the computer. When stable edge tracking has been established, the narrow field camera is used to zoom in and capture high resolution images of the component that can be evaluated by fault detection image processing algorithms.

Faults such as broken insulator bells and frayed wires are detected off line in a two pass process that uses as input the recorded video tape data base generated during the helicopter inspection flights. The collected high resolution inspection video is digitized with signal processing and data storage computer equipment. Then, custom component filter and pattern recognition algorithms are applied to the digitized video data base to locate specific components within the frame sequences and determine if fault characteristics are present. Once fault detection occurs, the frame ID, fault location and fault type are supplied to the inspection evaluation operator.

1.4 SIGNIFICANT MILESTONES

Significant INSPECT program milestones are summarized in the following list:

1. Initiate Design Activity	September 1994
2. Critical Design Review	December 1994
3. Purchasing and Fabrication	January 1995
4. Component Testing in Lab	February 1995
5. Vibration Flight Tests at Muscle Shoals	April 1995
6. Gimbal Assembly Testing in Lab	July 1995
7. First Stage Integrated Lab Tests & Demo	August 1995
8. Full System Integration and Lab Tests	October 1995
9. System Flight Test/Data Collect at Muscle Shoals	November 1995
10. Test Results Presentation and Report	December 1995

1.5 FUNCTIONAL DESCRIPTION

The INSPECT equipment can be described by organizing its many components into three major subsystems working in time phased, integrated concert to provide for the collection of high resolution images of power line components from an airborne sensor suite and for the evaluation of these images to isolate and detect component failures.

Two subsystems are installed in and operate as part of the helicopter mounted, airborne sensor platform. These two helicopter mounted components are described in the paragraphs below. A block diagram of the INSPECT configuration of these subsystems is shown in Figure 2-1. The third subsystem comprises non-flight, off-line computer hardware and software that evaluates collected inspection data needing access only to tape recorded wide and narrow field camera video of the power line inspection scenes.. The off-line processing construct is described in Section 4.

2 FUNCTIONAL DESCRIPTION

The INPSECT equipment can be described by organizing its many components into three major subsystems working in time-phased, integrated concert to provide for the collection of high-resolution images of power-line components from an airborne sensor suite and for the evaluation of these images to isolate and detect component failures.

Two subsystems are installed in and operate as part of the helicopter mounted, airborne sensor platform. These two helicopter mounted components are described in the paragraphs below. A block diagram of the INSPECT configuration of these subsystems is shown in Figure 2-1.

The third subsystem comprises non-flight, off-line computer hardware and software that evaluates collected inspection data needing access only to tape recorded wide and narrow field camera video of the power-line inspection scenes. The off-line processing construct is described in Section 4.

2.1 GIMBAL/PLATFORM SUBSYSTEM

The gimbal/platform subsystem functions as the sensing payload portion of the INSPECT system and includes all the equipment mounted outside the helicopter. The subsystem components are contained in a two axis gimbal/turret package and protected from the external environment by a graphite-epoxy, spherical aero-shroud. There is a lexan slot window in the turret that provides an elevation (pitch) viewing aperture of +15 to -60 degrees for the sensor package mounted on the turret inner gimbal. the aero-shroud rotates with the azimuth (pan) gimbal axis to provide the ±120 degrees of side-to-side field of regard. The turret package is mounted to an interface attachment plate on the forward bottom centerline of the helicopter.

The inspection camera payload is mounted on an inner set of limited angle fine gimbals which are in turn mounted to and carried by an outer set of wide angle coarse gimbals. The inner gimbal uses voice coil actuators to generate the required angular motions over a ±1° range. The outer gimbal uses DC torque motor actuators to generate the ±120° azimuth axis motion range and the +15 to -60° elevation axis motion range. The inner and outer gimbals are operated in two basic modes. These modes are Position and Rate. In the Position mode, the servo loops are closed around position sensors mounted at the respective gimbal rotation points. Linear Voltage Differential Transformer (LVDT) position sensors are used for the inner gimbal and precision potentiometers are used for the outer gimbal. In the Rate mode, the servo loops are closed around inertial rate sensors mounted on the respective gimbals. The Position mode is used to command the gimbal to a specific angle. The gimbal will remain at this angle until the command is changed.

The Rate mode is used to command the gimbal to a specific rate. The gimbal will continue to slew at this rate until the command is changed or the angle limit stops are engaged. The Rate mode is the prime operational mode and provides for line-of-sight stabilization and track loop closure.

The sensor payload consists of two visible waveband cameras. One camera is a wide field (16x16°), black and white CCD and provides the acquisition and tracking video to the operator and controller processor. The other camera is a narrow field (10 to 1° square), zoom lens, color CCD and provides the inspection video instrumentation. The narrow field camera is equipped

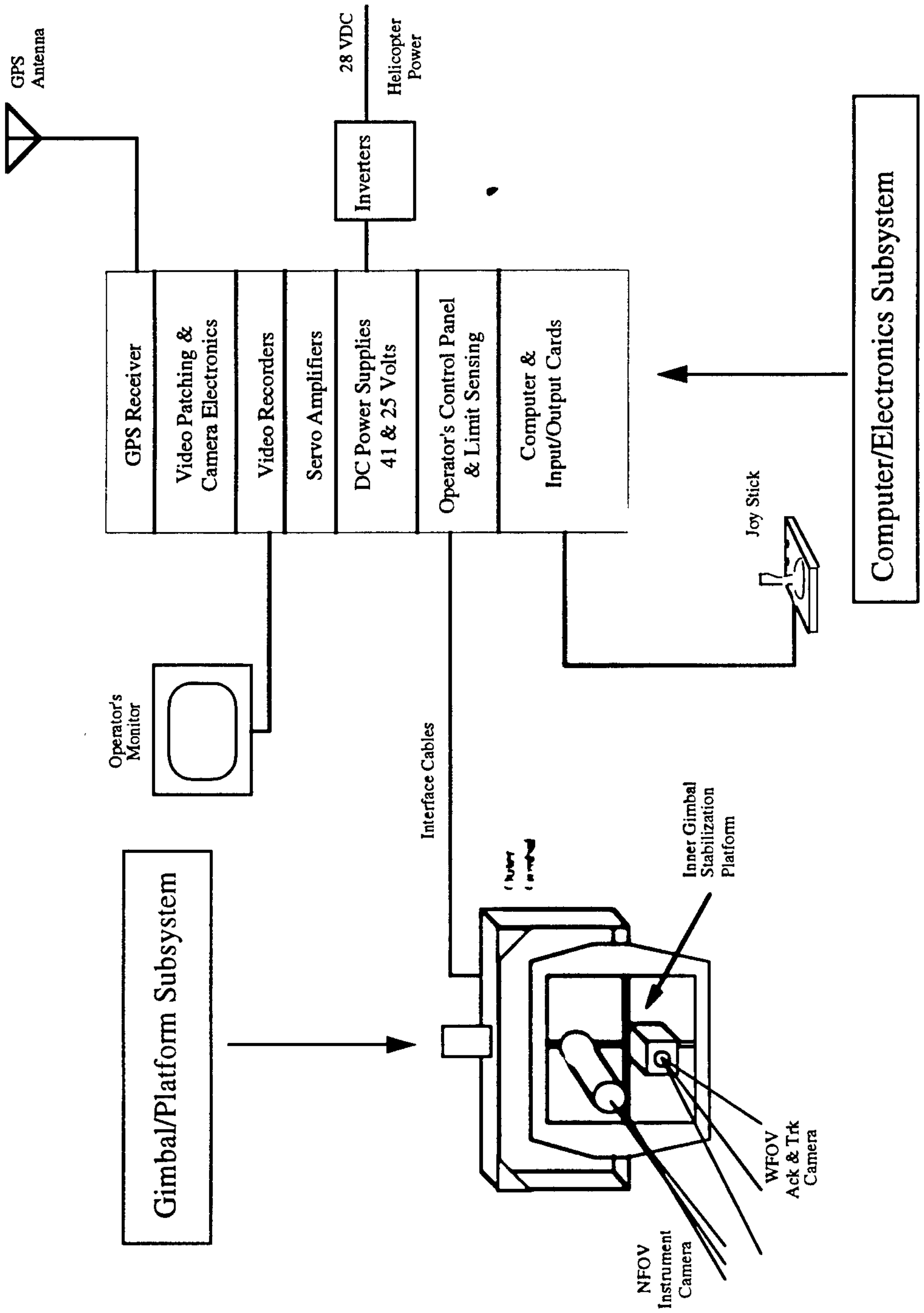


Figure 2-1. INSPECT Configuration Block Diagram

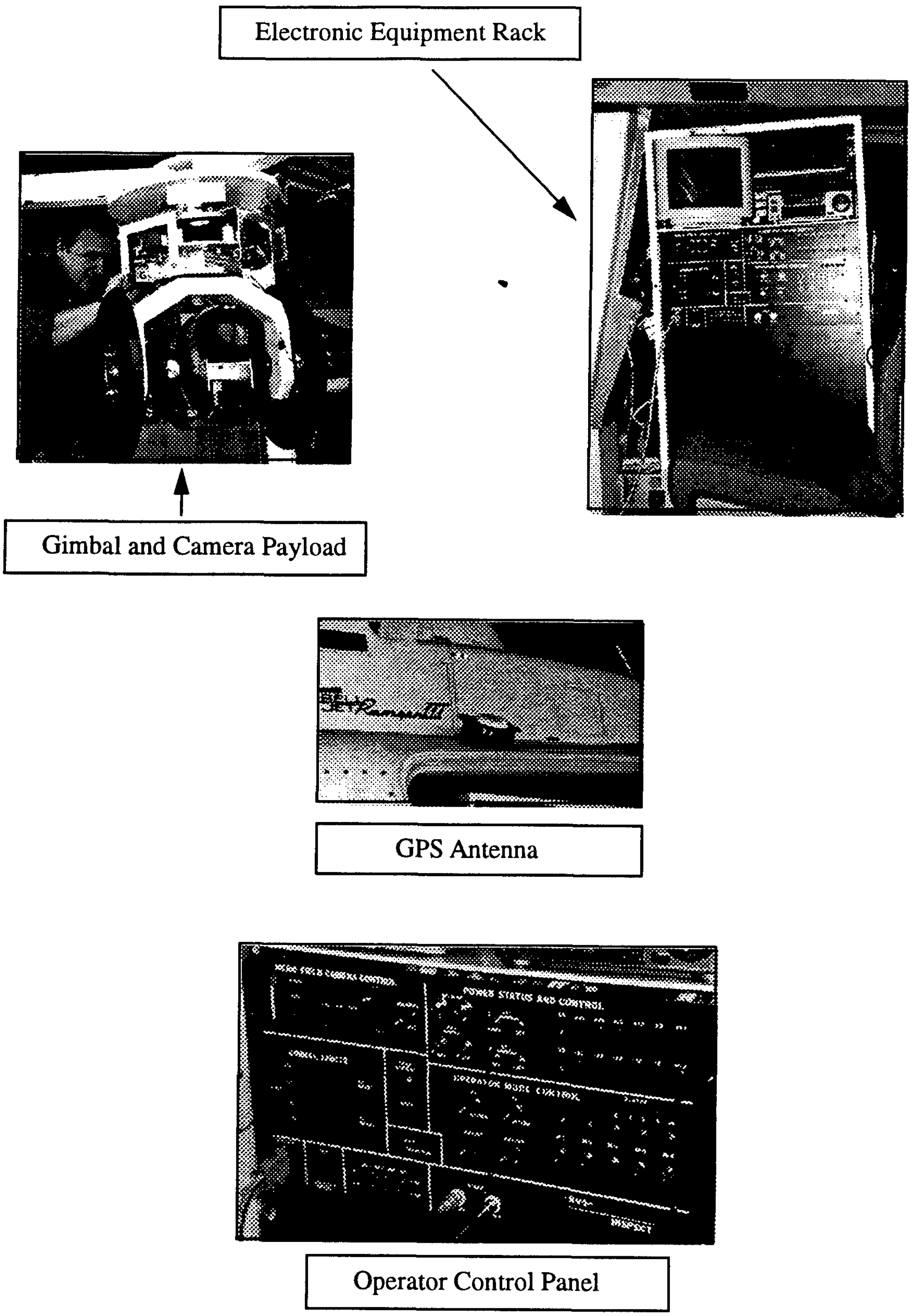


Figure 2-2. INSPECT Component Details

with both zoom and focus control. The cameras are mounted on the payload plate which forms the inner most portion of the nested gimbal sets. The outer gimbals provide full field of regard coverage for the cameras while the inner gimbals provide the limited range motion necessary to cancel vibration disturbances and keep the respective lines-of-sight highly stable in order to produce blur free images.

Several of the gimbal/platform subsystem components are shown in Figure 2-2.

2.2 COMPUTER/ELECTRONICS SUBSYSTEM

The computer/electronics subsystem functions as the controlling operations center of the INSPECT system and includes all the equipment mounted inside the helicopter. The subsystem components are housed in an electronics rack mounted in the right two thirds of the rear passenger compartment. The remaining one third of the compartment is used for the inspection system operator position. A color computer monitor, gimbal controller joy stick and system control panel provide the interface between the gimbal, computer, cameras and operations sequences of the INSPECT system and the inspection operator.

The controller processor computer is key to the operation of the computer/electronics subsystem. The computer hardware and software package provides the image processing, tracker functions, gimbal servo controller functions, interface operations and mode sequence control that are necessary for the inspection mission. There are two processors internal to the computer. One is used entirely for the image and track processing functions while the other provides the servo controller and mode control functions. There are 16 analog input and 8 analog output channels that are used to interface with the gimbal, operator and other subsystems.

The gimbal torque motors and voice coil actuators are powered by linear amplifiers that are located in the electronics rack. These power amplifiers receive input voltage commands from the computer servo controller and respond by generating current drive commands to the gimbal actuators which in turn create fine and coarse gimbal motion. Power for the linear amplifiers is obtained from DC voltage supplies that operate from 115 VAC, 60 Hz. The AC power is generated from the helicopter +28 VDC prime power by a pair of inverter supplies.

A GPS receiver unit is provided to precisely measure the location of the helicopter during the inspection data collection operations. The GPS position and time are displayed on the operator's monitor and eventually will be recorded on the instrumentation video frames.

There are two video recorders in the electronic rack which are used to record the narrow and wide field camera video during the inspection operations. Both are 8 mm, S-video format to provide maximum resolution and clarity. Some of the individual computer/electronics subsystem components are shown in Figure 2-2.

3 TEST RESULTS

There were three major testing activities planned and accomplished during the Inspection program. The first testing activity involved installation of the gimbal mechanical system components and a simulated camera payload on a Jet Ranger helicopter. The gimbal and helicopter were instrumented to determine the vibration environment at the base of the gimbal mounting and at the simulated camera payload plate. The vibration characterization flight tests were conducted at the TVA helicopter flight facilities in Muscle Shoals, Alabama. The second test activity was performed in the Inspect integration and test laboratory at Kirtland AFB, Albuquerque, NM and involved integrated testing of all Inspect components and subsystems to characterize system performance and operation prior to full up flight testing on the helicopter platform. The third testing activity was performed again at the TVA facility in Muscle Shoals, Alabama and involved utilizing the installed INSPECT system and the Jet Ranger helicopter to acquire, track and collect high resolution images of power lines and components

3.1 VIBRATION TEST RESULTS

Vibration characterization testing was performed in late April, 1995 at the TVA helicopter support facility in Muscle Shoals, Alabama. The objectives of the helicopter vibration testing is summarized in the following descriptions.

1. Collect angular position data from highly sensitive angular displacement sensors (ADS) attached to the helicopter body.

2. Collect angular position data from an ADS mounted on the INSPECT gimbal camera platform structure.

3. Collect linear accelerometer, rate and position data from accelerometer cubes co-located with the ADS instruments.

4. Collect video data from a camera mounted on the gimbal sensor platform adjacent to the gimbal ADS instrument.

The vibration envelope was characterized over several test flights for solid mount gimbal, soft mount gimbal and wedge mount gimbal configurations. Helicopter speeds and transmission line survey techniques were varied to insure a full regimen of operational conditions was covered. Good video, ADS and accelerometer data were collected; however, with the exception of quick look reductions and the video recordings, much of the data reduction had to be performed after the flight tests had been completed due to a malfunctioning data reduction computer interface card.

The significant results of the vibration testing and data analysis are described by the following:

1. The helicopter vibration environment did not exceed expected levels.

2. There was benefit in using Barry Isolator type mounts (soft mounts) to help reduce transmitted vibrations in the roll and pitch axes.

3. There was significant residual vibration at the sensor/payload plate to warrant inclusion of the inertially stabilized, inner gimbal axes.

4. Aerodynamic loading and induced vibrations from a spherical, protective shroud were manageable with the current design control system bandwidths.

Figure 3-1 is a Power Spectral Density (PSD) plot showing a typical comparison of measured sensor platform jitter for hard and soft (Barry) gimbal configurations.

3.2 LABORATORY SYSTEM INTEGRATION AND TEST RESULTS

Laboratory system integration and test was begun in September, 1995 and completed at the end of October, 1995. The purpose of the integration and test activity was to bring all the INSPECT components together in a system configuration and establish operational and performance readiness prior to moving the equipment to Muscle Shoals, Alabama for installation on the helicopter, flight testing and data collection.

Significant results of the laboratory system integration and testing are described by the following:

1. Gimbal position and rate loops were compensated, characterized and adjusted to meet requirements for the outer and inner axes. Rate and position sensors were aligned and scale factors calibrated and recorded.

2. Gimbal limit switches, caging mechanisms and hard stop locations were tested, checked and final adjustments made.

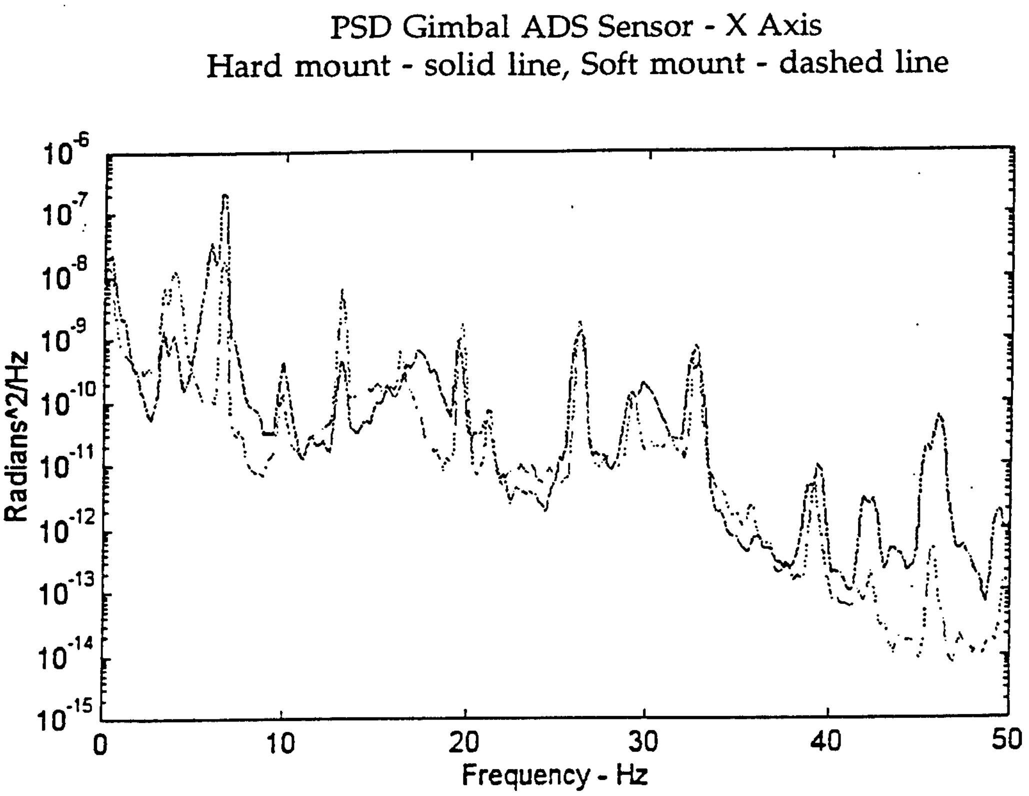
3. Operator console, video monitor, display symbology and gimbal joy stick controller functions were refined, calibrated and tested. 4. Computer interfaces with the servo drive amplifiers and gimbal sensors were tested, calibrated and refined to meet system control requirements.

5. Mode control and executive operating software was tested, adjusted and modifications incorporated. The bus communication link with the tracking processor was established, tested and adjusted. The flight processor self boot hardware and software was installed, tested, modified and calibrated.

6. Payload camera video operation and distribution was established, tested and adjusted to meet system requirements. Video instrumentation recorders were installed, patched and tested.

7. The centroid and edge tracking algorithms and track loops were installed, tested and modified using a simulated target and scene generator.

8. The GPS receiver/computer package was integrated with the control/executive computer. Display symbology and data paths were checked, adjusted and optimized. The GPS functions were checked by installing an outside receiving antenna adjacent to the laboratory.


PSD Gimbal ADS Sensor - X Axis
Hard mount - solid line, Soft mount - dashed line

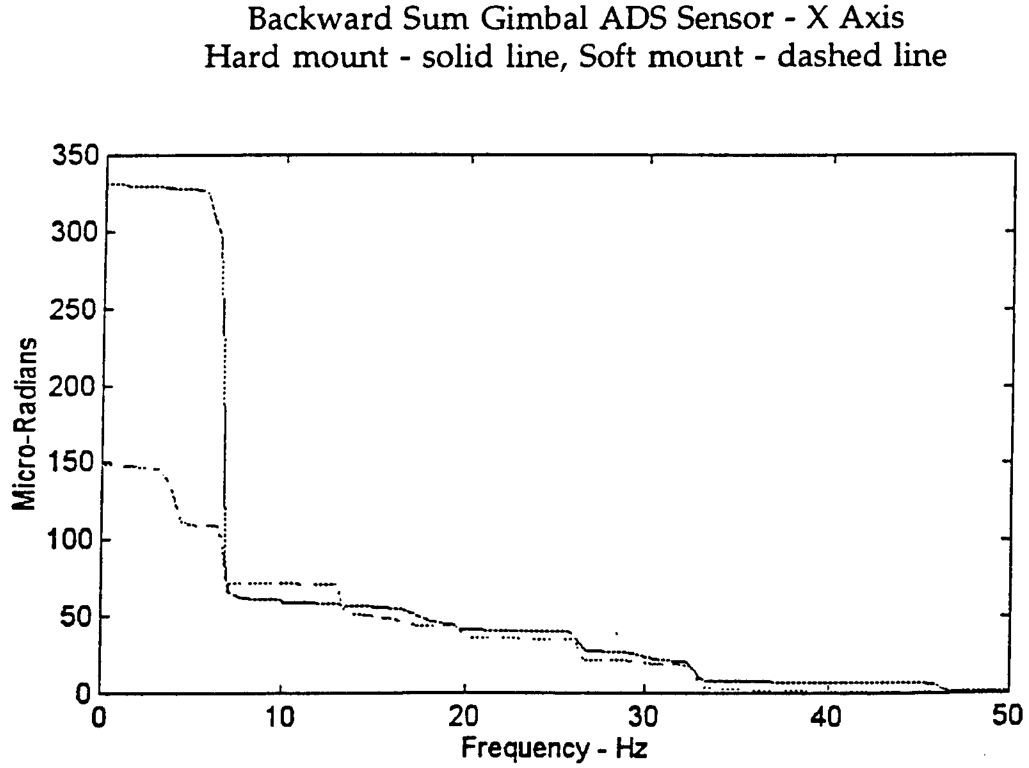

Backward Sum Gimbal ADS Sensor - X Axis
Hard mount - solid line, Soft mount - dashed line

Figure 3-1. Comparison of Gimbal-to-Helicopter Mounting Techniques

3.3 HELICOPTER SYSTEM INTEGRATION AND FLIGHT TEST RESULTS

Field integration and flight testing of the INSPECT equipment was begun on 1 November, 1995 and completed eight days later on 9 November. The integration and flight testing was performed at the TVA helicopter support facility in Muscle Shoals, Alabama. The INSPECT system components and installation are shown in Figure 3-2.

Significant results of the system integration and flight testing are described by the following and also shown in two test results videos already provided to the TVA, one quick look data video delivered shortly after the completion of flight testing in November and the other delivered as part of a formal management briefing in December, 1995.

1. Gimbal stabilization performance was successful in eliminating helicopter and aerodynamically induced vibration disturbances on the sensor line-of-sight. Gimbal slew rates and acceleration performance was adequate.

2. Operator interfaces proved satisfactory for monitoring and controlling the Inspection processes although space, lighting conditions and additional displays would enhance efficiency in a full up operational environment.

3. Gimbal and electronic rack weight far exceeded what a nominal operational system design would be expected to meet. The interface structure and gimbal attachment were considered sound enough for early, low-Q flight testing. After gaining experience with the handling and integrity of the INSPECT equipment, the envelope was opened and no adverse effects noted during normal line survey and ferry operations.

4. The graphite epoxy aero-shroud and sensor window performed admirably in keeping the aerodynamic loading of the gimbal to a minimum and in protecting the components from the environment even during a brief squall shower although not designed with hermetic seals.

5. GPS operation and monitor display functions performed as expected. The location of the GPS antenna and the resultant shielding of sections of the sky view did not significantly hamper the generation of reasonable position and time data.

6. The Pulnix NFOV camera failed after only a few days into the flight tests. Although the manufacturer was able to repair and return the camera before the end of flight testing, significant inspection video data collection opportunity was lost. The repaired camera video appeared marginal and most likely, further repair actions are warranted.

7. The NFOV zoom and focus manual controller is not fast enough against even a slow survey of power lines. There should be an auto focus loop incorporated in the NFOV camera. The operator work load is very high and the time to react to focus needs between poles is very short.

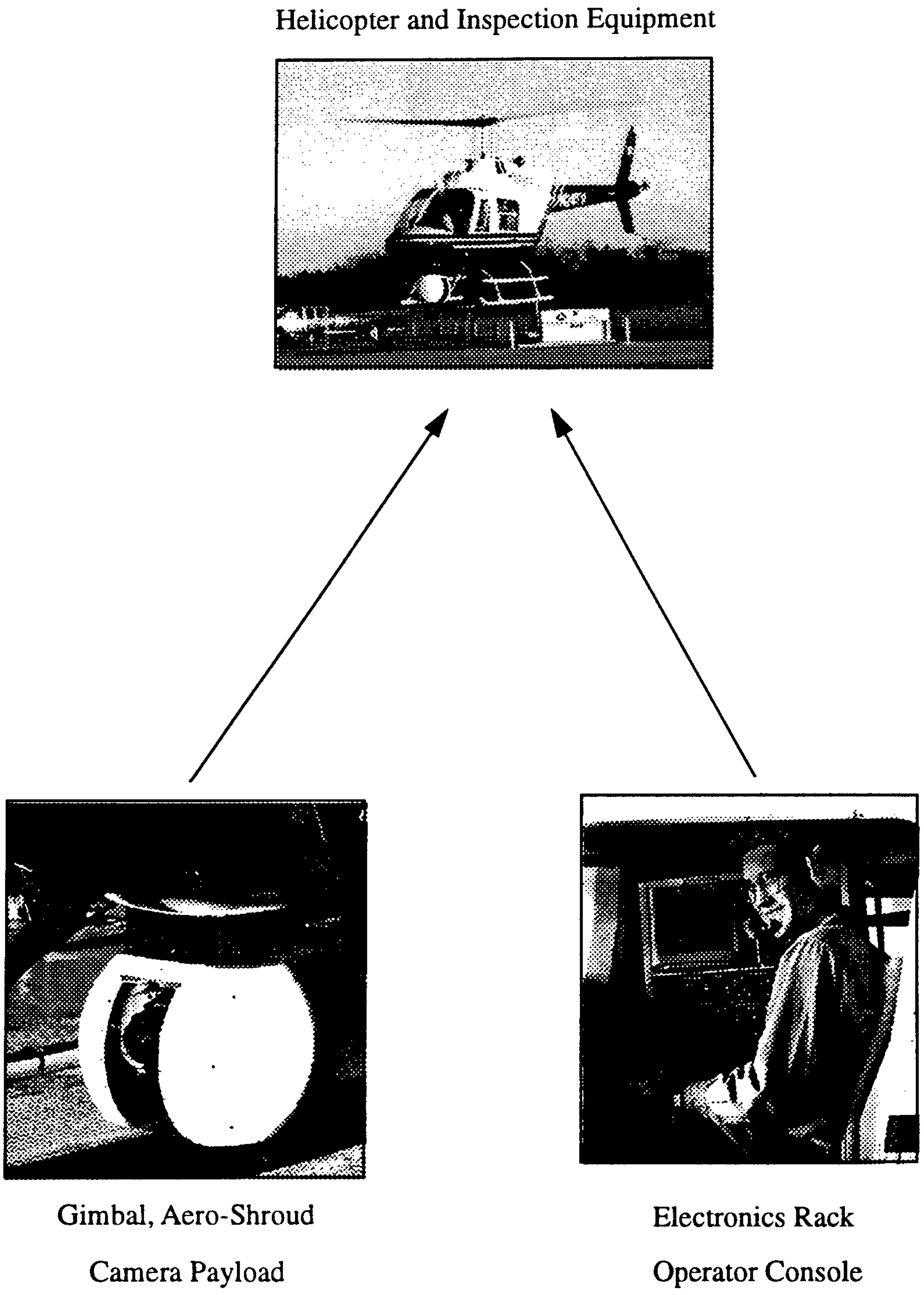


Figure 3-2. Inspection System Components and Installation on Helicopter

8. The gimbal drive power amplifiers performed suitably but were prone to failure. This did not adversely effect flight testing since there were adequate spare amplifiers and components for repair and replacement.

9. The edge-correlation tracking algorithm exhibited marginal performance mainly due to difficult and confusing edge maps and clutter. The map and threshold robustness to typical power line scenes needs to be improved. Attempts at using centroid tracking as a backup to the edge algorithm showed that despite some capable tracking performance demonstrated, the edge tracker can be a preferred solution the power component tracking task.

10. The track processor will need more computing power in next generation hardware implementations since several video and control operator features had to be sacrificed to make room for the tracking loads.

The following Figures, 3-3 through 3-6, are typical servo control plots taken during flight testing to characterize the "as operated" gimbal loops.

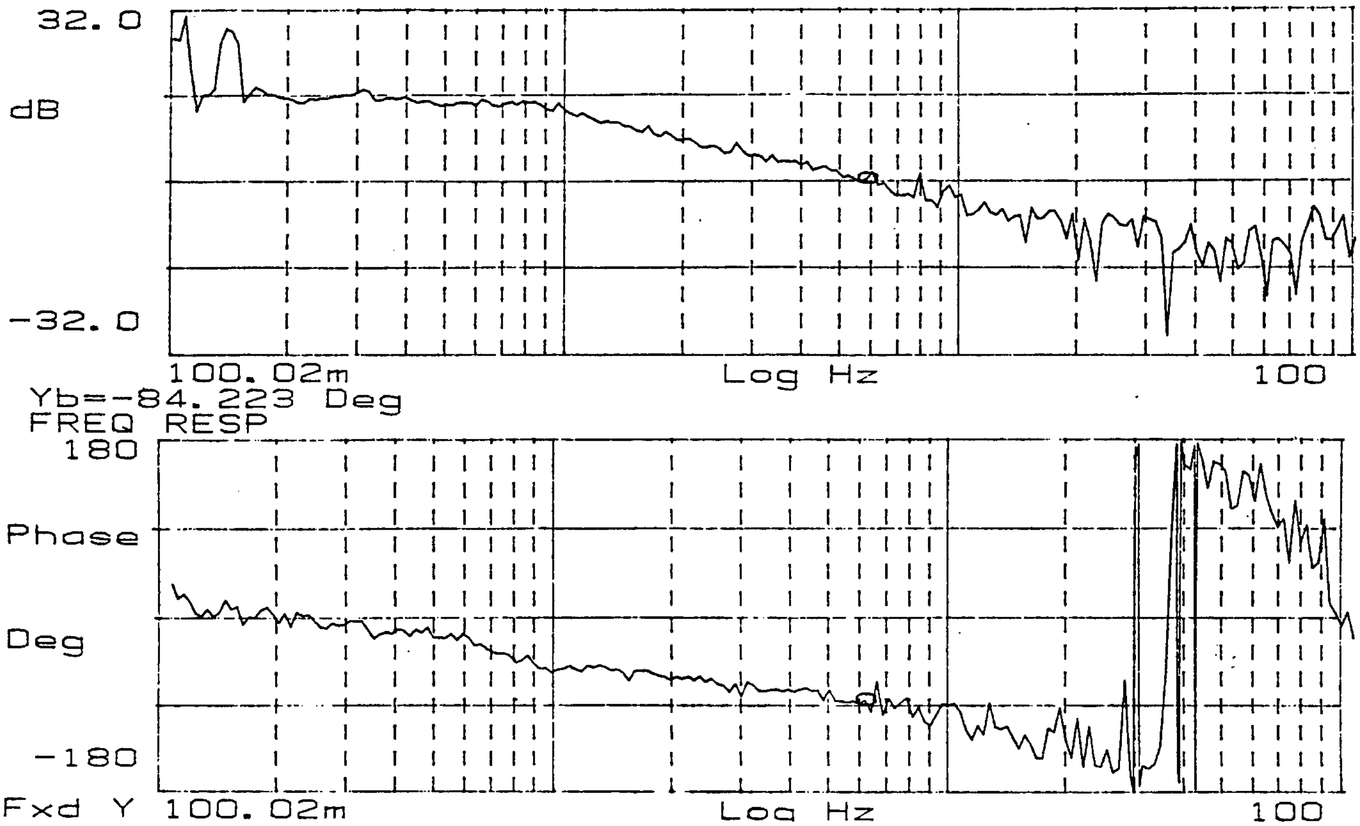


Figure 3-3. Open-Loop Gain and Phase vs. Frequency of Outer Azimuth Rate

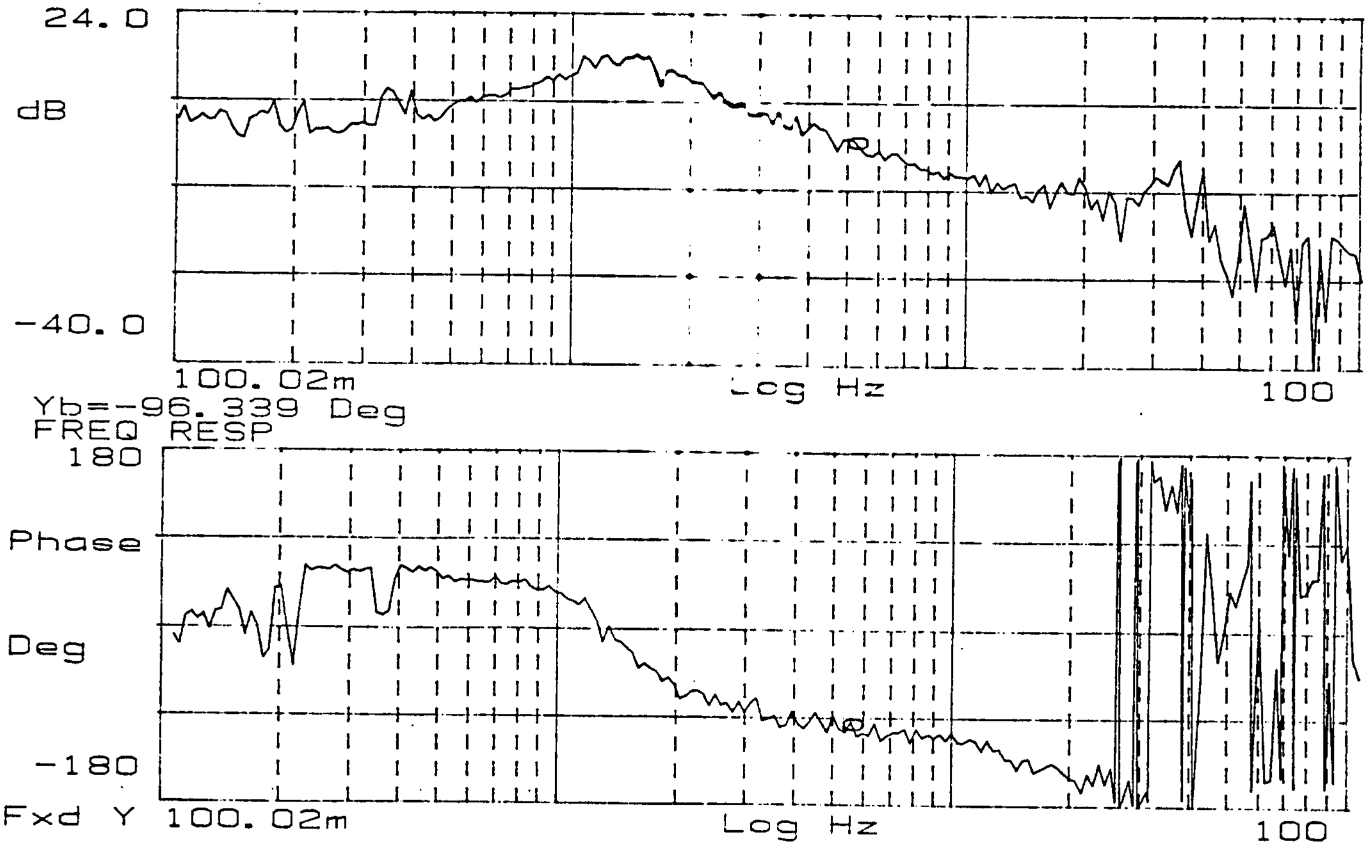


Figure 3-4. Open-Loop Gain and Phase vs. Frequency of Outer Elevation Rate

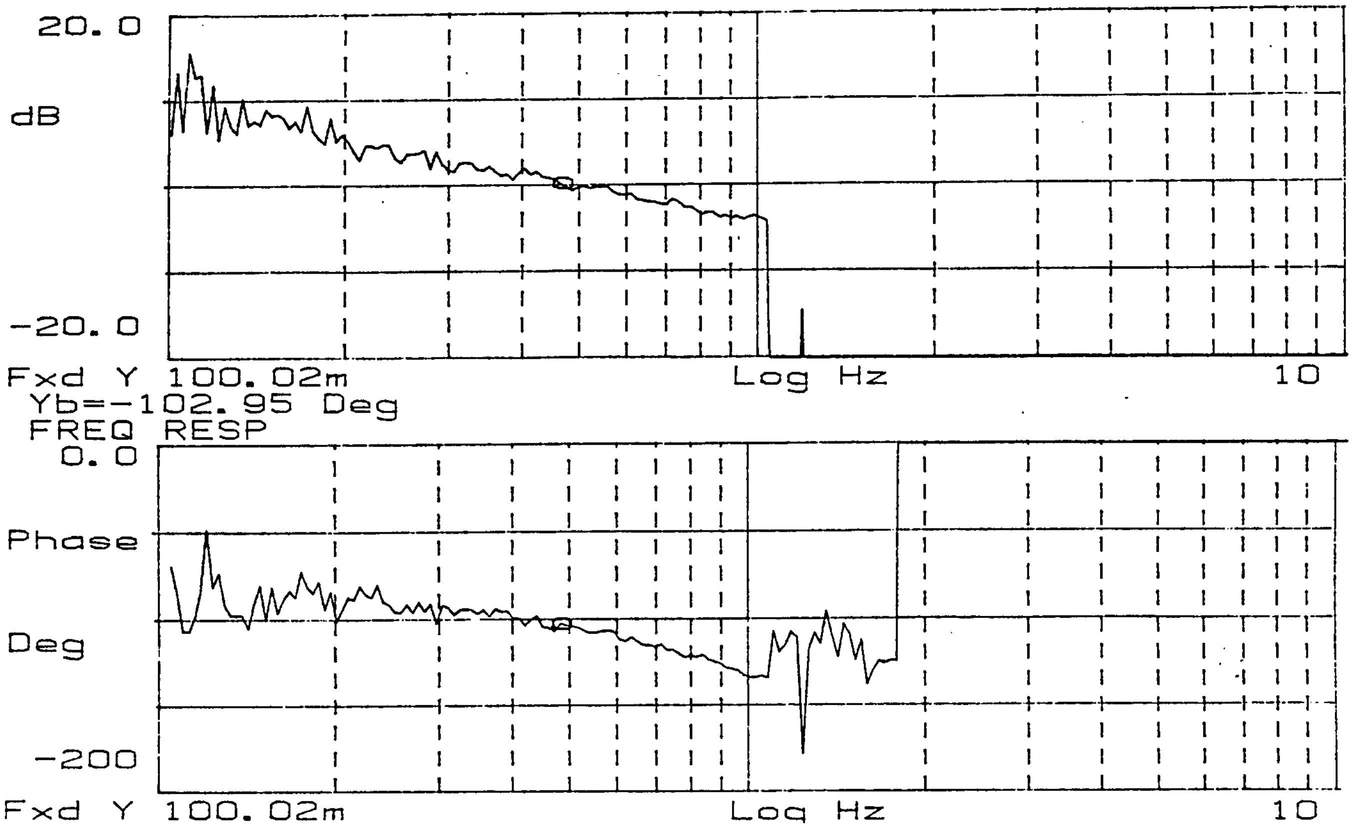


Figure 3-5. Open-Loop Gain and Phase vs. Frequency of Outer Azimuth Track

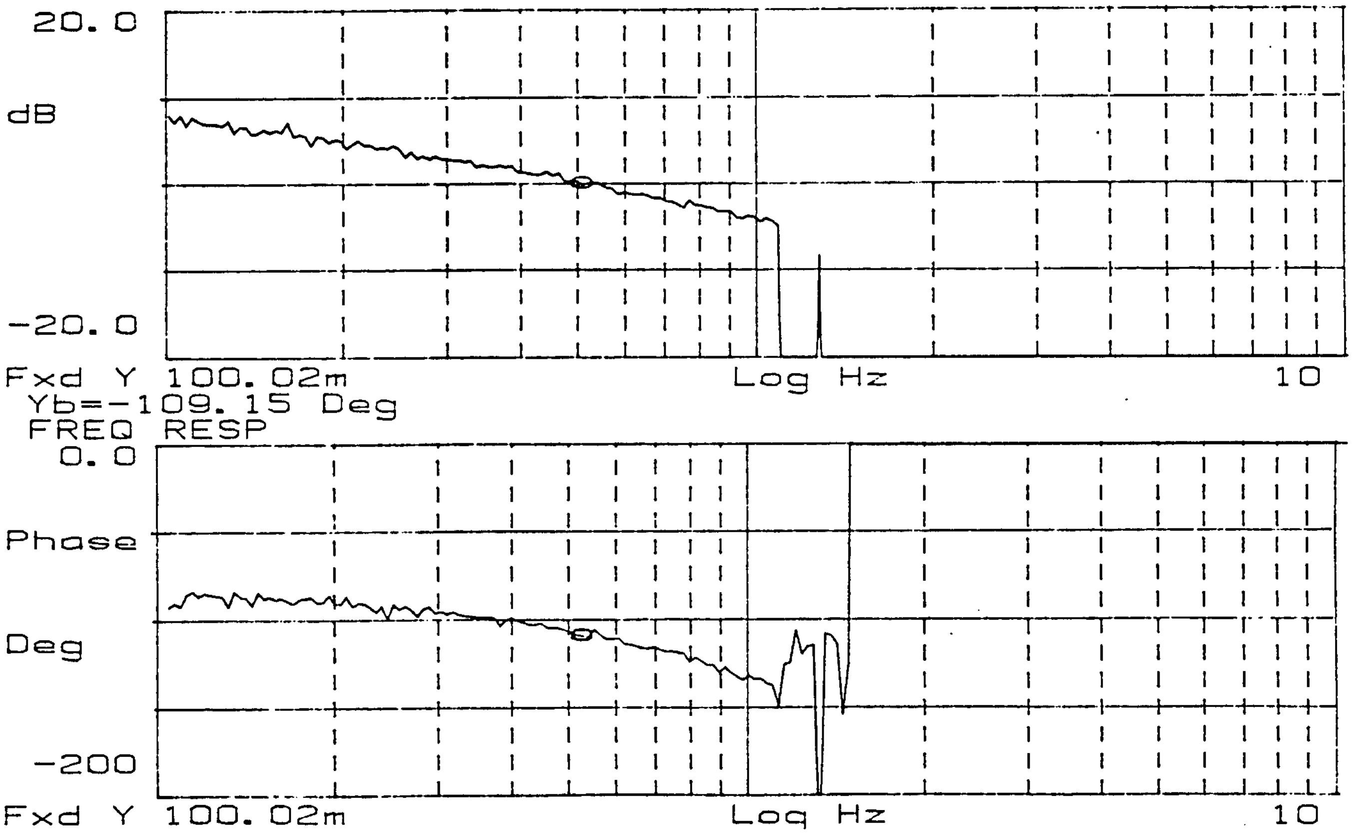


Figure 3-6. Open-Loop Gain and Phase vs. Frequency of Outer Elevation Track

4 ALGORITHM DEVELOPMENT RESULTS

There are two major processes and their associated computer implemented algorithms that were developed and refined for use with the INSPECT program. One involved development of a unique edge-correlation tracking algorithm especially suited to the component construct of commercial power transmission lines. The other involved development of component filter and pattern recognition algorithms that could be applied to isolate and detect faulty power line components in scenes digitized from high resolution images recorded by helicopter mounted video cameras.

The algorithms were developed using a scripting matrix manipulation language called MatLab. Matlab is known as a pseudo-high level language that creates scripts that are interpreted one line at a time during execution. Once the algorithms have been developed and are properly debugged, they can be translated to whatever language is necessary to match hardware platforms and meet performance requirements. The hardware developmental platforms used during the INSPECT activity consists of several 486-DX2 desktop PCs and two Sun SPARC 20 workstations.

Summary descriptions of the development activity and results are provided in the following paragraphs.

4.1 TRACKING ALGORITHM

In the course of designing a tracker for the INSPECT program, several specialized solutions were considered. The tracking solutions that were explored can be grouped under the following four categories:

1. The Morphological Tracker
2. The Deformable Template Tracker
3. The Adaptive Edge Tracker
4. The Edge Energy Tracker

Of the solutions investigated, the adaptive edge tracker was selected as the final and most appropriate tracker for INSPECT. This tracker provides a robust, versatile solution by using the deformable template tracking methodology but with generation of its own templates on the fly. Laplacian-of-Gaussian edge detection and vector correlation are used to match a template to the image subsection inside the track gate when the operator clicks on the desired target. The template is used until correlation with the image falls below a selected threshold. At this point, a new template from the scene within the gate is generated automatically. This approach was especially suited to the vertical, horizontal and angular intersections so naturally prevalent in images of power line components and structures. Template matching with automatic refresh as a function of threshold overcame the problems encountered with other methods when working against such differentiated target structure and especially with the wide variation in backgrounds seen along the course of a typical inspection flight.

4.2 INSPECTION ALGORITHM

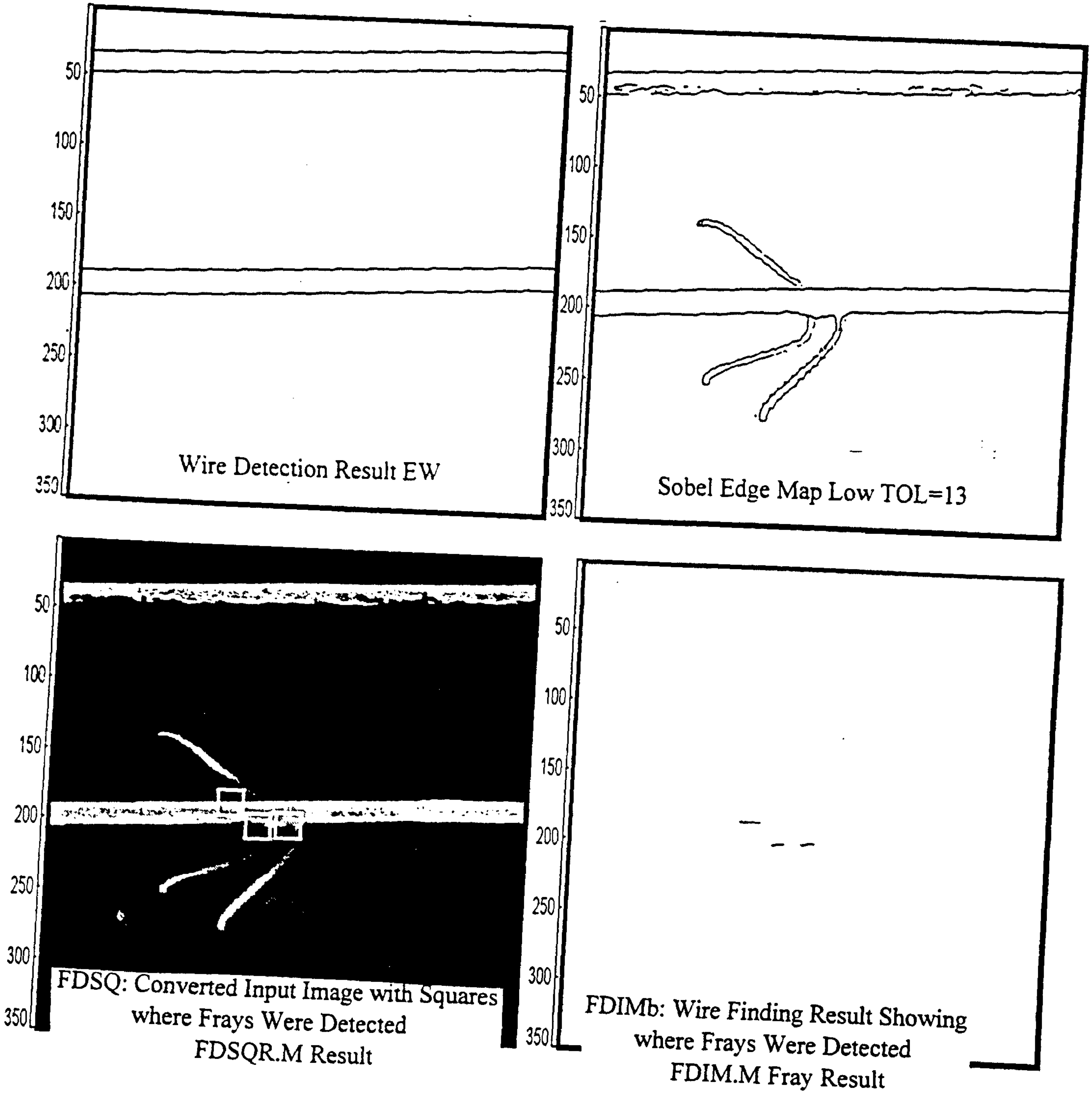
Three areas of component inspection were addressed during the INSPECT program effort. These are insulators, transmission wires and line spacers. Although the tracking algorithm developmental effort dealt extensively with transmission structures and distribution poles, the inspection and detection algorithm effort did not investigate these components.

The goal of insulator inspection is to identify the defects of an insulator. Once each insulator is extracted from other structure and background associated with the composite image, any defects such as a missing or broken bell (disk on the insulator) can be detected by counting the number of bells and measuring the size of bells and comparing each to the average of all bells in the frame. A two step process was used for the automated inspection and detection of insulator faults. First, the insulator is located within the 640X480 digitized image made from the flight video data tape. Location is extracted by using a template matching process applied to the image field. After the insulator is located, a binary sub-image with noise filtering is created. The binary image is suited to object counting and sizing pattern processors; and thus, provides the basis to fault detection and location.

A similar problem exists for detection of power lines themselves within the recorded images. Once the exact coordinates of the power lines are found, tasks such as fray detection and analysis can be pursued. The wire extraction and location algorithm is basically a gradient routine using a Sobel operator to perform an edge map search of the left side of the morphed, digitized image for a short horizontal run of pixels. It then follows the same process to define the location of the other edge. The result is definition of the exact location and a position map of the wire within the image frame.

Since the wire finding routine gives the exact locations of each wire, a program can be created to follow along the wires and search for features that are of interest, such as frays and spacers. The frays and spacers are seen as "perpendicular" anomalies to the normally well behaved roughly horizontal wires. The fray detection routine is key to both the fray and spacer fault process in that a spacer can be located as multiple fray detection that are well behaved with respect to template locations.

The final versions of the insulator, fray and spacer fault detection algorithms were tested on 35 mm Haverfield digitized photographs of frays and spacers, video frames from wide field flight test images of insulators and spacers, and narrow field video frames of flight test wire, spacer and insulator images. The algorithms successfully detected multiple frays, spacers and broken insulator bells. Illustrations of the fray detection process are shown in Figure 4-1 below.



Wire Detection Result EW

Sobel Edge Map Low TOL=13

FDSQ: Converted Input Image with Squares where Frays Were Detected FDSQR.M Result

FDIMb: Wire Finding Result Showing where Frays Were Detected FDIM.M Fray Result

Figure 4-1. Fray Detection Algorithm Process Sequence

5 CONCLUSIONS

The INSPECT SBIR program has successfully demonstrated the feasibility and benefit of transferring and applying high-tech solutions developed to solve problems on government and defense department programs toward the solution of commercial market problems. The INSPECT program applied advanced technologies in the inertial stabilization, edge-correlation tracking and pattern recognition fields to the commercial power line inspection and data base collection processes that are currently performed manually with human observers. Proof of principle hardware and software was designed, built, tested and demonstrated in flight tests over the relatively short 15 month duration of the program. The equipment demonstrated the feasibility of the design to acquire, track, provide images, and determine the location of several typical power line components including the detection of broken insulator bells.

The INSPECT program demonstrates that the potential benefit in applying these technologies for speeding up the inspection process is great and significant cost reductions can therefore be realized. It is also recognized that in the case of many technology transfers, the extent of the operational difficulties and the scope of the commercial requirements is not fully realized until equipment is tested in the field. This is a typically normal process for most demonstration programs. The next step for the INSPECT program will be to refine the proof of principle design according to the results of the field testing and to further participate with potential customers in the definition of operational and support requirements that can be incorporated in a pre-production unit.

DISTRIBUTION LIST

AUL/LSE Bldg 1405 - 600 Chennault Circle Maxwell AFB, AL 36112-6424	1 cy
DTIC/OCP 8725 John J. Kingman Rd, Suite 0944 Ft Belvoir, VA 22060-6218	2 cys
AFSAA/SAI 1580 Air Force Pentagon Washington, DC 20330-1580	1 cy
PL/SUL Kirtland AFB, NM 87117-5776	2 cys
PL/HO Kirtland AFB, NM 87117-5776	1 cy
Official Record Copy PL/VTS/Capt Cobb Kirtland AFB, NM 87117-5776	2 cys
PL/VT Dr Wick Kirtland AFB, NM 87117-5776	1 cy