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Final Technical Report
June 1976

ACE DESIGN STUDY AND EXPERIMENTS

Bendix Research Laboratories

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ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441

This report has been reviewed and approved for publication.

APPROVED: Donald G. Hall

DONALD G. HALL
Project Engineer

APPROVED: Howard Davis

HOWARD DAVIS
Technical Director
Intelligence & Reconnaissance Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

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Arliss E. Whiteside, Leonard A. Forrest
Gerald A. Brumm, Alar J. Hutchenreuther
Henry L. Ohlef

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Studies and experiments were performed to establish a design for a production photogrammetric system referred to as Advanced Compilation Equipment (ACE). The function of this equipment is to rapidly measure terrain heights from aerial photography and to record this data in digital form. The work included study and evaluation of user requirements, preparation and analysis of a tentative ACE design, performance of experiments on the AS-11B-X automated stereomapper in support of the ACE studies, and preparation of ACE system and viewer design specifications. Design specifications were prepared for two versions of the

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ACE system, one optimized for near-term needs and the other optimized for longer-term needs.

PREFACE

A study and experiments were performed for Rome Air Development Center, Griffiss AFB, New York by Bendix Research Labs, Southfield, Michigan to establish a design for a production photogrammetric system referred to as Advanced Compilation Equipment (ACE). This is the final Technical Report on Contract F30602-74-C-0260. Job Order Number is 43020301.

Mr. Donald Hall was the RADC Project Engineer.

The Bendix technical team was directed by Mr. W. E. Chapelle. The Program Manager was Mr. G. A. Brumm. Principle contributors to this project include Mr. A. E. Whiteside, Mr. H. L. Ohlef, Mr. L. A. Forrest and Mr. A. J. Hutchenreuther.

The assistance of Mr. Frank Scarano of RADC is gratefully acknowledged.

ACE DESIGN STUDY AND EXPERIMENTS

FINAL TECHNICAL REPORT

SUMMARY

In recent years, the Defense Mapping Agency (DMA) has had a need for photogrammetric instruments which can very rapidly measure terrain heights from aerial photography and record this data in digital form. Under Contract F30602-72-C-0042, Bendix Research Laboratories developed an experimental system, based on a new approach referred to as Epipolar Scan Stereomapper (ESS), to meet this goal. The experimental system, now officially designated as the AS-11B-X automated stereomapper, uses a modified viewer and control computer of the proven AS-11B-1 automated stereoplotter because this approach offered the shortest and least expensive route to a system adequate for demonstrating the ESS concept.

During the course of the AS-11B-X development, the Air Force instituted a program entitled "ACE Design Study and AS-11B-X Experiments" (Contract F30602-74-C-0260) aimed at defining a system design concept that was not limited by AS-11B-1 technology. This program called for studies to refine the ESS concept and to establish a design for a production system referred to as Advanced Compilation Equipment (ACE). Design goals for the ACE included improvements with respect to the AS-11B-X in overall speed and accuracy while minimizing cost and complexity.

Work on the ACE program began near the end of the AS-11B-X development. The ACE program included (1) study and evaluation of user requirements, (2) preparation and analysis of a tentative Strawman ACE design, (3) performance of experiments on the AS-11B-X system in support of the ACE studies, and (4) preparation of ACE system and viewer design specifications.

During the course of work on these two programs (AS-11B-X and ACE Design Study), two outstanding facts emerged. First, evaluation tests of the AS-11B-X system established that this experimental system is extremely effective. Compared to previous systems, the AS-11B-X achieves an increase in data collection rates of from 10 to 50 times, at no decrease in accuracy.

Second, the studies performed on ACE system concepts indicated that improved performance over the AS-11B-X can be achieved only by incurring significant costs.

In view of these facts, Air Force, DMA, and Bendix personnel held new discussions to determine what guidelines should be used in future effort on the ACE program. It was decided that emphasis would be placed on a semi-optimum ACE system. Bendix was directed by the Government to investigate a number of ACE design variations to determine if a different approach was appropriate in light of the new guidelines. Several design variations were investigated.

After considering the various alternative ACE designs, the Government indicated a preference for a version based on an AS-11B-1 viewer and computer, referred to as Version 4, in that it provided most of the capabilities of the optimized ACE but at a significantly lower cost and shorter schedule.

The Version 4 ACE design is based on an AS-11B-1 viewer and computer, and the optimized Strawman ACE design is based on dual PDP-11/45 computers and a Bendix-developed viewer. It was concluded that Version 4 design configuration will probably meet the Government's near-to-mid-term needs and can be developed more cheaply in less time and with less risk than the Strawman configuration. It was therefore recommended as the most logical choice for the ACE development based on near-to-mid-term needs. If long-term needs are more important, however, the ACE Strawman design with its greater capability and flexibility is recommended.

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EVALUATION

This effort was initiated to provide a design study and specifications for production photogrammetric system that incorporated the technology emerging from the AS-11B-X development. The new system is referred to as the Advanced Compilation Equipment (ACE). It will provide the DMA a capability to very rapidly derive terrain heights at high spatial density from conventional and non-conventional aerial photography and record this data in digital form at fixed x and y increments.

The work under this effort consisted of four major tasks; (1) a study of the user's requirements; (2) conducting experiments on the AS-11B-X; (3) the development of a tentative strawman ACE design and (4) the preparation of ACE system and viewer design specifications.

A completely new optimum design concept was formulated during the course of study. However, due to fiscal restraints, the contractor was directed to study alternative design concepts that would provide more cost effective approaches and an earlier operational implementation date. The successful operation and efficiency of the AS-11B-X became well established in the early months of this study leading to a decision to adapt a design for the ACE similar to the AS-11B-X, based upon an AS-11B-1 viewer and computer. It was determined that this approach provided most of the capabilities of the desired optimized ACE but at a significantly lower cost and shorter delivery schedule.

The basic purpose of this effort has been accomplished in that an ACE design has been developed and specifications have been prepared that will provide the necessary equipment to satisfy the user's requirements.

Donald G. Hall

DONALD G. HALL
Project Engineer

LIST OF ILLUSTRATIONS

SECTION 1

INTRODUCTION AND SUMMARY

This report presents the results of work done on the ACE (Advanced Compilation Equipment) Design Study and Experiments, under Contract F30602-74-C-0260, during the period from 20 May 1974 to 23 October 1975. The purpose of the study and experiments was to provide a preliminary conceptual design for an ACE production system. During the period covered by this report, a user requirements study was carried out; a Strawman design study was completed, including studies on the viewer, scanner, and correlator and control system; a data collection and analysis plan was prepared; AS-11B-X experiments were performed; and system and viewer specifications were prepared. In addition, at the Government's request, alternative ACE design approaches were investigated and a tentative design was prepared for implementation of a variation based on an AS-11B-1 viewer and computer. Revised system and viewer specifications were prepared for this approach.

1.1 OVERVIEW

In recent years, the Defense Mapping Agency (DMA) has had a need for photogrammetric instruments which can very rapidly measure terrain heights from aerial photography and record this data in digital form. Under Contract F30602-72-C-0042, Bendix Research Laboratories developed an experimental system, based on a new approach referred to as Epipolar Scan Stereomapper (ESS), to meet this goal. The experimental system, now officially designated AS-11B-X automated stereomapper, was implemented primarily as a modification of the proven AS-11B-1 automated stereoplotter because this approach offered the shortest and least expensive route to a working system.

During the course of the AS-11B-X development, the Air Force instituted a program (Contract F30602-74-C-0260) aimed at defining a system design concept that was not limited by AS-11B-1 technology. This program called for studies to refine the ESS concept and to establish a design for a production system referred to as Advanced Compilation Equipment (ACE). Design goals for the ACE included improvements with respect to the AS-11B-X in overall speed and accuracy while minimizing cost and complexity.

Work on the ACE program began near the end of the AS-11B-X development. The ACE program included (1) study and evaluation of user requirements, (2) preparation and analysis of a tentative Strawman ACE design, (3) performance of experiments on the AS-11B-X system in support of the ACE studies, and (4) preparation of ACE system and viewer design specifications.

During the course of work on these two programs (AS-11B-X and ACE Design Study), two outstanding facts emerged. First, evaluation tests of the AS-11B-X system established that this experimental system is extremely effective. Compared to previous systems, the AS-11B-X achieves an increase in data collection rates of from 10 to 50 times, at no decrease in accuracy. Second, the studies performed on ACE system concepts indicated that improved performance over the AS-11B-X can be achieved only by incurring significant costs. By the time these facts had become evident, Bendix had virtually completed the ACE system studies and experiments. The results of these studies and experiments are documented in Sections 2, 3, and 4 of this report.

In view of the facts mentioned above, Air Force, DMA, and Bendix personnel held discussions to determine what guidelines should be used in the remaining effort on the ACE program. It was decided that emphasis would be placed on a semi-optimum ACE system.

As a result, Bendix was directed by the Government to investigate a number of ACE design variations to determine if a different approach was appropriate in light of the new guidelines. The new guidelines and the design variations which were investigated are described in Section 5.

After considering the various alternative ACE designs, the Government indicated a preference for a version based on an AS-11B-1 viewer and computer, referred to as Version 4, in that it provided most of the capabilities of the optimized ACE but at a significantly lower cost and shorter schedule. The implementation of the Version 4 ACE is described in Section 6. Design specifications for the Version 4 ACE overall system and for the viewer are given in Appendices A and B, respectively.

1.2 USER REQUIREMENTS STUDY

The user requirements study included visits by Bendix personnel to the Defense Mapping Agency Aerospace Center (DMAAC) and the Defense Mapping Agency Topographic Center (DMATC). During the visits, the desired capabilities and performance of the ACE system were discussed. Specific topics discussed included: products, input materials, production cycle, pre-processing, present plotting procedures, post-processing, and future data requirements. The requirements and desires of the two production centers were compiled and analyzed by Bendix. The major result of the user requirements study was a list of user requirements which was presented in the interim technical report. These requirements have been reviewed and revised at each of the in-process-review meetings. A discussion of the user requirements study, including summaries of the visits to DMAAC and DMATC and a summary of the agreed-upon user requirements, is presented in Section 2.

1.3 STRAWMAN DESIGN STUDY

The ACE Strawman design study included an overall system study, a correlator and control system study, and a viewer scanner study.

The overall system study was concerned with functional definition of the overall system. It included analysis of system requirements, preparation of a functional ACE design intended to satisfy the system requirements, and outlining the requirements of the major subsystems. The overall system design is described in Section 3.1.

The correlator and control system study included analysis of correlator and control system requirements, investigation of major design alternatives, making major design decisions, and selection of design approaches. It also included preparation of a tentative implementation approach which involved selection and analysis of major hardware and software sections of the correlator and control system, and a study of alternative hardware configurations. A discussion of the Strawman design approaches for the correlator and control system are presented in Section 3.2.

The viewer and scanner studies included analysis of viewer and scanner requirements, making major design decisions, preparation of viewer and scanner configuration layouts, and preparation of an ACE viewer specification. The Strawman design approaches for the viewer and scanner are presented in Section 3.3. The ACE Viewer Specification (DC-879) was submitted to the Government as contract Item A006.

The final result of the Strawman design study was an ACE system specification (DS-878) which was submitted to the Government as contract Item A005.

1.4 AS-11B-X EXPERIMENTS

Work done on the AS-11B-X experiments included preparation of a Data Collection and Analysis plan and performance of the experiments. Experiments were conducted to test the performance of an experimental video amplifier and to test the use of reduced sample spacing and reduced spot size. It was concluded that no general improvement resulted from the use of soft-limiting in the video amplifier or from the use of reduced spot size; however, the provision of some flexibility in the selection of image sample spacing was shown to be desirable. The AS-11B-X experiments are discussed in Section 4. The Data Collection and Analysis Program Plan was submitted before beginning the experiments in accordance with Item A004 of the contract.

1.5 ACE DESIGN ALTERNATIVES

After completion of the Strawman Design Study and the AS-11B-X Experiments, the ACE design study was redirected towards the development of a semi-optimized ACE design. This was done primarily because of the high cost estimated for the development of an ACE system based on the Strawman design. New guidelines were prepared and alternative ACE designs variations were investigated. The new guidelines and design variations are presented in Section 5.

1.6 VERSION 4 IMPLEMENTATION

As a result of the redirection of the ACE study, effort was concentrated on an ACE design variation based on an AS-11B-1 Viewer and Computer, referred to as Version 4. The Version 4 study resulted in a final set of features for the Version 4 ACE, a recommended hardware configuration, and a recommended program configuration. The Version 4 implementation is described in Section 6.

1.7 CONCLUSIONS AND RECOMMENDATIONS

The ACE study resulted in two alternative ACE design configurations: the Strawman design, which is based on dual PDP-11/45 computers and a Bendix-developed viewer; and the Version 4 design, which is based on an AS-11B-1 viewer and computer. It was concluded that the Version 4 design configuration will probably meet the Government's near-to-mid-term needs and can be developed more cheaply in less time and with less risk than the Strawman configuration. It was therefore recommended as the most logical choice for the ACE development based on near-to-mid-term needs. If long-term needs are more important, however, the ACE Strawman design with its greater capability and flexibility is recommended.

SECTION 2

USER REQUIREMENTS STUDY

2.1 APPROACH FOR DEFINING REQUIREMENTS

In order to assure maximum usefulness, the requirements and desires of the DMA were considered so that the ACE would fit into a production cycle with minimal interface problems. The user requirement's study was aimed at investigating the following areas:

- o User input and output requirements
- o The characteristics of operational photographic input materials
- o Control and correction information
- o Operating procedures
- o Desired systems capabilities and performance

Specifically, DMAAC and DMATC personnel were consulted so that their needs and desires could be determined and implemented where feasible and cost-effective. The following approach was used for defining user requirements:

- o Learn user requirements and desires
  - Visits and discussions at DMAAC and DMATC
  - Analyze implications
- o Consider cost/performance trade-offs
- o Bendix suggest ACE capabilities for DMA/RADC review
- o DMA/RADC specify changes required to list of ACE capabilities
- o Prepare preliminary system specification

2.2 SUMMARY OF VISITS

Bendix personnel visited DMATC on 29 July to 31 July 1974, and visited DMAAC on 5 August to 7 August 1974, to discuss user requirements. A wide range of topics were discussed, some of them not directly related to the ACE design but important in terms of understanding its desired performance. In general, the discussions centered around the following topics: products, input materials, production cycle, pre-processing, present plotting procedures, post-processing, and future data requirements.

2.2.1 <u>Visit to DMATC</u>

DMATC sees the ACE system as a potential replacement for the

UNAMACE in the production of 1:50,000 line maps and map manuscripts. The ACE should be designed to increase throughput and, at the very least, should handle those functions the UNAMACE handles as part of the present production cycle. The DMATC production cycle is briefly outlined below:

- o Analytic triangulation from frame photography
  - Using comparators and UNIVAC 1108
  - Orientation of frame photos is determined
- o Reseau measurement on comparator and reseau correction calculation on UNIVAC 1108 (for frame photography)
- o Control point measurement on comparator and absolute orientation computation on UNIVAC 1108 (for panoramic photography)
  - Also compute MDC correction
- o Interior orientation on UNAMACE and read orientation data
  - Check locations of check points
- o Trace boundaries of adverse areas on UNAMACE (model coordinates)
- o Automatic point measurement of UNAMACE
  - Manual measurement when cannot automatically measure
- o Automatically edit and smooth recorded data on UNIVAC 1108
- o Print orthophoto on off-line printer
- o Automatically compute contours on UNIVAC 1108 and plot on CALCOMP
- o Manually trace planimetry and drainage from orthophoto*
- o Manually edit and trace plotted contours to obtain completed contour manuscript*
  - Edit errors
  - Add missing contour detail
  - Combine stereomodels
  - Contours adjusted to drainage chart and spot elevations
  - Referring to orthophoto, rectified photos, original photos
- o Normal cartographic finishing operations*

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* Not always done if not immediately printing line map

The ACE system should handle the following jobs presently done by the UNAMACE:

- o Interior re-orientation and read orientation data
  - Provisions for checking absolute orientation
- o Trace boundaries of adverse areas
- o Automatic point measurement
  - Manual intervention for lost condition

Some basic requirements that DMATC feels the ACE system should meet are the following:

- o Use for production of 1:50,000 line maps and map manuscripts
  - 20 meter contours
  - Class B or better
  - 10 - 15 meters rms elevation accuracy relative within map sheet
  - Map size 18 by 28 kilometers (approximate)
- o From non-conventional panoramic and frame photography
  - Contact scale or enlarged 3 times
  - Cut or roll film
- o Replace UNAMACE in normal production cycle
  - Digital grid elevation measurements only
  - About 50 meter grid point spacing
  - About 15 hours per map
- o Improvements desired over UNAMACE
  - Higher speed (maps per year), or lower cost
  - Less down time and maintenance cost (especially magnetic tape recorder)
  - Easier to modify computer programs
  - More consistent production rate
  - Require less control of film processing

2.2.2 Visit to DMAAC

DMAAC has a wide variety of data needs which can be satisfied by the development of a digital data base. They have placed increasing emphasis in recent years on digitizing data from source materials. The following is a DMAAC production cycle for digitizing data from source photography.

- o Model setup and orientation
  - A number of AS-11B-1 and UNIVAC 1108 steps
  - Also obtain MDC correction for panoramic models
  - Panoramic models joined using MDC corrections
- o Computation of desired point model coordinates on UNIVAC 1108
- o Model re-set on AS-11B-1
  - Measure check points for quality analysis
- o Manual or automatic elevation measurement on AS-11B-1
  - By profiling along desired grid lines read from punched tape
  - Automatic recording of elevation and position at desired points
  - Manual evaluation of profiling accuracy
- o Processing of recorded elevation data on UNIVAC 1108
  - Conversion from model to geographic coordinates
  - Offset, rotation, and scale
  - Merging and ordering of data points in master file on magnetic tape
  - Automatic editing of data and interpolation of missing points
  - Automatic adjustment for bias between profiling directions
- o Manual tracing and digitizing on AS-11B-1 of needed planimetry (culture and landscape features)

Presently, DMAAC has three AS-11B-1 systems with magnetic tape capability for recording automatic profile data. The ACE system will have considerably greater throughput than an AS-11B-1 system. The ACE system should handle the following jobs presently done on an AS-11B-1:

- o Interior re-orientation
- o Model re-set for quality analysis
- o Automatic point measurement
- o Manual evaluation of measurement accuracy

The proposed features for the ACE system as detailed in Section 3.1 do not make provisions for the following:

- o Initial interior orientation
- o Relative, exterior, or absolute orientation
- o On-line reseau correction determination

- On-line MDC correction determination
- Manual fill-in of gaps
- Manual plotting

These jobs can all be handled by back-up AS-11B-1 units with a net increase in throughput.

In addition, DMAAC placed emphasis on off-line post-processing of ACE data. The ACE system in production might reasonably digitize points at rates as high as 500,000 points per hour. Presently, processing programs can be run on the Univac 1108. However, other more cost-effective ways for bulk processing raw ACE data without adding to the work load of the Univac 1108 need to be investigated.

2.3 SUMMARY OF USER REQUIREMENTS

Section 3.1 presents a complete list of tentative ACE requirements and capabilities. Those items which have been specified by the user community as basic requirements for the ACE system have been included in the list. Of course, the user community is primarily interested in performance, and those items which affect the ACE design but are not related to performance criteria have been specified by Bendix. The following is a summary of those specific items that DMA and Rome Air Development Center (RADC) want as required ACE capabilities.

- Handle non-conventional panoramic and frame photography
- Use high density magnetic tape
  - 1600 BPI, phase encoding, 9 track
- Provide maximum film segment size of 10 by 20 inches
- Provide base to height ratio range of 0.25 to 1.5
- Provide photo-to-photo scale ratio range from 0.8 to 2.0
- Provide minimum focal length of 75 mm and maximum of 6000 mm
- Make viewing reference mark size 0.020 mm diameter
- Permit on-line measurement of adverse areas
- Provide ability to accept pre-determined model set-up and orientation data
- Make maximum use of vendor supplied software

In addition, there are items to be specified which need to be evaluated for trade-offs between cost and performance. A number of features desired by DMA are not included in Section 3.1 because a trade-off decision has not yet been reached. Each is desired for some reason of convenience or flexibility, but each feature would measurably increase the ACE development and/or production cost. Some of these desired capabilities are:

(1) Produce output data in ground coordinates. Also, perform earth curvature, atmospheric refraction, and MDC corrections on-line.

(2) As an operating option, record output data on a removable magnetic disk and/or magnetic tape.

(3) Record an automatic-measurement figure-of-merit with each output point.

(4) Provide the ability to accept input data directly from a central computer (such as a pooled minicomputer) over a telephone line instead of reading input data from magnetic tape. The selection between magnetic tape or central computer transmission would be an operating option.

(5) Provide for recording of digitized image data on magnetic tape or removable magnetic disk.

(6) Increase the automatic measurement speed from 9 to 30 mm^2/sec.

(7) Provide a reference viewer.

(8) Provide on line capabilities for relative and absolute orientation. Also, include capabilities for determination of correction parameters and data.

(9) Provide for on-line manual fill-in of gaps in the elevation data.

SECTION 3

STRAWMAN DESIGN STUDY

The purpose of the Strawman design study was to prepare a preliminary overall system design for the ACE system. These studies concentrated on how to perform the system functions, and provide the tentative system performance determined in the user requirements study. A "Strawman" or tentative system design was prepared to meet the tentative requirements.

The Strawman design study was conducted in two phases. The first phase consisted of a functional definition of the overall system design. This included selection of overall system functions, performance parameters, operating modes, input and output requirements, operator interface, etc. It also included outlining of the functions of the ACE subsystems including the correlator, control system, viewer, and scanner. The overall system design generated in Phase 1 of the Strawman study is described in Section 3.1.

The second phase of the Strawman design study was the preparation of a tentative implementation design for the main subsystems. This was done in sufficient detail to permit verification of feasibility and preparation of detailed cost estimates. It included selection of detailed design approaches and major components. The Strawman implementations for the correlator and control system and the viewer/scanner are presented in Sections 3.2 and 3.3, respectively.

3.1 OVERALL SYSTEM DESIGN

This section summarizes the tentative performance and overall design features of the ACE Strawman design.

3.1.1 System Functions

3.1.1.1 General

The ACE system rapidly and automatically measures point elevations from stereo aerial photography. This is done by automatic measurement of corresponding image areas along corresponding epipolar lines on the photographs. The points measured are recorded digitally in model coordinates on magnetic tape. To perform its functions, the system uses predetermined photograph and stereomodel data which is read from magnetic tape.

3.1.1.2 Manual Measurements

Although the ACE system will make most measurements automatically, the system operator will be permitted, or required, to manually make the following measurements on the photographs:

(a) Interior orientation reference points.

(b) Elevations of stereomodel check points.

(c) Boundaries of adverse areas.

(d) Elevations of initial points in corner of areas to be measured automatically.

(e) Elevations of restart points when automatic measurement is completely lost.

(f) Elevations of automatic-measurement-accuracy evaluation points.

The computer shall provide some assistance for most manual measurements, including:

(a) Computer prompting of next manual step.

(b) Automatic drive to nominal locations.

(c) Automatic typing and/or recording of measured locations and deviations from nominal locations.

3.1.1.3 Operation Sequence

The ACE system operating sequence is basically as follows:

(a) Read computer programs from magnetic disc.

(b) Read orientation and correction data from magnetic tape or communications link.

(c) Perform manual measurement of two to four interior orientation reference points. These points are measured in photo coordinates.

(d) Perform manual elevation measurement of some stereomodel check points. These points are measured in model coordinates.

(e) Manually outline adverse areas which are not to be automatically measured. These adverse areas are outlined in model coordinates. Optionally, prior measurements of adverse areas may be read from magnetic tape.

(f) Perform manual elevation measurement of corner initial point. This point is in the corner of the stereomodel area which is to be automatically measured.

(g) Perform automatic measurement of epipolar points.

(h) When automatic measurement operations become lost, perform manual elevation measurement of a few points for restart of automatic measurement.

(i) Perform manual elevation measurement of some points to evaluate automatic measurement accuracy. As an operator option, prior point measurements may be read from magnetic tape rather than requiring manual measurement at this time.

3.1.2 System Diagram

The ACE system consists of four major parts: the viewer, scanner, correlator, and control system, as shown in Figure 3-1. This diagram shows in simplified form the four main parts of the ACE system and its main input and outputs. As indicated, the system inputs include stereo photographs, stereomodel data, and operator inputs. The operator inputs include the optical controls, monitor display controls, and system controls. The system outputs include epipolar points and operator outputs. The operator outputs include eyepiece views, monitor displays, and control displays. Although separate functional parts of the system, the viewer and scanner form one mechanical assembly and use some common components.

The major inputs and outputs of each major part are also shown in Figure 3-1. The heavy arrows in the diagram indicate items with the highest data rate.

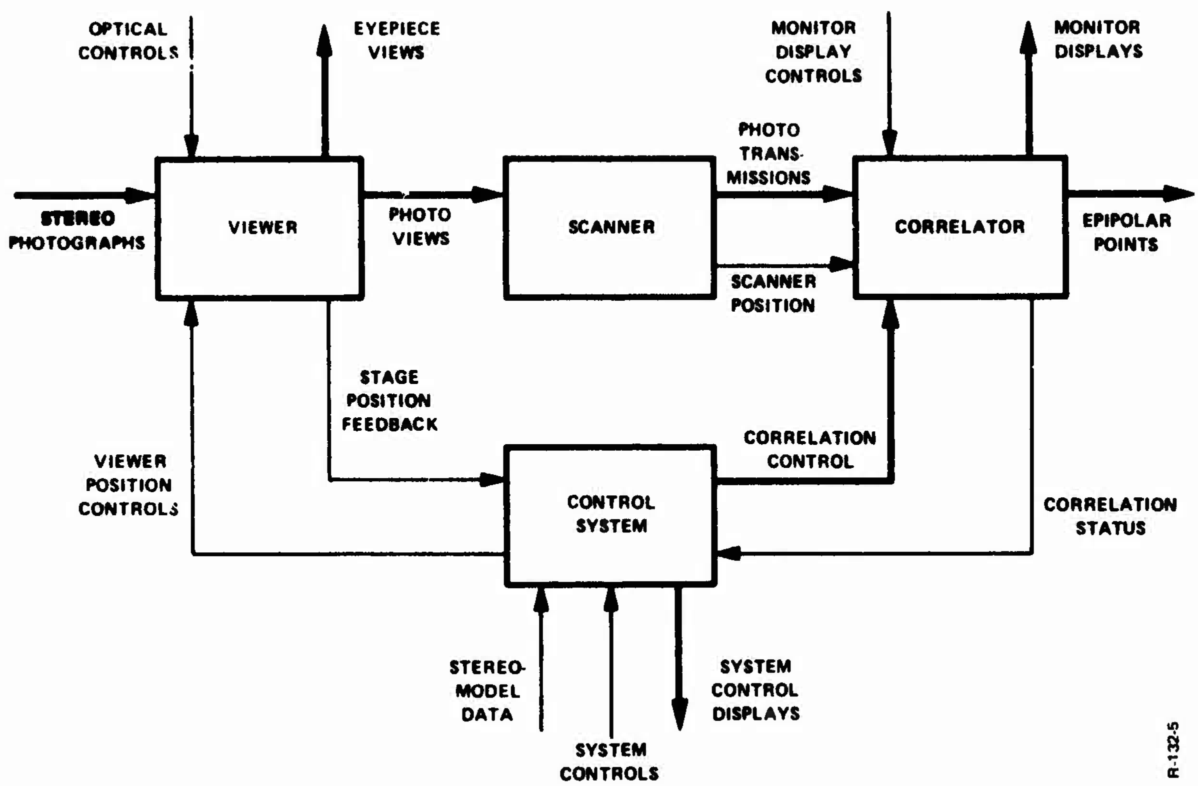

Figure 3-1 - ACE System Diagram

3.1.3 System Interfaces

3.1.3.1 Photograph Acceptance

3.1.3.1.1 General

The ACE system accepts vertical and convergent frame and panoramic photography. Photographs are accepted with the air base in any stage direction; however, in the case of panoramic imagery the air base will be approximately parallel to the axis of the panoramic cylinder.

3.1.3.1.2 Photograph Format

The ACE system accepts film positive flats with segment sizes up to 10 x 20 inches (250 by 500 mm). Photographs are on film with a base between 2 and 7 mils thick. The ability to handle rolls of film up to 500 feet without cutting can be provided as an option but is not planned.

3.1.3.1.3 Parameter Ranges

The ACE system accepts photographs within the following parameter ranges:

(a)	Effective focal length:	75 to 6000 mm (300 to 6000 mm for normal speed)
(b)	Convergence angle phi:	$\pm 45^{\circ}$
(c)	Kappa and omega angles:	$\pm 20^{\circ}$
(d)	Panoramic sweep angle theta:	$\pm 60^{\circ}$
(e)	Base-to-height ratio:	0.25 to 1.5
(f)	Model-to-photo-scale ratio:	0.5 to 2.0

3.1.3.1.4 Photogrammetric Corrections

The ACE system computationally performs the following photogrammetric corrections:

(a) Reseau correction

(b) Vehicle motion

(c) Image motion correction

(d) Lens distortion for frame photography

(e) Photograph rotation, offset, and shrinkage (for interior orientation)

3.1.3.2 Operational Controls and Displays

3.1.3.2.1 General

The ACE system design includes the following operator controls and displays:

(a) Two handwheels and one footwheel

(b) Alphanumeric CRT display

(c) Typewriter keyboard

(d) Printer or typewriter output

(e) Viewing optics control

(f) Automatic operation monitor displays

3.1.3.2.2 Viewing Optics Controls

The ACE system provides the following operator controls of the viewing optics:

(a) Eyepiece focus, separate for each eyepiece

(b) Viewing brightness, separate for each stage

(c) Viewing illumination on-off, separate for each stage

(d) Inter-pupillary distance

(e) Stereo parallax adjustment, vertical and horizontal

(f) Rotation, separate for each stage

(g) Magnification, separate for each stage

3.1.3.2.3 Monitor Display

The ACE system includes the following displays for monitoring automatic operation:

(a) Graphic CRT display (monitor oscilloscope), capable of displaying measured profiles, cross correlation quality, or cross correlation curves.

(b) Graphic plotter, capable of printing measured profiles

3.1.3.3 Input Data

The ACE system is capable of reading the following input data in digital form from magnetic tape or from a central computer via a communications line:

(a) Orientation data for both interior and relative or exterior orientation

(b) Photogrammetric correction data

(c) Evaluation point data

(d) Adverse area definition data

3.1.3.4 Output Data

The ACE system will be capable of outputting the following data:

(a) Epipolar point data in digital form on magnetic tape or over a communications line to a central computer

(b) Stereomodel evaluation data in typed form

(c) Automatic operation evaluation data in typed form, including evaluation point measurements, evaluation point errors, overall measurement errors, area plotted, time taken, and average speed

3.1.4 System Characteristics

3.1.4.1 Performance

3.1.4.1.1 Speed

The average system speed during automatic operation will be at least 100 points per second or 9 mm^2/sec when the points are spaced 0.300 mm in nominal photo scale. It shall be a design objective that the automatic speed be at least 30 mm^2/sec. These speeds may be reduced if necessary to maintain accuracy or to reduce cost when the focal length is less than 300 mm. The ACE system should operate with an average overall speed of 50 points per second, when the points are spaced 0.300 x 0.320 mm apart in nominal photo scale. This overall speed should include all required system time, from the time photographs are placed upon the stages until they are removed from the stages.

3.1.4.1.2 Accuracy

The ACE system will have an automatic correlation parallax error of 0.015 mm rms or less. This error is measured by manual evaluation of automatically measured points, manually measuring elevations at randomly selected points on the ACE system with the same stereomodel setup. The manual measured elevations are compared to the fully processed automatically measured elevations. The elevation error measure is the standard deviation of the elevation errors found, after exclusion of all points with elevation errors greater than 0.100 mm in photograph scale. This elevation error is converted to parallax error by multiplication of the elevation error by the base-to-height ratio of the stereo model, and conversion of the error into average photograph scale.

In addition to the automatic correlation error, the ACE system will have a static mechanical parallax error of 0.008 mm rms or less. This error is a parallax error, combining the effects of the errors in the two stages.

3.1.4.1.3 Test Stereomodels

The ACE system will have the specified average speed and accuracy when tested over the following test stereomodels:

(a) Ft. Sill (frame)

(b) Arizona (panoramic)

(c) California (frame)

The speed and accuracy shall be determined on these three stereomodels, with the results being averaged.

An average area of 20,000 mm^2 will be automatically measured on each stereomodel, or times will be adjusted to simulate such operation. Any adverse areas will be measured in advance. Points will be automatically measured at the nominal spacing of 0.300 by 0.320 mm in nominal photo scale.

3.1.4.2 Reliability

The ACE system will have a reliability characterized by a mean time between failures of 150 hours.

3.1.4.3 Maintainability

The ACE system is designed for ease of maintenance. The mean time to repair is four hours or less. The time required for scheduled maintenance (for calibration, checking, and preventive maintenance) is no more than two shifts out of 40 working shifts plus two hours out of 10 working shifts. Maintenance procedures, facilities, and/or computer programs are provided for the following:

(a) Checking correct system operation upon every stereomodel by evaluation of measurement accuracy at check points.

(b) Periodically checking correct system operation by operating with a standard stereomodel using automatic accuracy evaluation.

(c) Diagnosis of improperly operating system components.

(d) Performing and checking system calibration.

3.1.4.4 Environmental Conditions

3.1.4.4.1 Temperature

The ACE system will operate over a temperature range of 21° to 24°C. The room temperature will be within this range both during and prior to system operation. The ACE system will tolerate a non-operating temperature range from 18° to 28°C.

3.1.4.4.2 Relative Humidity

The ACE system will operate with a relative humidity between 40 and 60 percent. The relative humidity will also be in this range prior to the operation. The ACE system will tolerate a non-operating relative humidity between 10 and 80 percent.

3.4.4.4.3 Vibration

The ACE system will be capable of operating with a vibration of 0.01 G in the frequency range of 2 to 200 Hz measured in the floor upon which the viewer is placed.

3.1.5 Design and Construction

3.1.5.1 Minimum Cost

The ACE system will be designed and constructed in such a manner as to minimize development time and cost. In addition, cost will be minimized for system production, operation, and maintenance. In order to do this, the system will be designed so that it has minimum system complexity and uses existing designs and computer programs whenever practical. In particular, the system will use standard commercial components such as computers where this is practical.

3.1.5.2 Ease of Operation

The system is designed to minimize the difficulty of system operation. The system requires a minimum number of manual operations by providing good computer aids to necessary manual functions.

3.1.5.3 Computers

The computers and other hardware of the ACE correlator and control system include the following features:

(a) Use commercially available general purpose digital computers

(b) Use magnetic disc memory for computer program storage.

(c) Use an industry-compatible magnetic tape format, with 1600 bits per inch, 9 tracks, and phase encoding

(d) Be constructed for mounting on a false floor

3.1.5.4 Computer Programs

The computer programs which perform many of the correlator and control system functions have the following characteristics:

(a) Use Fortran programming where practical

(b) Use a standard operating system program where practical

(c) Be coded and described in modular sections

(d) Provide computer aids to necessary manual functions wherever practical

(e) Use a Fortran language subroutine for computation of photograph coordinates corresponding to given model coordinates.

3.1.5.5 Viewer Design

The viewer is designed with greater emphasis upon automatic operation than upon manual operation. The design avoids compromising scanner performance with viewing optics. The viewer and control system are designed for smooth, accurate, low-speed motion.

3.1.6 Viewer Characteristics

3.1.6.1 Functions

The viewer provides facilities for holding the two photographs of a stereo pair, independently positioning the photographs with respect to viewing and scanning optics, manual viewing of the photographs in stereo, and permitting the scanner to scan the two photographs. The functional elements of the viewer are as shown in Figure 3-2. Major information flowing in and out of the various functional elements is as shown in the diagram.

The viewer includes the viewing optics which provide eyepiece views of the stereomodel, and operator controls of the viewing optics. All other operator controls and displays are considered as part of the correlator or control system. The viewer provides support and mounting space for the scanner and for many of the other controls and displays, although they are not part of the viewer.

The viewer includes, as part of the stage optics, the optical rotators which rotate the scan lines with respect to the photographs. This permits a single rotator to be used for each photograph, being used for viewing and scanning.

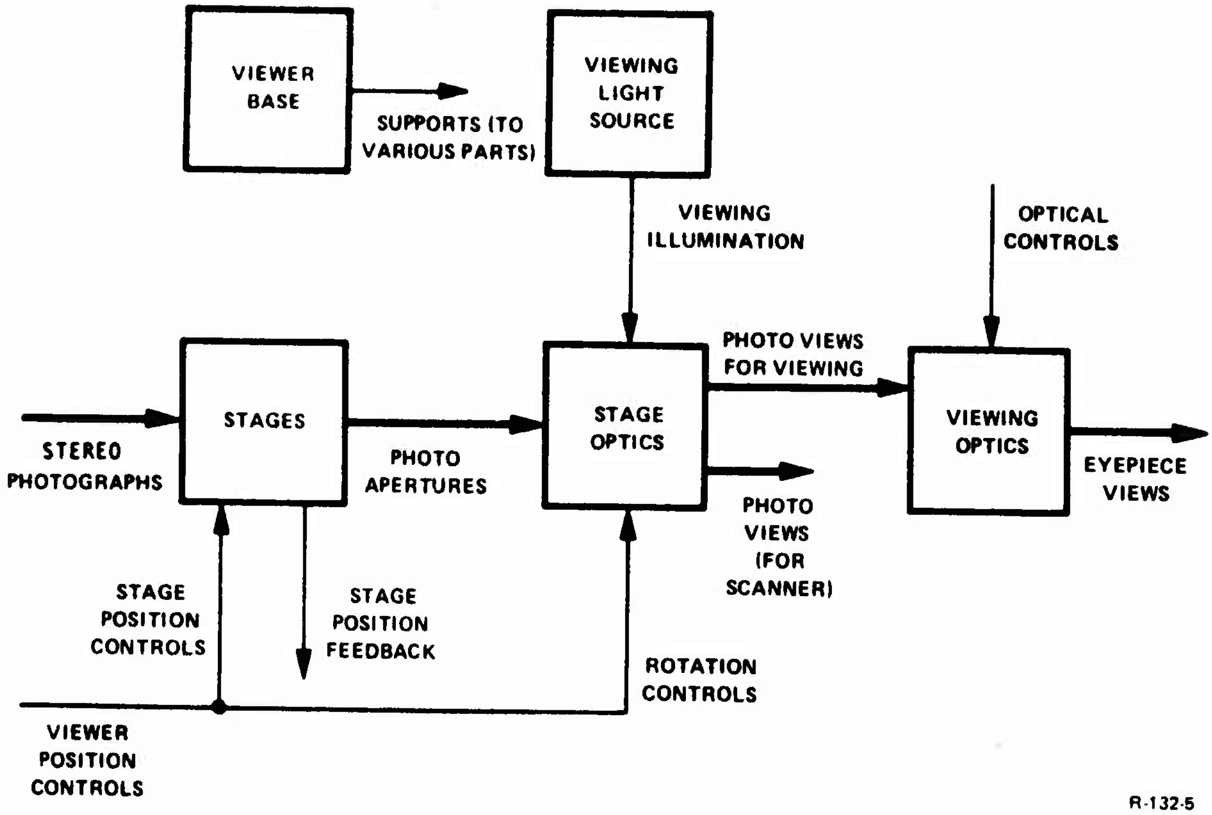

Figure 3-2 - ACE Viewer Diagram

3.1.6.2 Interfaces

3.1.6.2.1 Operator

The viewer interfaces with the ACE system operator include:

(a) Placement of photographs upon the viewer stages, and their removal.

(b) Controls for the viewing optics

(c) Eyepiece views of the photographs and stereomodel

3.1.6.2.2 Other Interfaces

The viewer interfaces to other parts of the ACE system include:

(a) Stage position control from the control system

(b) Stage position feedback to the control system, including limit switches for end of stage travel

(c) Optical rotation control information from the control system

(d) Effective aperture through which the scanner scans each photograph

(e) Mounting spaces and supports for the scanner and for various controls and displays associated with the correlator and control system

3.1.6.3 Stages

The viewer contains two stages each having a mechanical motion with respect to the optics of at least 10 by 20 inches (250 by 500 mm). The area of clear view through each stage is at least 11 by 21 inches (275 by 525 mm). The total position error of each axis after calibration is 0.005 mm rms or less. The positioning stability of each stage axis over a period of one hour is within 0.003 mm rms or less. The maximum positioning speed obtainable with normal operating accuracy is at least 3 mm/sec. The maximum slewing speed obtained (without accurate position) is at least 20 mm/sec.

3.1.6.4 Viewing Optics

The viewer includes provisions for viewing the photographs optically as a stereo model with the following features:

(a) Rotation range: $\pm 190^{\circ}$

(b) Rotation accuracy: 0.5° rms

(c) Rotation under computer and manual control

(d) Zoom magnification under manual control: 10X to 30X (3:1)

(e) Photograph field of view: 10 mm at 20X magnification

(f) Resolution: 100 lines pairs per mm for 1000-to-1 contrast target at maximum magnification

(g) Interpupilary distance adjustment: 55 to 75 mm

(h) Eye relief: 20 mm

(i) Stereo parallax adjustment range: ± 0.04 radians vertical and horizontal

(j) Eyepiece focus: ± 4 diopters each eyepiece

(k) Reference mark: 0.020 mm diameter black dot, fixed

3.1.6.5 Stage Optics

The viewer includes stage optics which permit simultaneous scanning and optical viewing of each photograph. The stage optics shall include provisions for rotating the scan line on each photograph, with the following characteristics:

(a) Independent computer control of rotation for each photo

(b) Rotation range: $\pm 190^{\circ}$

(c) Rotation accuracy: 0.005 radians rms

3.1.7 Scanner Characteristics

3.1.7.1 Functions

The scanner scans the two photographs of a stereo pair mounted upon the viewer stages. The photos are simultaneously scanned along straight lines, with the photo transmissions being detected and electronically sent to the correlator. The functional elements of the scanner are as shown in Figure 3-3. Major information flowing out of the scanner are the photo transmission of each photo and the scanner sweep position, both going to the correlator.

3.1.7.2 Interfaces

The scanner interfaces with the other parts of the ACE system include:

(a) Effective aperture through which the scanner scans each photograph, provided by the viewer

(b) Photo transmission of each photo to the correlator

(c) Scanner sweep position to the correlator

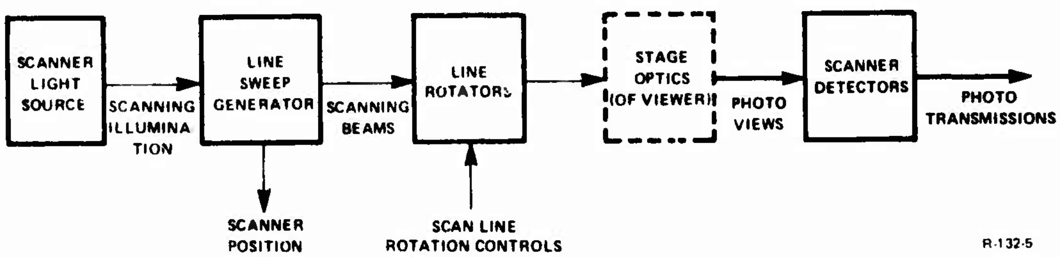

Figure 3-3 - ACE Scanner Function Diagram

3.1.7.3 Performance

The scanner has the following performance characteristics:

(a) Usable line length: 1 inch (25 mm)

(b) Sweep frequency: 50 lines per second desired objective, fixed

(c) Spot size range, manually controlled: 0.010 to 0.050 mm diameter

(d) Scanning spot: generated by a 15 mW laser

3.1.7.4 Accuracy

The accuracy of the scanner, after calibration and computer correction if any, is sufficient to keep maximum errors within the following limits:

(a) Position along line: 0.005 mm rms

(b) Straightness of line: 0.008 mm rms

(c) Stability: 0.003 mm rms

3.1.8 Correlator Characteristics

3.1.8.1 Functions

The correlator correlates image transmission data, produces the elevations of epipolar points, and provides automatic operation monitor displays. Correlator functions are diagrammed in Figure 3-4. Photo transmission data is accepted from the scanner and processed to produce epipolar point data which is recorded for output. Correlation control data is received from the control system, and correlation status data is returned to the control system. In addition, monitor displays are generated for the benefit of the system operator, and operator controls are provided for these displays.

3.1.8.2 Interfaces

The correlator contains monitor displays to the system operator as described in Section 3.1.3.2.3. In addition, the correlator includes suitable means for operator control of the information being displayed. The correlator can digitally record ACE output epipolar point data upon magnetic tape.

The correlator contains interfaces to the scanner as described in Section 3.1.7.2. The correlator provides necessary status data to the control system to indicate current status of the correlator. The correlator accepts the following correlation control information from the control system:

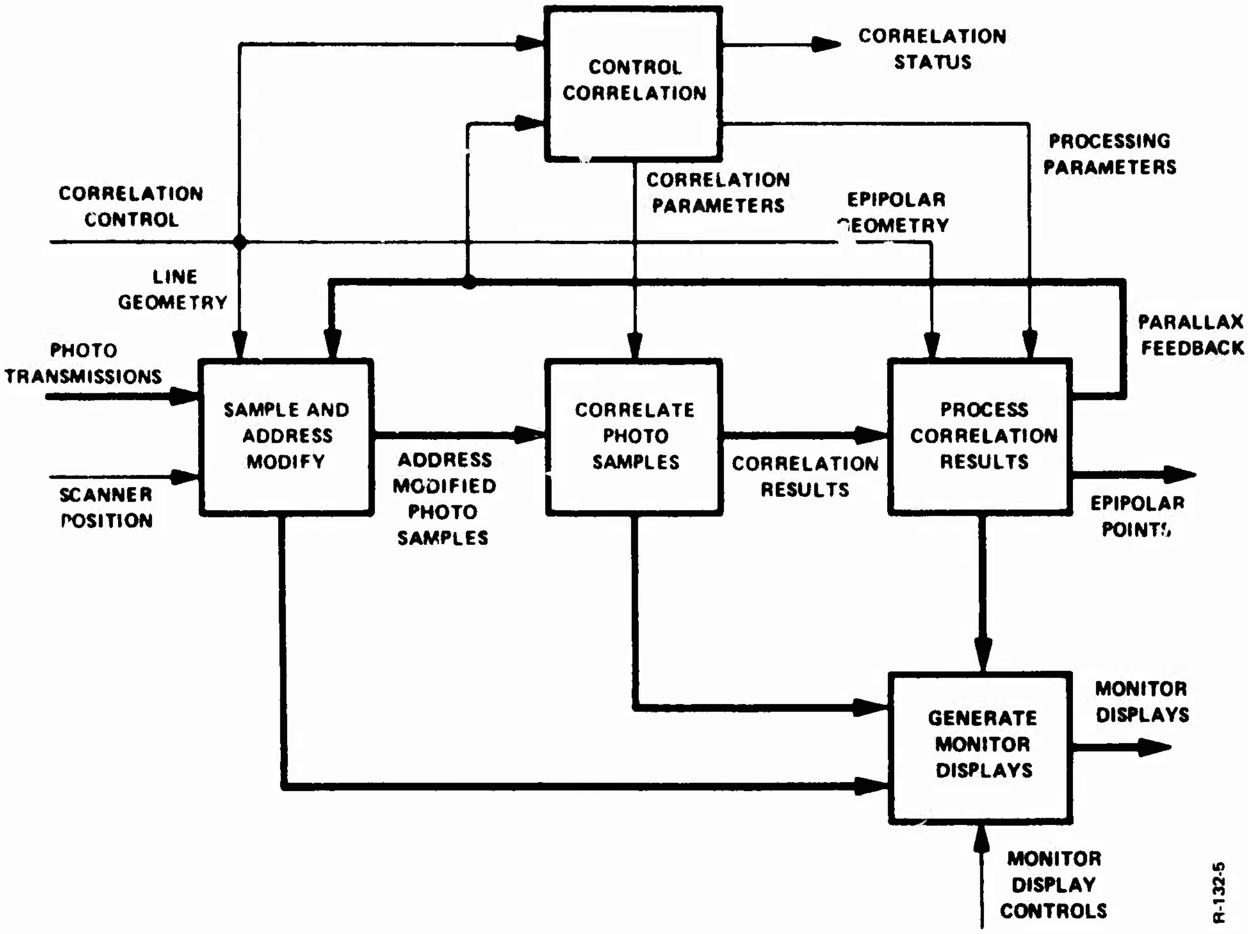

Figure 3-4 - ACE Correlator Design

(a) Correlation control parameters

(b) Photography geometry along each scan line

(c) Epipolar geometry information needed for converting measured parallaxes to model coordinates of output points

3.1.8.3 Performance Characteristics

The correlator provides at least the following performance capabilities:

(a) Maximum area correlation rate: 40 mm^2/sec with nominal point and density sample spacing.

(b) Nominal spacing of measured points (at normal speed): 0.320 mm along epipolar lines and 0.300 mm between epipolar lines.

(c) Maximum line correlation rate: 50 lines per second

(d) Epipolar line length correlated: 15 mm

(e) Nominal density sample spacing correlated (at normal speed): 0.020 mm along epipolar lines and 0.050 mm between epipolar lines.

3.1.9 Control System Characteristics

3.1.9.1 Functions

The control system controls the other parts of the system to perform all the functions specified herein. The system control functions are as shown in Figure 3-5. The viewer is controlled to view and scan corresponding epipolar lines. This is done using feedback from the correlation process and information input by the operator. Information is also sent to the correlator to control its operation and proper processing of the data scanned.

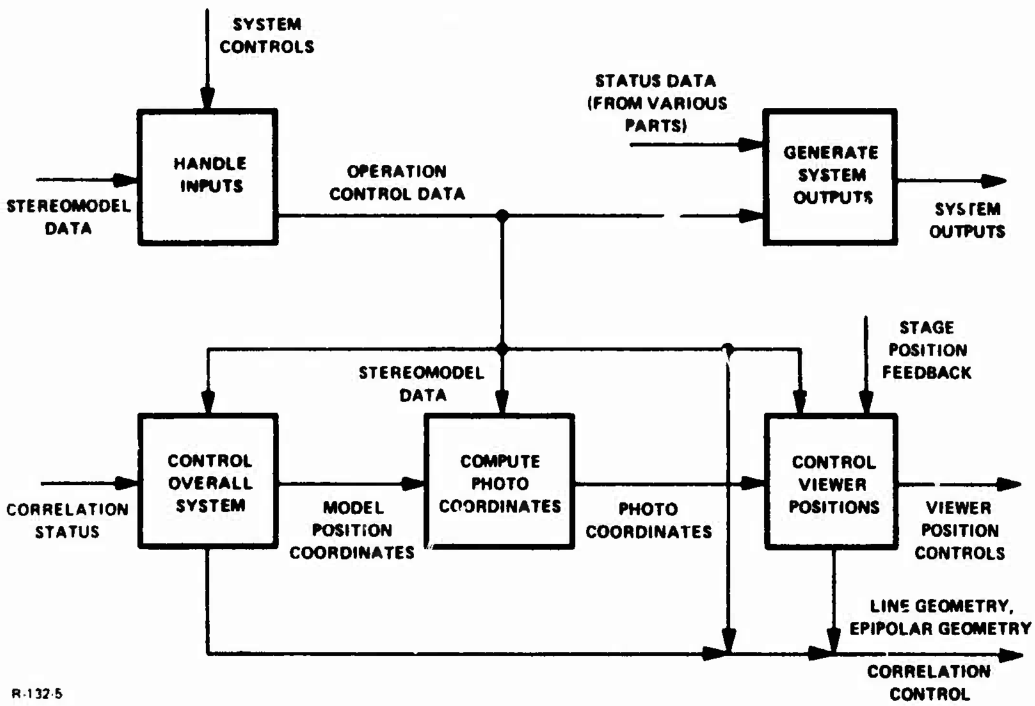

Figure 3-5 - ACE Control System Design

3.1.9.2 Interfaces

The control system contains interfaces to the other portions of the ACE system as specified herein. The control system provides for the input of system data as specified in Section 3.1.3.3. The control system provides for typing stereomodel evaluation data and automatic operation evaluation data as specified herein. The control system provides the following operator controls and displays for operator use in overall system control:

(a) Two handwheels and one footwheel

(b) Alphanumeric CRT display

(c) Typewriter keyboard

(d) Printer or typewriter output

3.1.9.3 Performance

The control system provides at least the following performance capabilities:

(a) Maximum scan line control rate: 50 lines per second

(b) Other capabilities as needed for consistency with specified correlator, scanner, and viewer performance characteristics.

3.2 CORRELATOR AND CONTROL SYSTEM IMPLEMENTATION

This section describes the Strawman configuration for the correlator and control system. It was prepared according to the requirements outlined in the Strawman system definition. Studies performed during the Strawman study verifiy that the Strawman correlator and control system implementation is feasible and will meet the Strawman requirements. In the course of the program, studies were made of alternate approaches to the correlator and control system. Some of the details of these studies are given in Appendices C and D.

3.2.1 Control System Hardware Configuration

A block diagram of the control hardware is shown in Figure 3-6. The main components of the control system are the control computer, peripherals, and viewer interface. These components are described below.

3.2.1.1 Control Computer and Peripherals

A PDP-11/45 computer with floating-point hardware and semiconductor memory are used in the control system. It is interconnected to the correlation computer through a shared dual-port memory connected to the UNIBUS of each computer. In addition, several DEC peripherals and the viewer interface electronics are connected to the UNIBUS. The details of the control computer configuration are given in Table 3-1.

Table 3-1 - ACE Computer and Peripherals

Configuration Checklist

DEVICE	CONTROL COMPUTER	CORRELATION COMPUTER	DEC. PART NO.
11/45 CPU WITH 16K PARITY CORE	YES	YES	11/45-FM
MEMORY MANAGEMENT	YES	YES	KT 11-D
FLOATING POINT PROC.	YES	YES	FP11-B
16K MOS. MEMORY	YES	YES	MS11-B
4K BIPOLAR MEMORY		YES	MS11-C
16K DUAL PORT CORE (SHARED)	YES	YES	MA11-FA
GRAPHIC CRT (MONITOR SCOPE)		YES	E611
ALPHA NUMERIC CRT AND KEYBOARD	YES		ANN ARBOR TERMINALS
MAG TAPE (1600 CPI, P.E.)	YES	YES	TJU-16
ELECTROSTATIC PLOTTER		YES	LV11
REMOVABLE DISK	YES		RK11-D
DEC WRITER	YES	YES	LA36

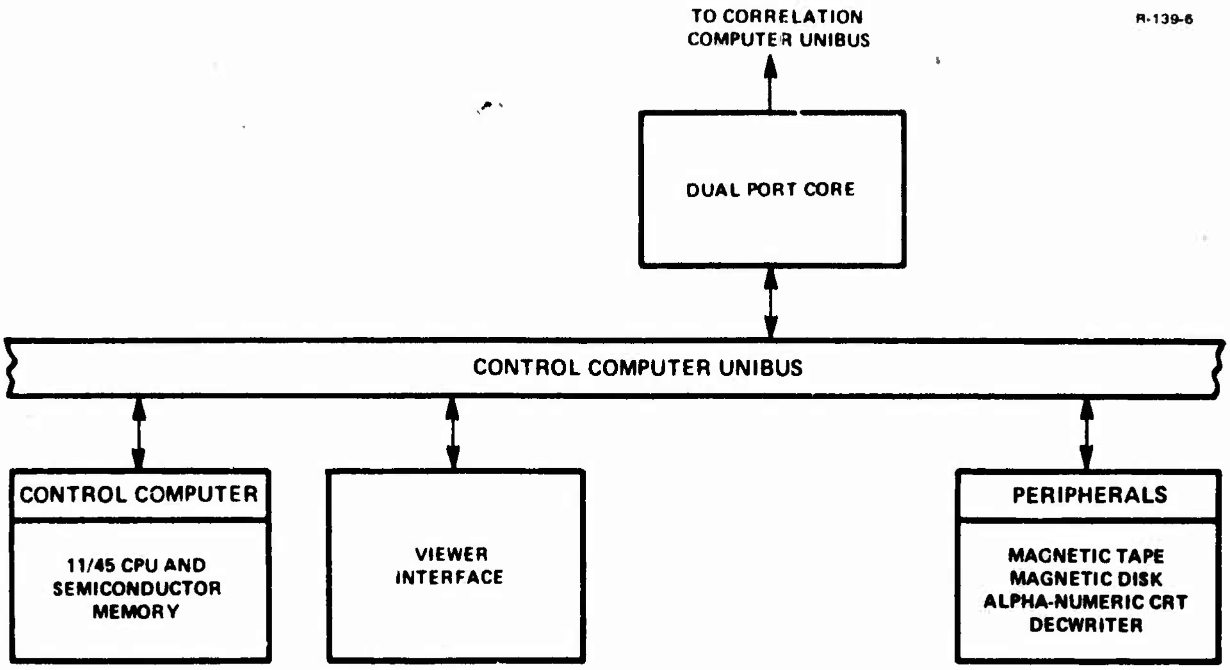

Figure 3-6 - Control System Block Diagram

3.2.1.2 Viewer Interface Electronics

The viewer interface handles all information passing between the viewer and the control computer. An overall block diagram of the viewer interface is shown in Figure 3-7. The interface is divided into four categories:

Serial interface electronics
Absolute servo electronics
Incremental servo electronics
Parallel interface electronics

All interfaces connect directly to the unibus. The same hardware used in the PTS system would be used insofar as possible.

The four types of interfaces are described in the following sections.

3.2.1.2.1 Serial Interface Electronics

The serial interface electronics handles inputs from the handwheels and footwheel. The interface converts the pulse train received from the encoder attached to the handwheels or footwheel to a binary number representing angular displacement. A block diagram of a serial input interface is contained in Figure 3-8. The handwheel encoder outputs

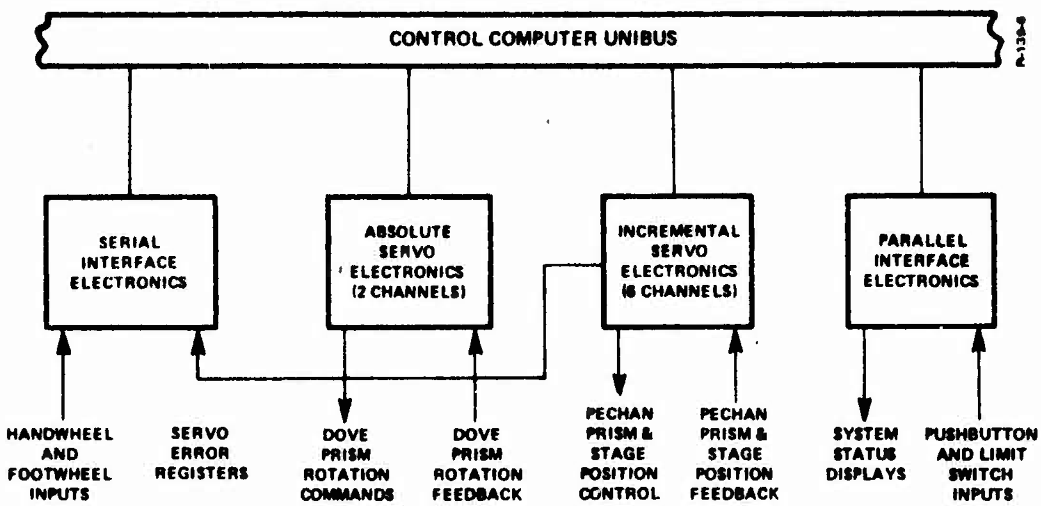

Figure 3-7 - Viewer Interface Block Diagram

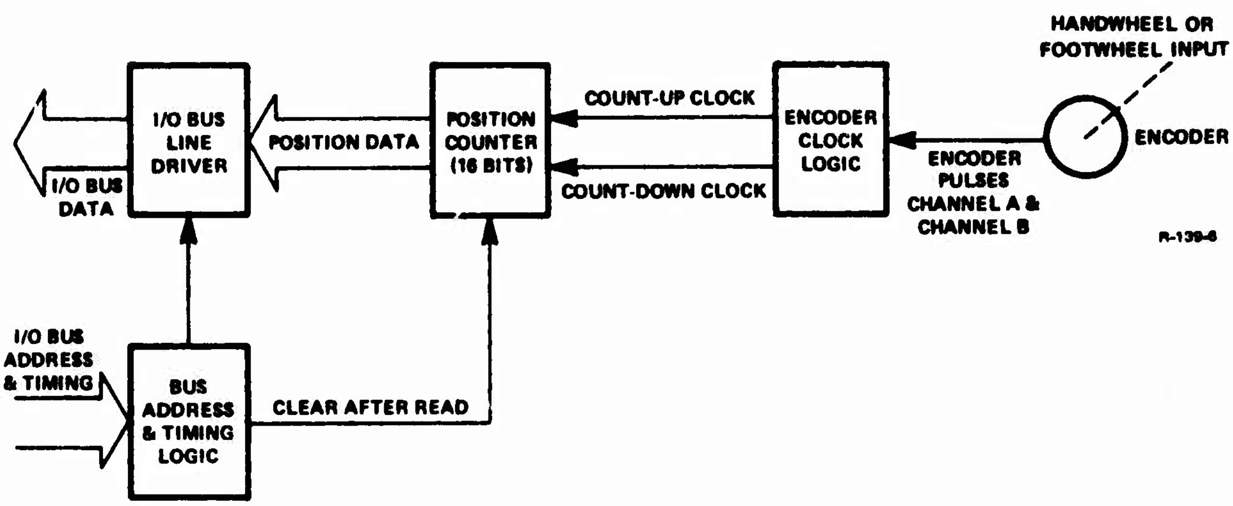

Figure 3-8 - Serial Input Interface Block Diagram two channels of square wave pulses in quadrature. The number of pulses output represents angular displacement and the phase angle between the two channels indicates rotation direction. These pulses are converted by encoder clock logic to count up or count down clocks which drive a position counter. During each interface transfer, the contents of this counter are transferred to the computer and then the counter is cleared.

The serial input interface represents angular displacement with a 16-bit two's complement number. The interface is designed to be read at a minimum of 50 times per second.

3.2.1.2.2 Absolute Servo Electronics

An absolute servo is used to control the image rotation optics for each photo. The servo system accepts digital position commands from the control computer and translates this information into an analog voltage representing an absolute position of the rotation optical assemblies. Each channel is connected directly to the UNIBUS. A block diagram of an absolute servo channel is shown in Figure 3-9.

Absolute position data with address and timing signals is presented to each device on the UNIBUS. The addressed channel transfers the position data (12 bits, two's complement) in the absolute position data storage register, replacing the previous contents of the register. When the transfer is completed, the data appears at the input to the digital-to-analog converter. The resulting analog position command is

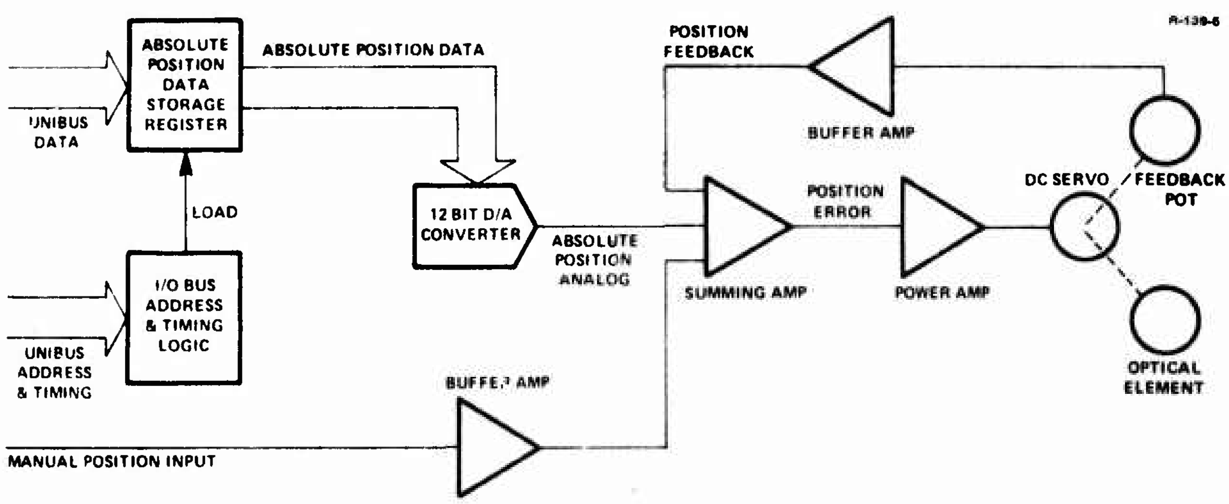

Figure 3-9 - Absolute Servo Channel Block Diagram sent through a summing amplifier to a power amplifier circuit which drives the dc servo. The manual position command potentiometer also feeds an analog position voltage through the summing amplifier. A potentiometer coupled to the servo generates a position feedback voltage which is also input to the summing amplifier and serves to cancel the sum of the computer position command and the manual position command voltages.

The absolute servo channel is designed to accept 12-bit two's complement absolute position data at a rate of 100 times per second. Both the digital-to-analog converter and servo power amplifier are commercially available modules.

3.2.1.2.3 Incremental Servo Electronics

Incremental servos are used to control the four stage axes, the two pechan prisms and the counter-rotating wedge scan generator.

The incremental servos accept digital incremental position commands at fixed time intervals and translate the information into servo rotation. The incremental servo logic is specifically designed to provide smooth, precise motion with a minimum of jitter.

The four stage axes (x and y for both channels) have the capability of slew rates up to 20 mm/sec with direct motor drive of the lead screws. Each servo axis is outfitted with limit switches to protect the stage assemblies in both positive and negative travels. In the negative direction two limit switches are used. The first limit switch signals the computer that a limit has been reached by setting a bit in the servo status word. The second limit switch, if activated, removes power from the servo but allows the system to back off the limit under computer control. This provides fail-safe protection of the stages. The status of the second limit switch is not available to the computer. In the positive direction of stage travel only the second limit switch is employed.

The stage zero point is established on system power up with the following procedure. First, the four stage axes are driven into the first limits. Each axis is then backed off its limit a predetermined distance. The resulting stage position is defined as the zero point.

The two pechan prism channels have a maximum slew rate of 9 revolutions per minute and are driven through worm gears. High resolution encoders are coupled to the pechan prisms at a 10 to 1 ratio to obtain the necessary precision for scan angle rotation. Zero reference logic is provided to determine the zero rotation point at system start-up time.

The scan generation servo is an incremental servo channel modified to serve as a rate control or as a position control. During scanning the servo operates at a constant velocity. At system startup the servo serves to position the counter rotating wedges at a zero reference point for alignment of the scanner optics. The zero referencing procedure is under program control and consists of looking for the encoder zero reference signal and offsetting by some predetermined angle to obtain the optical rotation zero point.

A block diagram of an incremental servo channel is shown in Figure 3-10.

During a data output, incremental position data along with an address and a data output timing is presented to all devices on the UNIBUS. The addressed channel transfers the position data into its incremental position storage register and incremental position counter.

When the I/O transfer is completed, the servo channel logic transfers the position command data into the channel position error counter. The position counter converts the data from parallel to serial form and provides clock pulses for incrementing the position error counter. The incremental position counter, initially loaded with the magnitude, is decremented with each clock. When the position error counter reaches zero, a stop signal is sent to the clock generator.

The position error count is presented to a 12-bit digital-to-analog converter which produces an analog error voltage for the servo amplifier. Velocity feedback is also provided at the servo amplifier to improve system dynamic response. Position feedback produced by a rotation encoder is converted by the encoder clock logic to error counter up/down clocks. Clock synchronizing logic eliminates timing interference between the command clocks and encoder clocks.

The incremental servo channel is designed to accept 12-bit signed magnitude incremental position commands at a rate of 100 times per second. The digital-to-analog converter and servo amplifier are commercially available modules.

3.2.1.2.4 Parallel Interface Electronics

Parallel Input Interface

The parallel input interface allows the computer to monitor the state of switch contacts. These inputs may include photo-carriage limit switches, and operator input switches. Switch inputs are packed into 16-bit words. The electronic interface for each work connects directly to the UNIBUS. Figure 3-11 is a block diagram of a parallel input interface.

Individual switches enter the interface through a switch debounce circuit which guarantees one logic state transition for each switch actuation. The leading edge of an output from the debounce circuit sets an anti-repeat flip-flop. A switch will normally be held in its

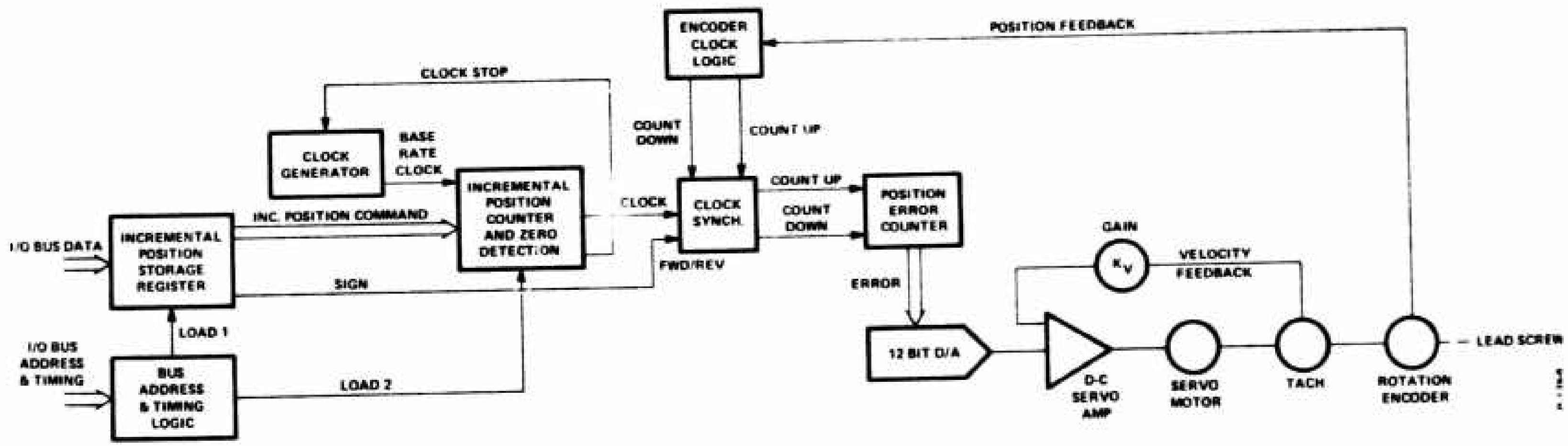

Figure 3-10 - Incremental Servo Channel Block Diagram

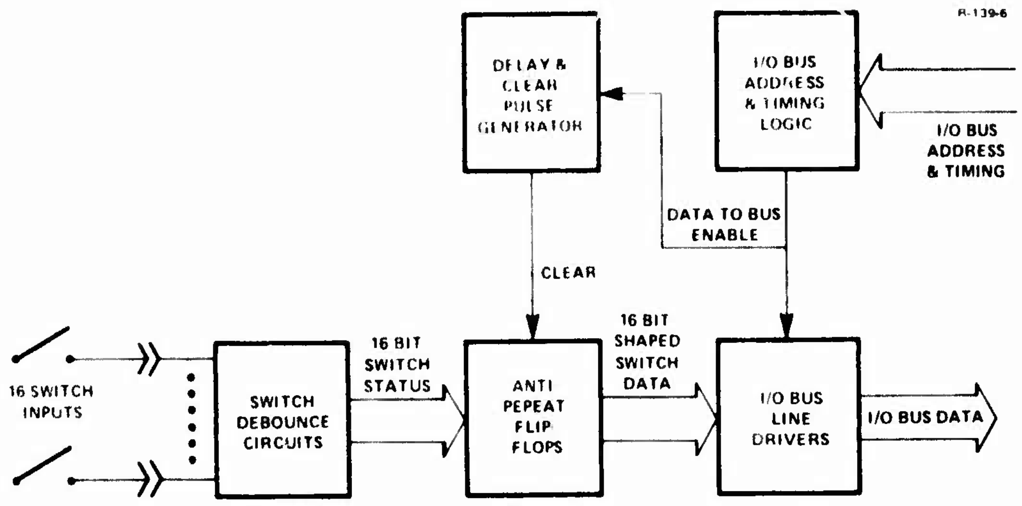

Figure 3-11 - Parallel Input Interface Block Diagram

asserted (actuated) state for a duration covering several computer reads of the switch state. The anti-repeat flip-flop logically deactivates the switch after the first read. For alternate-action pushbuttons and other switches where it is desirable to inform the computer as long as the switch is activated, the parallel input interface is fabricated without the anti-repeat function.

To read the flip-flop states, the appropriate interface address is placed on the UNIBUS. The interface gates a 16-bit word onto the UNIBUS until the address is removed. When the address is removed, a clear pulse generator causes the anti-repeat flip-flops to be reset.

Parallel Output Interface

The parallel output interface handles the flow of single word information from the computer to the special hardware. These outputs are grouped into 16-bit words. The electronic interface is connected directly to the UNIBUS. Figure 3-12 is a block diagram of the parallel output interface.

When the parallel output interface is addressed, it places the 16-bit data word on the I/O bus into its storage register. This data is sent to 16 individual lamps/relays via a bank of driver circuits. Each driver includes rise time limiting, lamp keep-warm circuits, and relay back-emf protection.

3.2.2 Correlator Hardware Configuration

A block diagram of the recommended correlator hardware is shown in Figure 3-13. The main components of the correlator are the correlation computer, peripherals, scanner interface, and the correlation processor. These components are described below.

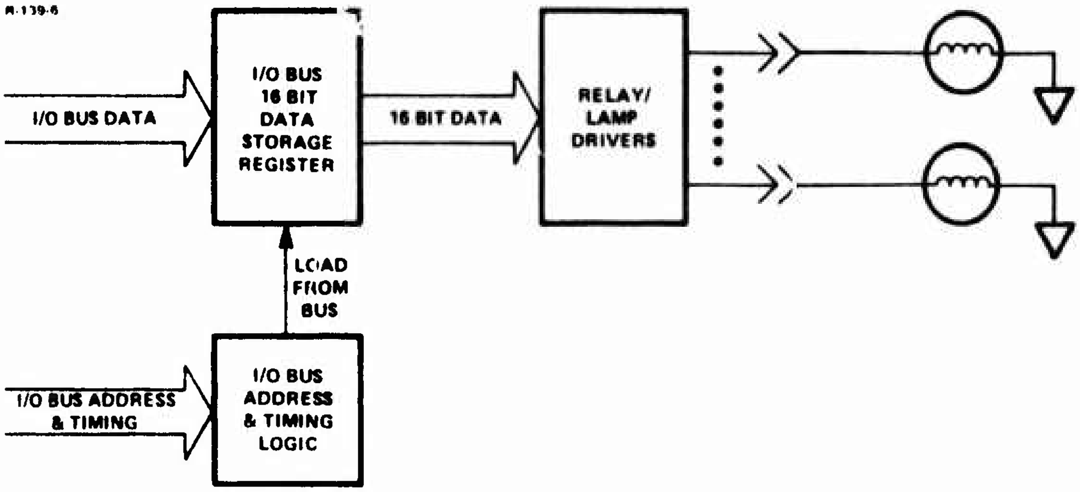

Figure 3-12 - Parallel Output Interface Block Diagram

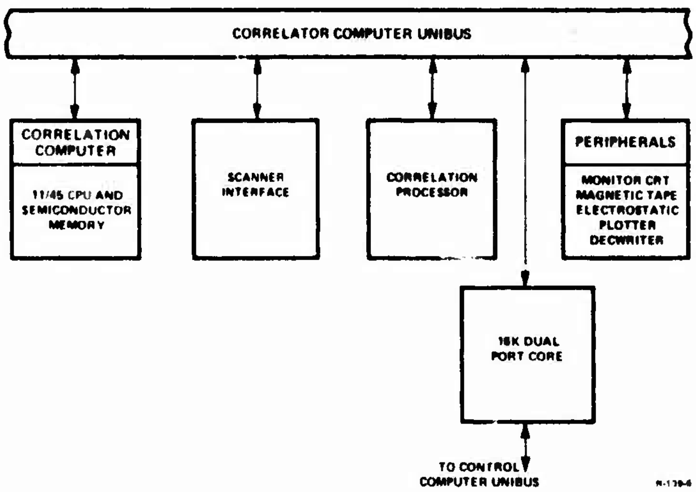

Figure 3-13 - Correlator Block Diagram

3.2.1.1 Correlation Computer and Peripherals

A second PDP-11/45 computer is used as the correlation computer. It is configured with maximum amount of semiconductor memory. The correlation computer is connected to several DEC peripherals, scanner interface, correlation processor, and the shared dual-port memory through the UNIBUS. The details of the correlation computer configuration are given in Table 3-1.

3.2.2.2 Scanner Interface Electronics

The scanner interface electronics gathers epipolar image density data and stores this data in computer memory. The scanner electronics package includes, for both photo channels, a photodetector, a video amplifier network, and a high speed analog-to-digital (A/D) converter. Also included is a parallel data transmission channel and a DMA interface with the correlation computer.

An overall block diagram of the scanner interface is shown in Figure 3-14. Scanner encoder pulses indicating the position of the laser beam along the epipolar scan line are sent to a frequency multiplying phase-locked loop. The loop effectively increases the resolution of the scanner encoder by multiplying its position output. The phase-locked loop output clocks a position counter found in the timing generator logic. The counter state defines scan position, the upper bits of which are sent to the control computer. The timing generation logic also produces sample commands to trigger the A/D converter. Image data sampling occurs at a constant time rate for a nominal scan angle of 60 degrees in every 180 degrees of scanner rotation. About 3800 samples are taken per scan line with an average spacing of 7 μm.

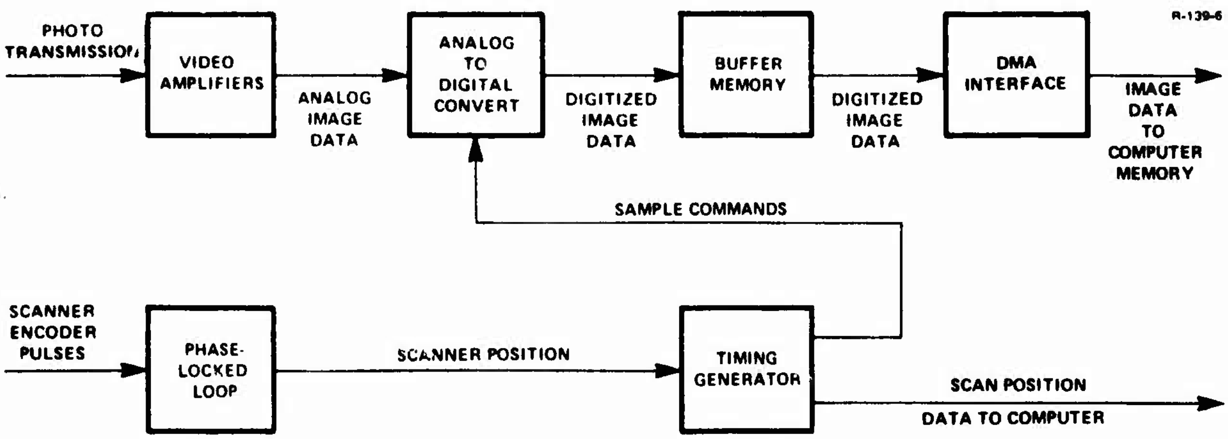

Figure 3-14 - Scanner Interface Block Diagram

The photodetector video-amplifier combination converts image light transmission to voltages compatible with the A/D converter. The photodetector is a low-noise, large surface area (1 cm^2) PIN photo diode, model SGD-444 manufactured by EG&G. Experience on the AS-11B-X has shown that the optimum video amplifier has a logarithmic, bandpass gain characteristic. Logarithimic gain provides maximum signal power for a large range of average photo densities. The bandpass frequency response removes dc components and thus enables higher amplifier gain while preventing signal aliasing at higher frequencies.

The analog-to-digital converter block consists of a track-store amplifier and a high-speed successive-approximation A/D converter with an 8-bit two's complement output. The digitized image data is transmitted over a parallel transmission link (not shown in the block diagram) to a buffer memory and DMA interface. These two devices are shown in more detail in Figure 3-15.

The buffer memory is a first-in first-out (FIFO) shift register and has a 64 word capacity at 16 bits/word. End-of-conversion signals from the A/D converter channels clock image data into the FIFO buffer. Data is clocked out of the buffer under control of the DMA interface. The interface is set up in advance of the sampling interval by the system program. The first data to enter the FIFO buffer causes a FIFO not-empty signal to request a memory cycle of the DMA interface. As the memory cycle is completed an end cycle signal from the DMA interface generates a FIFO output clock which advances the next image data element pair to the FIFO output. This process is repeated until all 3800 image data samples have been transferred into computer memory. The scanner DMA interface has priority for UNIBUS cycles over the CPU and other system interfaces to ensure that the FIFO does not overflow. The DMA control logic, however, is designed so that it will not lock out the next highest priority device using the UNIBUS for more than two consecutive cycles.

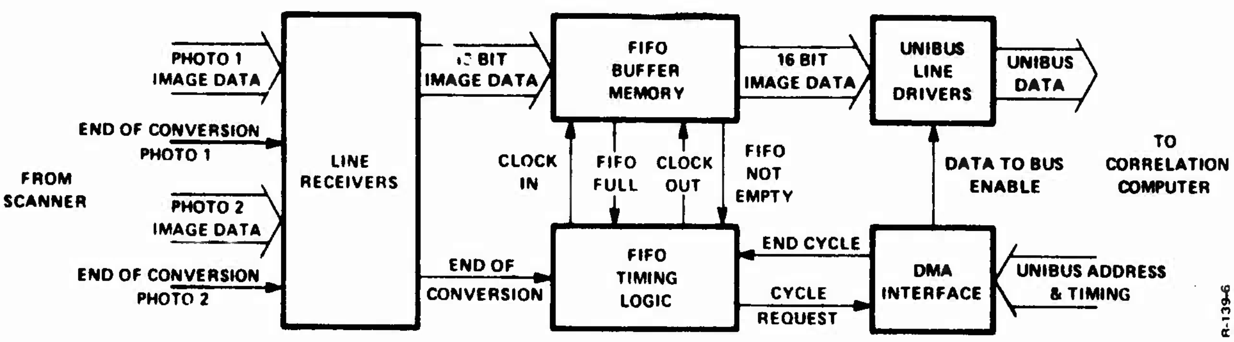

Figure 3-15 - Buffer Memory and DMA Interface

Most of the DMA interface is available as the DR11-B, a standard DEC product.

3.2.2.3 Correlation Processor

The primary function of the correlation processor is to do high-speed computation of parallax between two sets of photo image data. The correlation processor is attached to the correlation computer UNIBUS with a pair of DMA interfaces. The correlation computer loads the processor with image data through one interface while the processor outputs parallax, covariance, peak correlation, and photo 1 and photo 2 signal powers through the other interface.

Figure 3-16 is a simplified block diagram of the correlation processor. The high-speed buffer memory stores 1024 elements of address-modified epipolar image data for each photo channels. The memory is very similar to the four-line buffer memory in the AS-11B-X system. It is made up of high-speed, bipolar, random-access memories configured to be written into via the input DMA interface and read by the covariance computation logic. The covariance computation logic reads photo 1 and photo 2 image data with two different addresses during covariance calculations.

The primary function of the covariance computation logic is the computation of covariance between sets of image data samples obtained from the epipolar scanner. The following equation is solved:

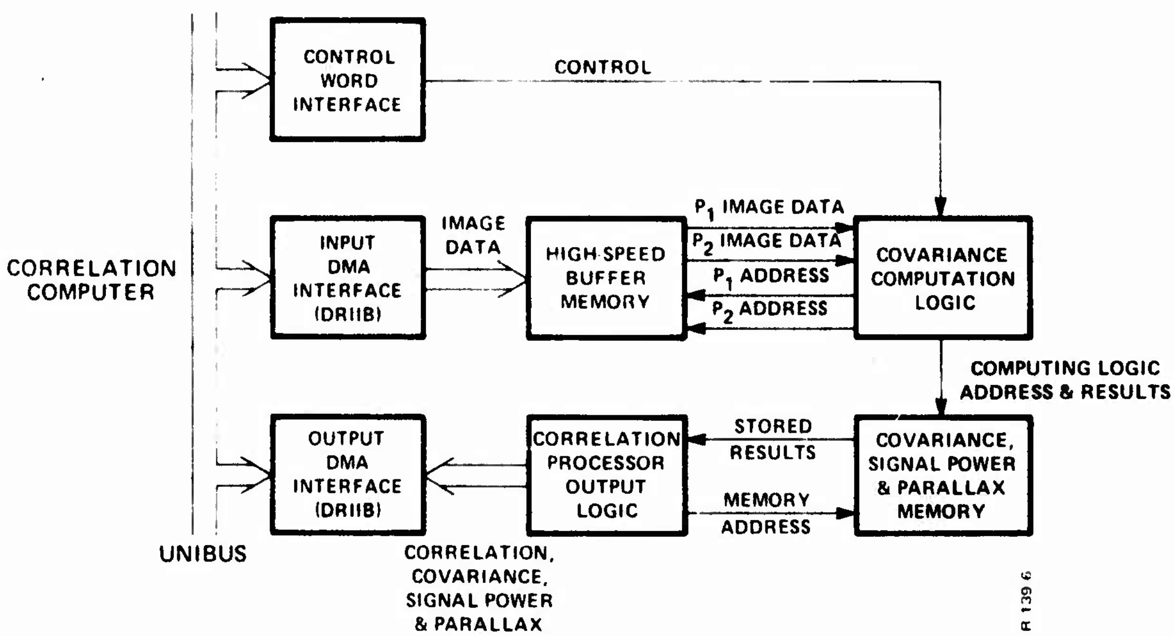

Figure 3-16 - Correlation Processing Simplified Block Diagram

$$C = \sum_N a_i b_{i+d} - \frac{1}{N} \sum_N a_i \sum b_{i+d}$$

where

- C is coveriance (by definition)
- a_i is the ith value of photo density along an epipolar line in photo 1
- b_i is the ith value of photo density along an epipolar line in photo 2
- N is the number of consecutive points used in the computation
- d is the distance by which the b_i data set is shifted relative to the a_i data set expressed as a whole number of sampled image elements

Parallax is obtained by making several trial covariance computations and recording the value of d which produced maximum positive covariance. The variation of d is implemented by computing the data address for b_{i+d} as the a_i address plus a programmed shift increment.

The covariance computation logic also computes the signal powers for photo 1 and photo 2 by selecting a_i or b_{i+d} for both inputs to the computation hardware. This is done in separate passes through the covariance computation logic.

The outputs of the covariance computation logic are stored in the covariance, signal power, and parallax memory. They are then sent to the correlation computer via the correlation processor output and the output DMA interface.

Correlation is also computed and sent to the correlation computer over the output DMA interface. Correlation is computed by the correlation processor output logic from data stored in the covariance and signal power memory. Correlation is defined here as the ratio of the peak covariance value to the larger of the photo 1 or photo 2 signal powers. The photo 2 signal power used in the comparison is that which is offset by the parallax amount.

A number of control inputs to the correlation processor from the correlation computer are received via a word interface. These inputs are segment size, start and end segment, number of shifts, and shift amount.

The blocks in Figure 3-16 entitled covariance computation logic; covariance, signal power, and parallax memory; and the correlation processor output logic are all contained in the existing AS-11B-X parallel processor. Only the computer interface portions are redesigned for the ACE system.

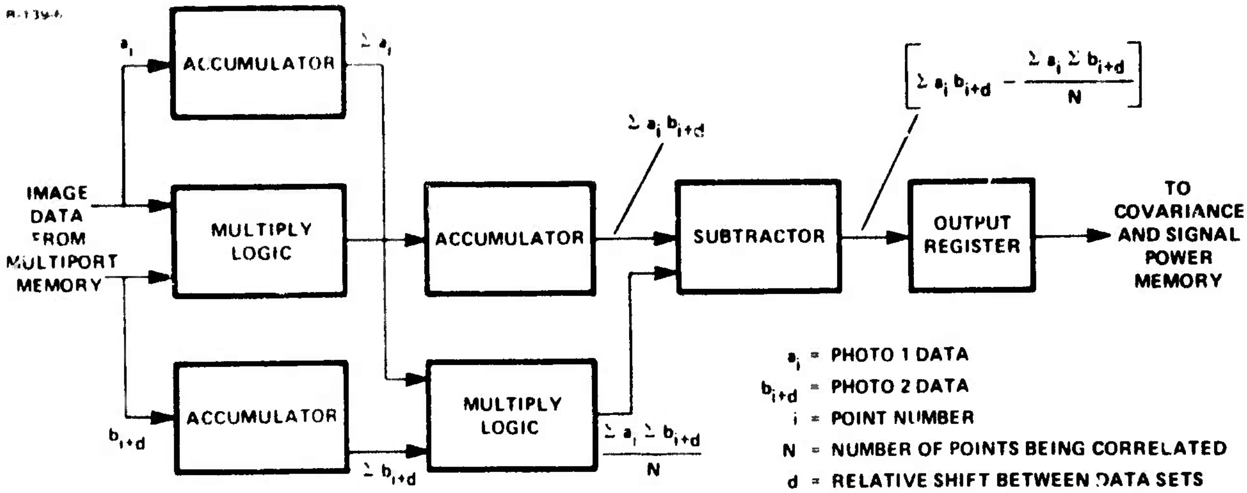

Figure 3-17 - Covariance Computing Logic

The block diagram in Figure 3-17 shows how the covariance equation is implemented in hardware. The a_i and b_{i+d} inputs come from the high-speed buffer. The covariance value in the output register is tested against the previous peak covariance for that set of points being correlated. If a new maximum is found the peak covariance and value of d is stored in the proper covariance and parallax memory location.

Not apparent in Figure 3-17 is that three covariance computations occur simultaneously in the hardware. Each of the computations is for different numbers of image data elements being correlated. Partial results which are common to all three computations are compiled and stored in accumulators. This saves the hardware from having to implement the same calculations at three different times or with three different pieces of hardware. A large savings in hardware complexity and computation time is therefore realized. The quantities may be computed and stored for three different ranges of epipolar scan line segment sizes: 16, 32, 64; 32, 64, 128; or 64, 128, 256 image data elements. The range is selected on-line as a function of correlation and signal power.

3.2.2.4 System Display Interfaces

Several ACE system displays provide high visibility of the system operating status. These displays include the monitor CRT, electrostatic plotter, alphanumeric CRT, and a calibration and maintenance panel.

The electrostatic plotter provides high-speed, hard copy, graphic outputs of terrain profiles. Multiple profiles could be plotted in real-time where the length of a swath is plotted down the length of the paper.

The points plotted would be the same as those recorded on magnetic tape. Other plotting or printing uses of the plotter are possible. A Gould printer attached to the correlation computer UNIBUS would plot with a resolution of 100 points to the inch across 11 inches of paper at 2 inches per second.

The alphanumeric CRT display keyboard replaces the viewer panel of the AS-11B-X system. Its advantages over a viewer panel are lower production cost, increased flexibility, and higher operator I/O rates when used in place of the teletype or DECwriter peripherals.

The CRT selected for ACE is the same as used on previous Bendix products. It is made by Ann Arbor Terminals and attaches to the computer via the DEC DL11-C interface.

3.2.2.5 Monitor CRT

The monitor CRT display provides the operator with real time displays of selected system data. The monitor CRT is the window through which the operator can assess system operation on-line. The heart of the ACE strawman display is the DEC EG11 engineering graphic display system, which includes a CRT display screen with light pen (DEC Model VR14) and a display processing unit (DPU), the DEC VT11. The light pen is used in the present design. The EG11 is a standard peripheral which attaches to the correlation computer UNIBUS in the ACE Strawman.

The EG11 has the following display modes: Character, Short or Long Vector, Point, Graph X and Graph Y, and Relative Point. Modes of use for the ACE application are Character (for labels), Long Vector (for grids), and Graph Y (for point plotting of data). The Graph Y mode appears to be the most efficient for point plots because the X axis increment need only be specified once in the display file. The remainder of the display file is simply a list of 10-bit Y coordinate words.

Timing estimates for complete displays can be based on information gathered from the VT11 manual. Alphanumeric displays are displayed at a rate of about 25 μs/character. Graph Y point plots are written at 25 μs/point. Vectors take a variable length of time to write but are guaranteed to take less than 200 μs/vector.

The VT11 DPU occupies a system unit in an 11/45 expansion box. A 20-foot cable separates the DPU and the VR14 CRT.

3.2.2.5.1 Display Operation

To initiate a display on the EG11 the program must first set up a display file in main memory. This file contains some predetermined information which establishes the graph origin on the CRT, specifies display intensity, light pen interrupt enable, and end-of-display interrupt enable.

The bulk of the display file is the graphic data. One hundred memory words are accessed to plot 64 points with title and a modest grid. The display unit is started when the program (a) initializes the CPU stack pointer and (b) loads the DPU program counter with the starting address of the display file. The DPU automatically accesses the display file while the main program is free to execute other code. The DPU steals UNIBUS cycles as file data is needed. When the display is completed the last instruction in the display file tells the DPU to simply stop (until the address counter is reloaded) or a CPU interrupt can be generated. A hardware DPU status bit indicating display completion is not available to the programmer.

3.2.2.5.2 Types of Displays

Three types of data are displayed in the ACE strawman:

Monitor Display Categories

1. Video Displays

   Non-Address-Modified Video

   Address-Modified Video

2. Covariance Displays

3. Computer Generated Displays

   Parallax Table

   Accumulated PX

   PX Error

   Peak Correlation

   Signal Power (Photo 1 or Photo 2)

   Selected Segment Size

   Lost Regions or Not Valid Regions

The following description outlines decisions that have been made towards implementing each of the three basic types of displays. The flexibility of the EG11 allows each display to be formatted with a grid and labels.

Video Displays

1. Provide address modified or un-address modified video.

2. X axis - 256 or 512 points/line

   Y axis - 256 levels.

3. Display one line per scan as long as CPU is available to compile the display file.

4. Provide capability to display full scan line length or just a line segment.

5. Provide capability to select scan direction displayed, normally both directions displayed.

Covariance Displays

1. Covariance data is picked off correlation processor COV XX lines by a special interface which transfers this data to the computer via DMA.

2. Operator inputs for covariance display are Trial Center, Segment Size, and Scale.

3. Operator inputs are through the alpha numeric keyboard.

4. Covariance display overflow will not fold over on the display screen but clip.

5. Negative covariance is displayed as zero covariance.

6. Computer program translates Trial Center and Segment Size to segment number which is presently being used on the AS-11B-X.

7. Selected Trial Center and Segment Size combinations for which no covariance are computed result in a blank display.

8. Display will consist of one point per shift.

9. Display is refreshed once per scan line.

10. Included in covariance display key correlation processor control parameters are ones such as those found on the AS-11B-X Parallel Processor Display panel. Included are Starting and Ending Trial Center Numbers, Segment Size, Number of Trials, and Increment.

Computer Generated Displays

1. Displays provided are Parallax Table, Accumulated Parallax, Parallax Error, Peak Correlation, Signal Power (Photo 1 or Photo 2), Selected Segment Size, Lost Regions, Valid Regions, and Keyboard Selected Displays.

2. 64-point displays are provided for all variables.

3.2.3 Program Organization

3.2.3.1 Control Computer Program Organization

The control computer programs are organized into two basic operating modes: the manual mode and the automatic mode.

Both operating program modes require viewer/plotter interface programs, console interface programs, interrupt handling programs, processing subroutines, processing sequence-control, and operating time support subroutines. Submodes are selected by the operator by means of a menu mode.

The manual and automatic program modes differ with respect to:

(1) Mode processing sequence control

(2) Organization of programs in control computer memory

For manual modes, the operator usually specifies the sequence of processing functions. Also, processing programs need not be memory-resident at all times, since millisecond time lags are not critical during manual operations. For automatic modes, the mode processing scheduling is performed automatically by a program, and all programs must be memory-resident.

Overall control computer organization is based on the use of the RSX-11M real-time operating system. The operating system is used for multiple task support. Processing and clock programs are RSX-11M tasks. Interrupt programs are RSX-11M peripheral drives. Operating-time support, memory management, and links to shared programs are also handled by the operating system.

Photogrammetric Targeting System (PTS) program will be adapted for use by the control computer whenever practical. The functions performed by the ACE control computer are very similar to those performed in the PTS control computer. The following functions would be performed by the control computer programs:

Overall System Control

Operator Interface

Model Setup

Ground-to-Photo Conversion

Servo Control

Epipolar Coordinate Conversion

Address Modification

Communication Link to Pooled Minicomputers

Profile Plotting Functions

3.2.3.2 Correlation Computer Program Organization

Correlation computer functions are required for ACE automatic modes only. Correlation computer program functional organization is less complex than the control computer organization since the operator and viewer interface programs are not required.

The organization of the correlation computer programs is as follows. Correlation computer submodes are initiated by the control computer. All correlation computer programs are memory resident and are included in 1 to 2 RSX-11M tasks to minimize task swapping time. Program scheduling is controlled by flags stored in memory common to the correlation computer and the control computer.

Time-critical correlation computer programs are executed out of semiconductor memory. Data which must be accessed at high rates is also stored in semiconductor memory.

The basic sequence of the correlation computer automatic plotting mode takes place in a 20 ms cycle. The following functions are performed:

(1) Scanner interrupt, data transfer complete

Initiate DMA for next scan line

Set buffer ready flags

Monitor control computer inputs

Select sequence

(2) Scan line processing loop

Trial center boundary

Correlation control outputs

Scan data output

X-parallax accumulate

Monitor CRT output

Output parallax and correlation status to control computer

(3) Correlator interrupt

Correlation #1 inputs

Correlation #2 inputs

(4) Continue scan line processing

Correlation analysis

Center parallax estimate

Correlation parameter computation

Interpolate parallax table

Average parallax table

Smooth parallax table

3.3 VIEWER AND SCANNER IMPLEMENTATION

This section describes the Strawman configuration for the viewer and scanner. The configuration was prepared according to the requirements outlined in the Strawman overall system definition. Studies performed during the Strawman study verify that the Strawman viewer and scanner implementation is feasible and will meet the Strawman requirements.

3.3.1 Viewer/Scanner Design Approach

The design approach used for the viewer and scanner is as follows:

(a) Use much of the basic design which is used in the RPIE Printer input stage.

(b) Use flat horizontal stages with stage-on-stage motion (and fixed position optics).

(c) Use preloaded roller bearings on stage guide.

(d) Drive stages with ball screws having preloaded ball nuts.

(e) Construct stages of aluminum.

(f) Construct stages as two separate stage assemblies.

(g) Mount stages and optics on the viewer base directly.

(h) Provide two sets of limit switches for each stage axes.

(i) Use an encoder mounted on the drive screw for stage position detection.

(j) Use PTS-M servo design as far as practical.

(k) Use separate rotators for scanning and viewing.

(l) Optically multiplex viewing and scanning.

(m) Use one counter-rotating dual-wedge scanner assembly. The scanning beam would be split for the two photos after the scanner assembly. The two wedges would be geared together.

(n) Use a 15 mW laser for the scanning light source.

The major design features of the viewer are the following:

(a)	Mechanical stage motion:	10 x 20 inches
(b)	Clear view:	11 x 21 inches
(c)	Maximum positioning speed	
	. Normal operating:	5 mm/sec
	. Slewing (not accurate):	20 mm/sec
(d)	Total static positioning error:	0.005 mm rms (each axis)
(e)	Image rotation:	$\pm$190 degrees
(f)	Zoom magnification:	8X to 30X

The major design features of the scanner are the following:

(a)	Use design similar to AS-11B-X	
(b)	Scan one inch (25 mm) line on each photo	
(c)	Scan at rate of about 50 lines per second	
	. Wedges rotate about 25 revolutions per second (1500 rpm)	
(d)	Provide manually controlled spot size:	0.10 to 0.050 mm dia.
(e)	Design for accuracy (after calibration) as follows:	
	. Position along line:	0.005 mm rms
	. Straightness of line:	0.008 mm rms

3.3.2 Viewer/Scanner Layout

Tentative layouts of the viewer and scanner designs were prepared during the Strawman design study. Schematics of the viewing and scanning optics are shown in Figure 3-18 and 3-19, respectively. Layouts of the overall viewer configuration are shown in Figures 3-20, 3-21, and 3-22. Front, side, and top views are shown.

It is estimated that the viewer will weigh less than 5000 pounds and require a space less than 8 feet wide by 5 feet deep by 6 feet high.

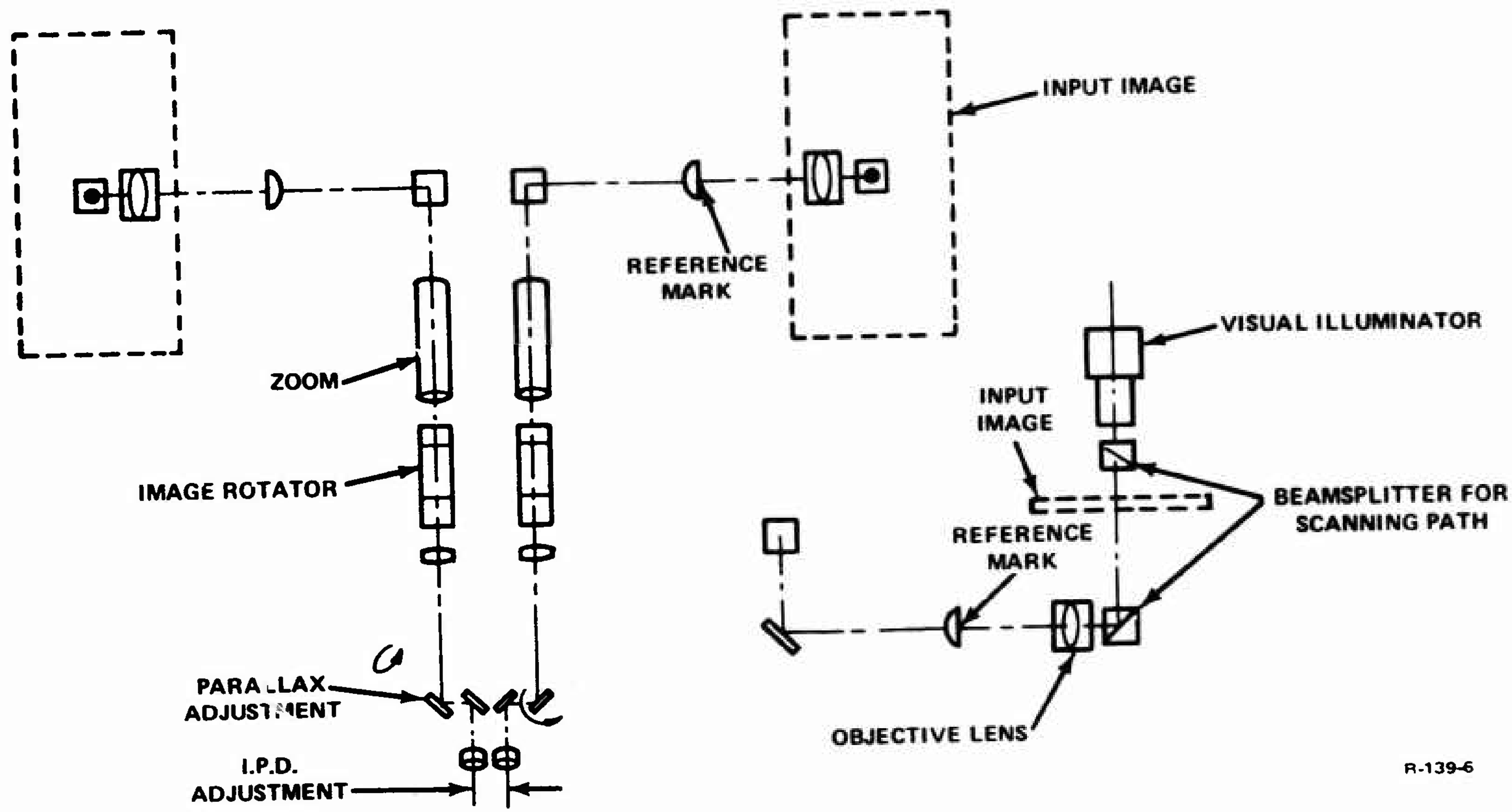

Figure 3-18 - Viewing Optics Schematic

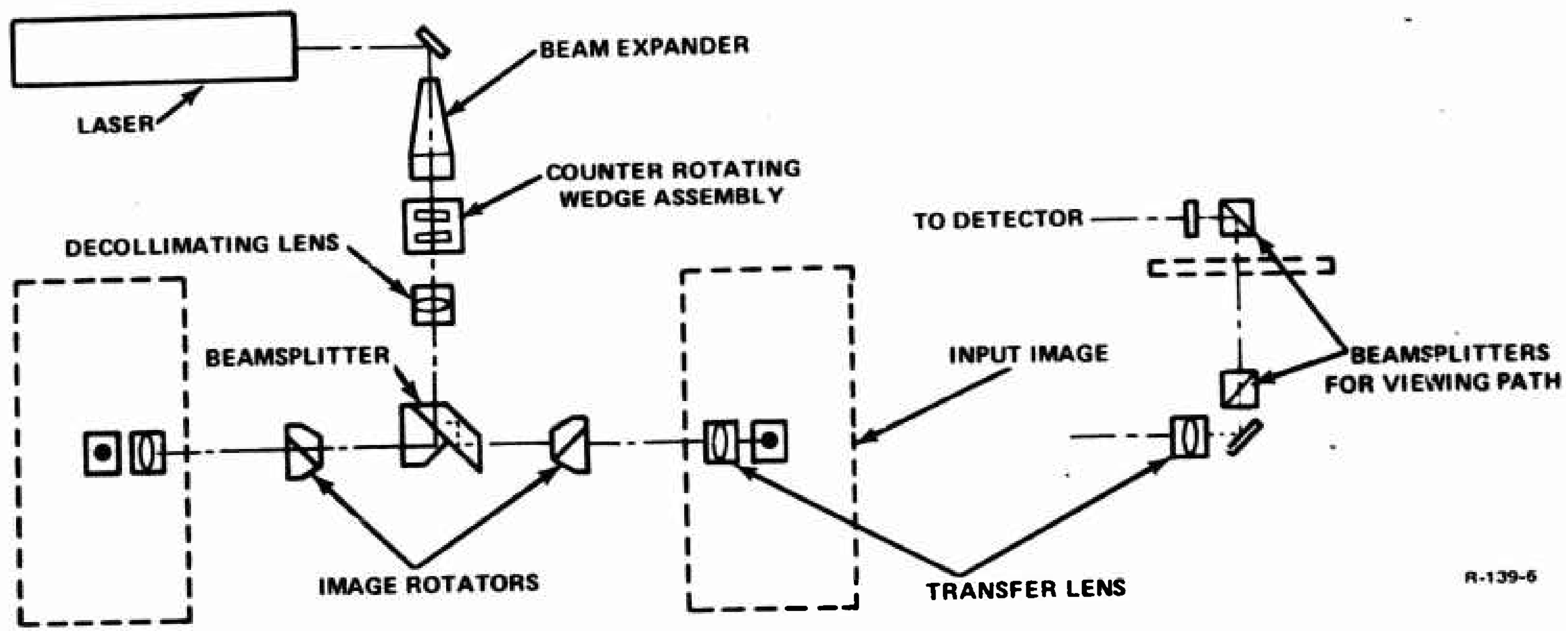

Figure 3-19 - Scanning Optics Schematic

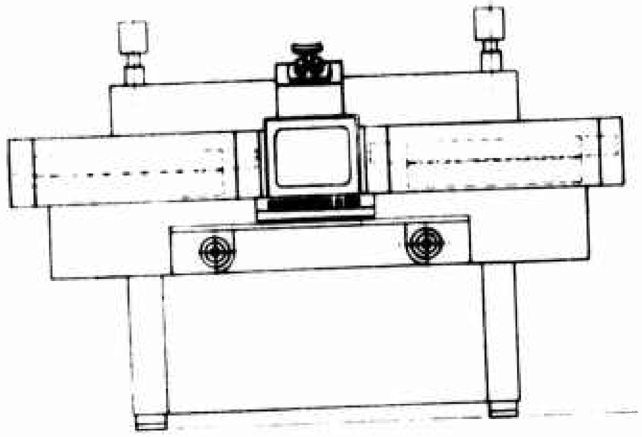

Figure 3-20 - ACE Viewer - Front View

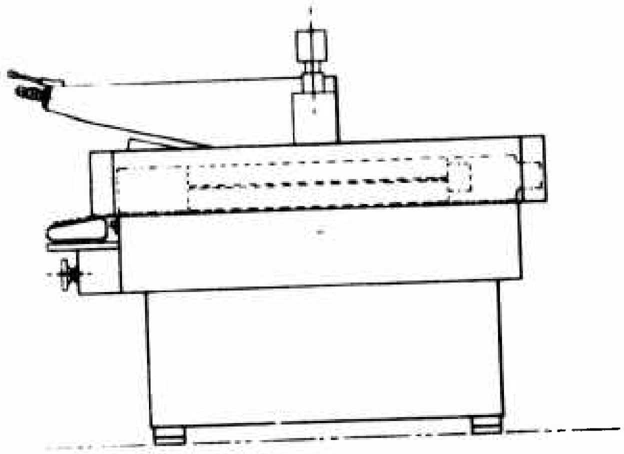

Figure 3-21 - ACE Viewer - Side View

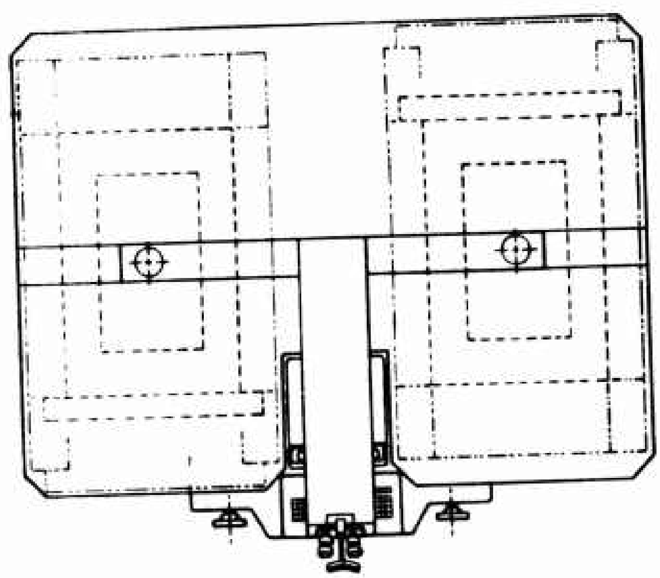

Figure 3-22 - ACE Viewer - Top View

SECTION 4

AS-11B-X EXPERIMENTS

This section presents the results of the AS-11B-X experiments conducted in support of the ACE Design Study. Included are descriptions of the experiments, analyses of the data, conclusions, and recommendations.

4.1 EXPERIMENTAL PLAN

4.1.1 Purpose of Experiments

The purpose of the experiments was to test potential improvements to the AS-11B-X design which could be incorporated into a production ACE. The design modifications tested focused on possible accuracy improvements. Those modifications which prove to be of value to the design of a production ACE can be considered in terms of cost versus performance.

4.1.2 Types of Experiments

The experiments tested AS-11B-X system performance with modified video amplifiers, with reduced sample spacing, and with a variation of parameters in combination with reduced sample spacing. The parameters which were varied are automatic plotting speed, video gain characteristics, and the laser spot diameter. The objective was to improve the system's ability to correlate images, and therefore, improve accuracy.

Experimental modifications were made by changing the gain curves for the video amplifiers to obtain a wider spread of video information. These changes required electrical design and some software strategy adjustments. The sample spacing of image density values was reduced from 20 μm to 10 μm along the scan line. This modification required some mechanical-optical changes and adjustments to provide an alternate set of counter-rotating wedges and some software design to accommodate the new spacing. The spot size of the laser was also changed from 20 μm to 10 μm. This modification was accomplished by changing a pin hole and microscope objective in the laser assembly. These experiments are described in detail in Section 4.2.

The experimental plan also included provisions for tuning and testing the system, recalibrating the scanner after installing new wedges, and restoring the AS-11B-X to normal design and operation after the experiments were performed.

4.2 EXPERIMENTAL DESIGN AND IMPLEMENTATION

4.2.1 Video Amplifier Experiments

The AS-11B-X correlator digitally analyzes the video from the viewer and correlates image detail from both photographs. The video obtained from laser scanning has an inherent signal-to-noise ratio in excess of 300, which is at least an order of magnitude over the typical grain noise from the photography. Given quality video, it remains for the system to extract as much information from the video as possible in order to maximize the correlation of the images.

The normal video amplifier system is shown in Figure 4-1. Signals from the photodiode are passed through a log amplifier, high-pass and low-pass filters, and a linear amplifier. The analog-to-digital converters change the video from an analog signal to an 8-bit, 255-level binary word, which is sent to the one-line buffer of the correlator. One bit represents about 40 mV of video.

The amplifier gain characteristic affects the shape of the video and the amount of amplitude or signal power sent to the correlator corresponding to a given image detail. In order to extract more information from the video, Bendix redesigned the video amplifier to

- o have higher gain in areas of low signal power
- o prevent hard clipping

If the gain in weak signal areas (low contrast areas) is increased, the correlator has more signal power to work with. At the same time, minimizing the clipping of strong signals reduces the loss of image detail. Together, these changes should improve correlation.

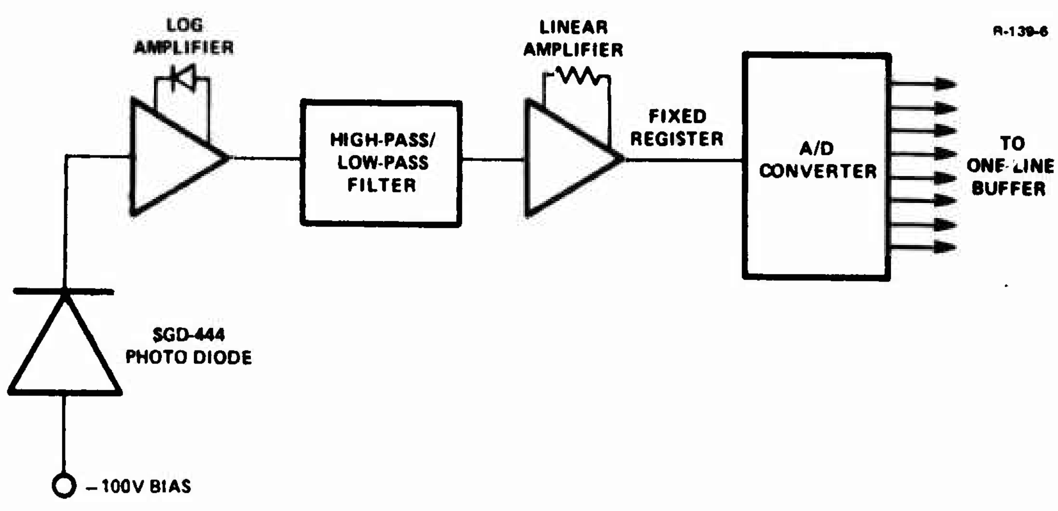

Figure 4-1 - Normal Video Amplifier System

Figure 4-2 shows the linear amplifier gain curve for the normal video amplifiers. Its linearity means that all levels of the video are treated equally. Figure 4-3 shows the gain curve of the redesigned video amplifiers. Weak signals respresented by the center of the curve are amplified by higher gain while the strong signals represented by the ends of the curve are amplified by lower gain, resulting in soft-limit clipping.

The gain of the normal amplifier is controlled by a fixed feedback resistor. To change the gain curve, the fixed resistor is replaced by a piecewise linear gain circuit which has two break-points. These two break-points separate the high-gain middle part of the amplifier curve from the end parts.

After modifications to the viewer electronics were made and checked out, the performance of the AS-11B-X system was checked, and software strategy changes corresponding to the new range of signal power were made to optimize performance.

4.2.2 Reduced Sample Spacing Experiments

The AS-11B-X system measures the average elevation at 58 points along each scan line. The points are spaced 320 μm apart. The measurements are derived from sampling image density values spaced 20 μm apart. There are 1280 density values sampled for each scan line, and a scan line is 25.6 mm long.

The digital correlator measures the amount of shift or parallax between corresponding segments of imagery on two stereo photographs. This is done by computing correlation from a sampling of corresponding image density values along the scan line for each photo. The sampling of density values is shifted to produce a different correspondence between scan lines. The correspondence with the highest calculated correlation value is taken to be the amount of shift or parallax required to match images for the profile point being measured. If the sample spacing of image density values were reduced, the resolution of measuring parallax would increase, and a corresponding increase in elevation accuracy should be possible.

The epipolar scanner uses the focused spot of a laser beam to scan the photographs. Figure 4-4 illustrates the scanner assembly. The light transmitted through the photograph is collected onto the photo-diode detector. The expanded laser beam is periodically deflected by a set of counter-rotating wedges which moves the laser spot over the photograph in a scan line 25.6 mm long. After the wedge assembly, the laser beam is split into two beams for simultaneous scanning of two photographs.

Bendix decreased the sample spacing by installing an alternate set of counter-rotating wedges to the scanner assembly. These half-angle wedges decrease the sample spacing from 20 μm to 10 μm. The normal set of wedges each have a 2-degree, 50-minute, and 32-second angle. The alternate set of wedges each have an angle of 1 degree, 25 minutes, and 16 seconds. On installing the alternate set of wedges, the scan line is reduced from 25.6 mm

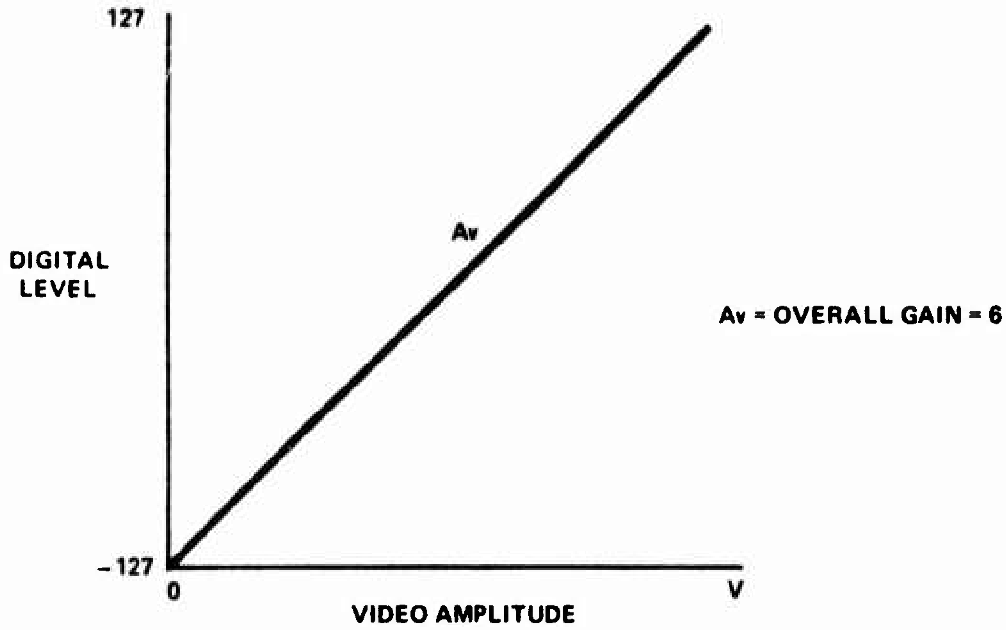

Figure 4-2 - Normal Video Amplifier Gain Curve

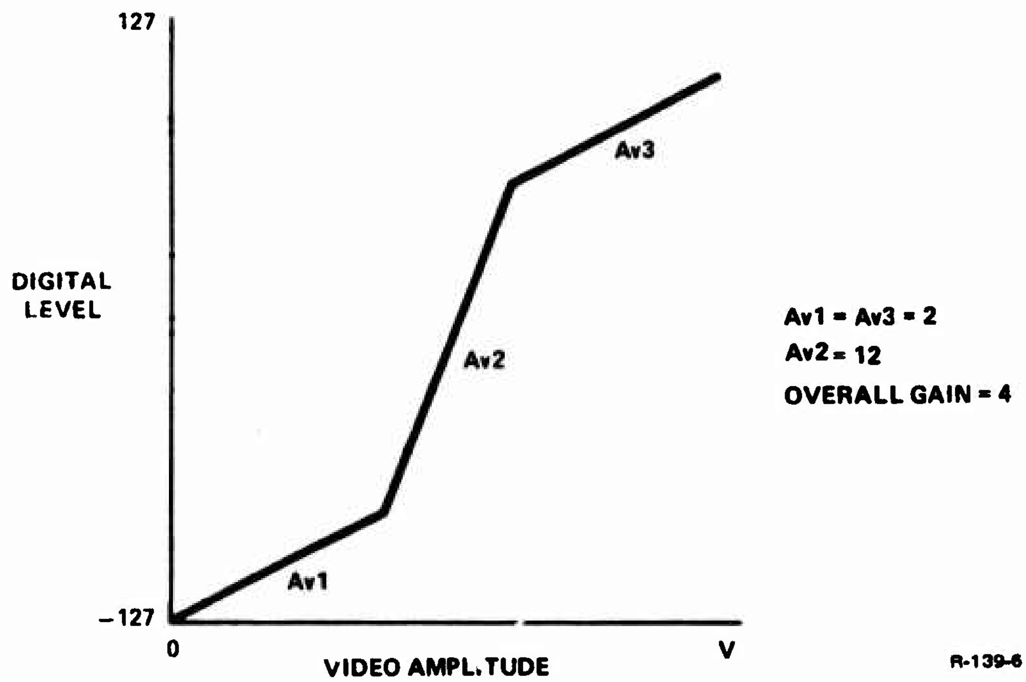

Figure 4-3 - Experimental Video Amplifier Gain Curve

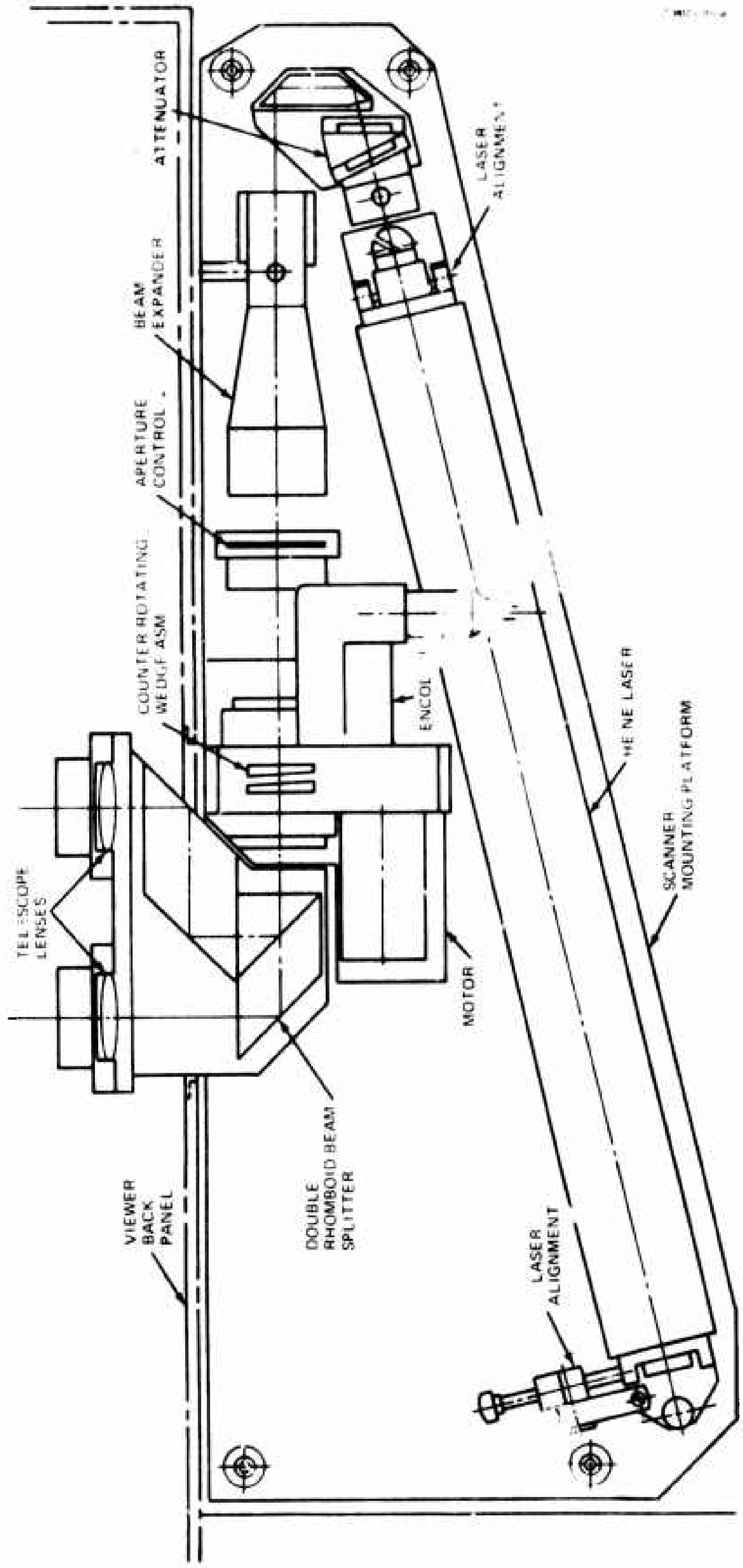

Figure 4-4 - Scanner Assembly

to 12.8 mm. Since all other components of the assembly are the same, the constant-increment encoder which is geared to the wedges still causes 1280 image density values to be digitized for each scan line. The spacing of these values is 10 μm.

To install the alternate set of wedges, the scanner was removed from the viewer. The normal set of wedges was removed and replaced with the half-angle wedges. The half-angle wedges were aligned and the scanner was put back in the viewer.

After installation of the new wedges, it was necessary to recalibrate the scanner. A standard AS-11B-X procedure was followed whereby a calibrated grid is scanned and image data is carefully collected. New address modification tables are then computed to take into account the nonlinearity of the scanner.

In addition to the optical-mechanical changes, software changes were made to take into account the new sample spacing of 10 μm. Also, the smaller scan line requires changes in computing geometric corrections and scanner boundaries. Most of these changes are in the control computer programs.

4.2.3 Reduced Spot Size Experiments

To achieve good automatic measurements, the video should render as much image detail as possible without being affected by photograph grain noise. The RMS grain noise passed by the scanner is approximately proporional to the inverse of the scanning spot diameter. However, the larger the spot size, the more low-pass filtering is done on the image detail. Therefore, a balance must be sought between conflicting effects. Since the frequency spectrum of photographic imagery can vary widely, compromises must be made in selecting spot size.

The reduced sample spacing experiments reduced image density sample spacing from 20 to 10 μm along the scan line. During these experiments, a few runs were made with a corresponding decrease in laser spot diameter of from 20 to 10 μm to determine if an improvement in accuracy would result.

The size of the laser spot was changed by installing a different microscope objective and pin hole at the rear of the beam expander shown in Figure 4-4.

4.3 TESTING

The AS-11B-X system was tested to determine the extent of accuracy improvement resulting from each experimental modification. Five test models were plotted after each modification and manually evaluated at about 80 randomly selected points. The accuracies obtained were compared to manual evaluations of the test models during normal operation; that is, without experimental modification affecting system operation.

Table 4-1 - General Characteristics of Test Models

Model	Type	Resolution	Quality of Imagery	Type of Terrain
Fort Sill	Frame	Poor	Fair	Hilly
California	Frame	Poor	Poor	Mountains, Very Rugged
Arizona	Pan	Fair	Good	Mountains, Rugged
Pan #1	Pan	Good	Good	Mountains, Very Rugged
Pan #2	Pan	Good	Very Good	Fairly Flat

The five test models are commonly referred to as Fort Sill, Arizona, California, Pan #1, and Pan #2. The general characteristics of these models are listed in Table 4-1. The models Fort Sill, California, and Arizona were used during preliminary acceptance tests for the AS-11B-X. The results obtained during preliminary acceptance tests could have been used as benchmarks for determining relative accuracy improvement. However, the disparity of results between various operators during preliminary acceptance tests illustrates the need for a consistent or formal approach. (See "Preliminary Acceptance Test Report, AS-11B-X Automated Stereomapper", Report No. 7517.) Insofar as time constraints would allow, each model was evaluated by the same operator within the time frame of the experiment. Prior to the experiments, the AS-11B-X system was given a complete overhaul. The optics were re-aligned and the system was recalibrated.

The procedures used to plot and evaluate each model are part of the normal operating procedures for the AS-11B-X system. All fast runs were made with the selectable PX adjustment feature off so that the scan lines float over the terrain. This was the same procedure used during AS-11B-X preliminary acceptance tests. The randomness of the evaluation routine used is inherent to the routine. The operator selects the scan line spacing, and the program randomly selects the profile point from 1 to 58 on the line which will be evaluated.

The evaluation routine also can visit a fixed grid of points whereby the operator selects the scan line spacing and the spacing of points along the scan line. This matrix type of evaluation was used on a selected area of the Pan #1 model.

An evaluation consists of comparing static manual elevation measurements with dynamic automatic elevation measurements digitized when plotting. The resulting RMS elevation errors are calculated as follows:

$$\overline{\Delta E_m} = \frac{1}{n} \sum_{i=1}^{n} (E_{me} - E_{mp})_i$$

$$RMS(\Delta E_m) = \left[\frac{1}{n} \sum_{i=1}^{n} (E_{me} - E_{mp})^2 \right]^{1/2}$$

$$\sigma(\Delta E_m) = \left[\{RMS\ (E_n)\}^2 - \overline{\Delta E_m}^2 \right]^{1/2}$$

$$\sigma(\Delta PPX) = B/H \cdot \sigma(\Delta E_m)$$

where

n = number of points used in error calculation

r = number of points rejected because of elevation error greater than 100 μm

$\overline{\Delta E_m}$ = average elevation error (μm)

$E_{me} - E_m$ = manually measured point elevation

$E_{mp} - E_m$ = recorded during automatic plotting

$RMS(\Delta E_m)$ = root mean square elevation error (μm)

$\sigma(\Delta E_m)$ = root mean square elevation error around mean (μm)

$\sigma(\Delta PPX)$ = root mean square X parallax error photo scale (μm)

B/H = model base-to-height ratio

4.4 SUMMARY OF DATA

The data obtained from the experiments have been summarized in Table 4-2. The test models that were automatically plotted and manually evaluated for a variety of test conditions are listed on the top of the chart. Each test performance run used a performance parameter or a combination of parameters that was different from normal performance operation. These parameters are listed in the left-hand column. The new parameters tested were soft-limit video which was the result of video amplifier modifications, a reduction of sample spacing along the scan line from 20 μm to 10 μm, a reduction of automatic plotting speed by one-half from 2.5 to 1.25 mm/sec, and a reduced spot size diameter from 20 to 10 μm. A speed reduction by one-half implies a reduction of Y scan line spacing from 50 to 25 μm. All models were randomly evaluated throughout the entire model except for the intensive grid evaluations done on a selected 15 by 15 mm square area of the Pan #1 model. The intensive grid evaluations are noted as a parameter change in the left-hand column.

Table 4-2 - Summary of Various Test Performance Runs Relative to Normal Operation Model

Performance Parameters \ Model	Fort Sill	California	Arizona	Pan #1	Pan #2
Soft-Limit Video	-2	+5	-1	-2	0
Reduced Sample Spacing					
Full Speed	-2	+4	+2	-3	0
Half Speed	+1	+7	+2	0	+2
Half Speed, Reduced Spot Diameter			+2	-1	
Half Speed, Soft-Limit Video			+5		
Half Speed, Intensive Grid Evaluation				+2	
Half Speed, Reduced Spot Diameter, Intensive Grid Evaluation				-3	

The values listed in Table 4-2 are $\sigma(\Delta PPX)$ root mean square X parallax error difference values. They are formed by subtracting the $\sigma(\Delta PPX)$ value for a test performance run from the $\sigma(\Delta PPX)$ value for the corresponding normal performance (normal video) run. The values are in micrometers at photo scale and therefore, can be compared roughly with each other.

4.5 CONCLUSIONS

No general trend of accuracy improvement for a variety of models was experienced using soft-limit video as a performance parameter. However, some measurable accuracy improvements were experienced for a couple of isolated cases using soft-limit video in combination with reduced sample spacing and half speed plotting. These cases were limited to poor image photography area as found in California and Arizona models. Such areas conceivably were easier to correlate with the wider range of image density value signal powers available with the soft-limit video. The accuracy results plus the fact that fewer operator manual assists were required to automatically plot all models using soft-limit video support this hypothesis. Thus the use of soft-limit video may be helpful in some cases.

All models deomonstrated at least a small accuracy improvement when reduced sample spacing was tried with the right combination of performance parameters. The performance parameter needed was the reduction of automatic plotting speed by one-half. This includes the Pan #1 model if one examines the intensive grid evaluation results. Reduced sample spacing in combination with the performance parameters full speed plotting or reduced laser spot diameter did not demonstrate a general trend of accuracy improvement. The average percentage of relative RMS accuracy improvement experienced for reduced sample spacing at half-speed is 14 percent. This improved accuracy is obtained at the expense of speed, however.

For the present AS-11B-X design, implementing reduced sample spacing with half-speed plotting has the following implications. Reducing the sample spacing causes the length of the scan line to be reduced by one-half. This, in combination with half-speed plotting, reduces the area plotting rate to one-quarter of the normal plotting rate.

4.6 RECOMMENDATIONS

Since no general accuracy improvement was produced by the video amplifier modification, Bendix is recommending that they not be implemented in a production ACE system. Bendix has, however, decided to leave the video amplifier modification on the experimental AS-11B-X system as a switchable option for the user. By flipping a switch and adjusting a few potentiometers for correct voltage levels, either a normal video curve or a soft-limit video curve can be used when collecting data.

Considering the small improvement in performance and the high cost to implement reduced sample spacing, Bendix does not recommend it. If it is implemented, however, it should be accompanied by a corresponding decrease in the automatic plotting area rate.

Bendix does recommend some flexibility in the density of points collected for a model on the production ACE system. This would allow the user to select image sample spacing along and between lines corresponding to the use for the data collected and the scale of the photography.

SECTION 5

ACE DESIGN ALTERNATIVES

5.1 NEW PROGRAM GUIDELINES

The original objective of the ACE Design Study was to provide a preliminary conceptual design for an optimized ACE production system. Specific design objectives were to increase data collection speed and improve accuracy. Also the limitations of the AS-11B-X design such as lack of flexibility, limited memory size, and inability to add standard peripherals were to be minimized.

The Strawman design approach described in Section 3 of this report was developed according to these objectives in coordination with personnel from the DMA Centers.

During the course of the ACE studies, however, a number of facts came to light. Most important, the development of a new optimized ACE system would involve a substantial cost. The cost of developing an optimized system would be about equal to the cost of the AS-11B-X development. Secondly, the AS-11B-X had proven very successful in its performance test. Specifically, it met its accuracy requirements, and it substantially exceeded its speed requirements.

In light of these facts, the Government requested a redirection of Bendix' effort on the ACE design study. The following guidelines were stated:

1. A major reduction in cost would be required - substantially more than 100 K reduction compared to a fully optimized ACE.
2. Implementation would be required by 1978 to meet near-term needs. Thus no new approaches should be considered which involve long-term development effort.
3. There would be no constraint on approach - we would not be bound by the ACE Strawman design.
4. ACE requirements would be reduced -
   (a) Data collection rates could be reduced 50 percent
   (b) The system could be limited to handling frame photos only
5. The same accuracy as provided by the AS-11B-X would be required.
6. 9 x 18 inch stages would be required.

Persuant to these guidelines, the Government asked that Bendix investigate alternative approaches to ACE system. Specific variations requested for consideration by the Government include:

(a) ACE systems based on GFE AS-11B-1, either by using the Bx-272 computer or not using the Bx-272 computer.

(b) Upgrading the present AS-11B-X to be an ACE

(c) Substituting a Modcomp II or IV for the PDP-11's.

These and other variations were considered. Cost and schedule estimates for the various approaches were subsequently prepared and presented to the Government.

5.2 ACE DESIGN VARIATIONS

The following paragraphs describe alternative ACE design approaches investigated as a result of the revised ACE design study guidelines.

5.2.1 Version 1 - Revised ACE Strawman

Description: This version is the same as the ACE Strawman with revisions as discussed at the Second ACE In-Process-Review (IPR). It includes the following changes and additions:

(1) High-speed bi-directional communication link to another computer - hardware and software additions are required.

(2) Output in ground (or model) coordinates - software development is required.

(3) On-line correction for earth curvature, atmospheric refraction, and ground to LCR coordinates - software development required.

(4) Handling of adverse areas - software development required.

(5) Addition of a reference photo viewer.

5.2.2 Version 2 - ACE System Using Modcomp IV's Instead of PDP-11's

Description: This version is the same as Version 1 except that dual Modcomp IV computers would be used instead of PDP-11's. The following items are different from those in Version 1.

(1) Computers and peripherals.

(2) Programming of control and correlation computers (additional programming is required because programs already written for the PDP-11 must be rewritten).

(3) Interfacing to viewer and correlator (some interface designs exist for the PDP-11's but may not for Modcomp). It was assumed that interface designs will not be available for Modcomp.

5.2.3 Version 3 - ACE System Using GFE AS-11B-1 Viewer

Description: This version is the same as Version 1 except that a GFE AS-11B-1 viewer is used instead of a Bendix-developed viewer. For this version, the development and production cost of modifying an AS-11B-1 viewer are substituted for the production and development costs of a new viewer. The reference photo viewer cost would also be affected since a reference viewer comes with the AS-11B-1 viewer. Development and production costs are therefore incurred by the following items:

(1) Addition of Leitz scanner to AS-11B-1 viewer.

(2) Addition of direct drive servos to viewer.

(3) Rewiring and cable modifications for viewer.

5.2.4 Version 4 - ACE System Using GFE AS-11B-1 Viewer and Computer

Description: This version is based on duplicating an AS-11B-X, starting with an AS-11B-1 viewer and computer, and adding features to update the AS-11B-X to an ACE (as far as practical). The following features would be added.

(1) Program Features

(a)* Output in ground (or model) coordinates.

(b)* On-line correction for earth curvature, atmospheric refraction, and ground-to-LCR (local curvilinear rectangular) coordinates.

(c) Minimal variable-sample-spacing capability.

(d) Figure-of-merit recorded with output data.

(e) Acceptance of input data on magnetic tape.

(f) Improved diagnostics, alignment, and test programs.

(g) Programs for high-speed communications link.

(2) Viewer Features

(a) Front panel controls for scanner alignment.

(3) Hardware Features

(a) High-speed communication link to another computer (input and output).

These features would (partially) update the AS-11B-X to an ACE.

The system would not include the following features:

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* Revised in final version (see Section 6.1)

(1) Program flexibility.

(2) FORTRAN programming.

(3) Modular programs.

(4) Modern operating system.

(5) Single type of computer.

(6) 9-track 1600 BPI magnetic tape.

(7) Electrostatic plotter.

(8) Alphanumeric display terminal.

(9) Computer prompting of manual operations.

(10) Guaranteed overall speed of 50 points/second.

5.2.5 Version 5 - Update of Existing AS-11B-X to an ACE Without Replacing Computers

Description: This version is based on modification of the existing AS-11B-X to update it to an ACE. It would have the same features as Version 4.

5.2.6 Version 6 - Duplicate AS-11B-X System

Description: Same as existing AS-11B-X without change starting with GFE AS-11B-1 viewer, coordinatograph, and Bx-272 computer.

5.3 ACE POST PROCESSING

In addition to the alternative ACE design versions described above, a limited study was made of ACE post processing requirements. Details of this study are given in Appendix E.

SECTION 6

VERSION 4 ACE IMPLEMENTATION

After consideration of the various ACE design configurations described in the previous section, Government personnel indicated a preference for Version 4 - ACE System Using GFE AS-11B-1 Viewer and Computer. They therefore requested that Bendix further investigate the implementation of this version.

As a result of this investigation, a revised set of Version 4 features was agreed on with the Government and tentative hardware and program implementations for Version 4 were prepared.

6.1 VERSION 4 FEATURES

The revised set of features for Version 4 is the same as described in Section 5.2.4 with the following changes:

(a) Model-to-ground conversion and corrections for earth curvature and atmospheric refraction are all done in the system processor* instead of in the ACE.

(b) Orientation, check point, and boundary data are received and measured in model coordinates.

(c) Outputs are in model coordinates.

6.2 VERSION 4 HARDWARE CONFIGURATION

6.2.1 Functional Requirements

The hardware requirements for Version 4 ACE are basically identical to the AS-11B-X prototype. Major differences are the following:

(a) Addition of front panel calibration controls.

(b) Addition of a high speed communication link to the post-processing system.

Also, to improve the maintainability of the system, the video and monitor display circuitry would be packaged on printed circuit cards. These changes, described in more detail below, would be developed during the fabrication of an ACE system and could be retrofitted onto the AS-11B-X.

---

* The system processor will be part of the ACE Post Processor.

6.2.2 Recommended Implementation

The ACE viewer/scanner will consist of an AS-11B-1 viewer where the flying-spot scanner has been replaced with an epipolar scanner using a laser light source. This design is found on the AS-11B-X. One addition to the AS-11B-X design is front panel calibration controls described here.

The digital correlator would be functionally identical to the correlator on the AS-11B-X. It is expected that the maintainability of the correlator will be improved by repackaging the scanner video a/d converters and the monitor display amplifiers on plug-in printed circuit cards

The control computer would be the same as for the AS-11B-X except that a programmed I/O channel to the system processor would be provided. Ampex 7-channel or 9-channel magnetic tape units would be provided for data evaluation and system backup.

6.2.2.1 Front Panel Calibration Controls

Over a period of hours, the AS-11B-X zero reference points of the scanner and viewer optics may drift apart. In preparation for digitizing a model the operator must adjust the viewing optics so that these points coincide. On the AS-11B-X this procedure requires access to points on the scanner drive and the pechan mirrors inside the viewer. The purpose of the modification described here is to make these adjustment points accessable from the operator's normal working position and minimize human entry into the viewer.

The calibration would be performed on the ACE by moving in the x and y directions the pechan mirrors which relay the scanning spot to the photographs. Four knobs accessable from the operator's position would be attached to the x and y adjustment points for two channels by flexible cable.

A method is needed to drive the scanner to its zero scan angle position. At the present time the most practical method appears to be a bimodal scanner motor control. The normal mode would provide constant scanner velocity as presently found on the AS-11B-X. The calibration mode would provide position control to drive the scanner to its zero position. Position feedback would be generated in the scanner encoder. The scanner zero position would be found during system installation and be expressed as a number of encoder incremental pulses after the encoder reference pulse. This quantity would be manually entered into the motor control hardware and would not change until major maintenance is performed on the scanner assembly. The calibration mode would be selectable with a toggle switch. A scanner-ready indicator would verify to the operator that the scanner optics is in its zero position.

6.2.2.2 Communication Link

In the process of digitizing a model, several types of data must be quickly and efficiently traded between the ACE system and the post-processing system. This data consists of setup, ground control data, and model coordinate output data. A high speed data communication link is the proposed method of implementing this information flow. The link would connect the Bx-272 control computer in the ACE to the MODCOMP II system processor.

The link will allow bidirectional flow of interrupts, control, and data at rates up to 100 Hz. Simple data transfers will be implemented without providing general purpose network capabilities found in the MODCOMP MAXNET operating system. While the ACE peripherals would not be accessable to the post-processor, selected post-processor peripherals will be accessable to the ACE over the link.

Data transfer operations on the link will consist of three basic steps. In the first step the initiating system sends an inquiry interrupt to the other system to claim use of the link. Second, the initiating system transfers a block of header information identifying the source destination and amount of data to be transferred. Finally, the data transfer takes place. The direction of data flow is program-controlled. The exact sequence of events of link communications is defined by the assembly level programs that will be generated at both ends of the link. The MODCOMP program becomes part of the MAXNET III operating system.

Figure 6-1 is a hardware block diagram of the complete link. On the post-processor end of the link is a standard MODCOMP interface called the General Purpose Data Terminal. This interface communicates with the post processor by direct memory access over the MODCOMP I/O bus. On the other side of the interface signals go via the link cable to the ACE link interface. This interface communicates with ACE control computer by programmed I/O. Each interface consists of a CPU interface which communicates with the computer I/O bus and Data Transfer Control logic which sends and receives device interrupts and word transfer timing signals. A third block implements flow of data, command, and status information between the CPU I/O bus and the link.

Inquiries and other status transfers are performed by placing a command code in the data, command, and status logic, and concurrently sending an interrupt to the system at the other end of the link. The command code which indicates the purpose of the interrupt is the status input at the receiving interface. Header data and real data travels over a 16-bit bus in the link. Word transfer handshaking signals perform interlocked timing for each data word traveling across the link.

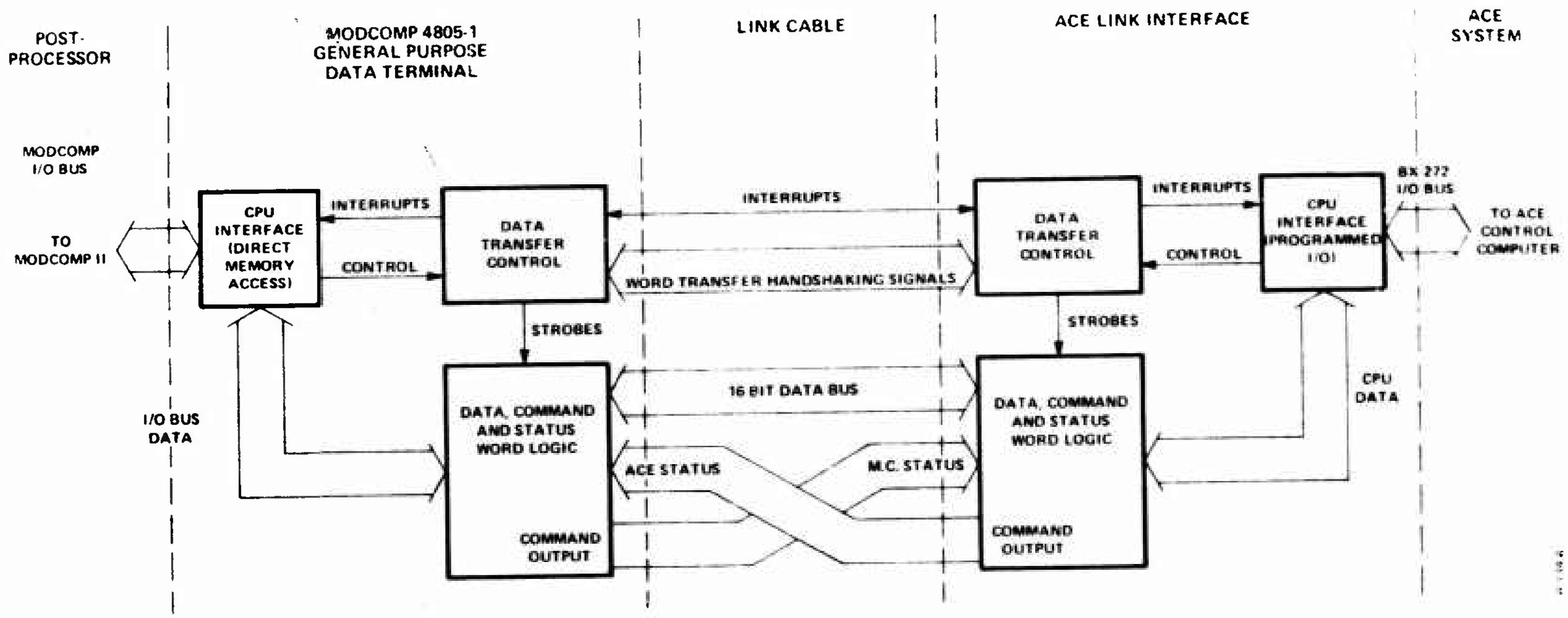

Figure 6-1 - ACE to MODCOMP Link Hardware Block Diagram

6.3 VERSION 4 PROGRAM CONFIGURATION

6.3.1 Functional Requirements

The Version 4 ACE program requirements are the same as for the AS-11B-X with the following exceptions:

(a) Set-Up mode

- Capability to input set-up and control data from MODCOMP over communication link
- Capability to read ground control and check points and send to MODCOMP over communication link
- No exterior or relative orientation
- No manual contouring or profiling capability

(b) Epipolar mode

- Figure-of-merit recording
- Variable sample spacing capability
- Output of model coordinates to MODCOMP over communication link

(c) Evaluation mode

- Capability to read epipolar data from magnetic tape or the communicator link
- Capability to evaluate epipolar data against manual measurements

6.3.2 Recommended Implementation

The implementation of the programs required for the Version 4 ACE is described in following subsections.

6.3.2.1 Program to Input Set-Up Data Over Link (Set-Up Mode)

This program would be nearly identical to the decimal input program except that it inputs set-up data through the I/O link control program instead of paper tape.

It processes input data from the I/O link on a character-by-character basis (2 characters per 16-bit word). Data from the link is read and stored in memory in blocks of 100-200 words by the link control program. A short routine is required to transfer data to the decimal shutdown input program. The decimal shutdown input program probably also needs 100-200 words of revision. No major changes in the decimal shutdown format are assumed.

6.3.2.2 Program to Output Ground Control Data Over Link (Set-Up Mode)

The functions of this program are:

(a) Reading ground control data and storing it in a buffer

(b) Outputting the data over the I/O link to the MODCOMP

The approach to (a) is to modify the AS-11B-1 exterior orientation routine to work with the I/O link routine. The point measurement control program would be extracted and modified to handle more points and the rest of the exterior orientation would be deleted. The (b) part would be similar to the decimal input transfer program described in Section 6.3.2.1.

6.3.2.3 I/O Link Control Subroutine

This program provides the basic control for transferring blocks of data between the control computer and the MODCOMP over the communication link. Both directions of transfer could be handled.

The functions of this program include:

(a) 3rd level interrupt handling

(b) I/O initiate

(c) Read and write subroutines

(d) Buffer storage

The approach to this program is similar to the approach used for control computer-to-minicomputer in the AS-11B-X. Other programs with data to transfer over the link would call this subroutine and specify the data to be transferred and the destination or source. The subroutine then takes over the actual transfer. The actual reading and writing of data is haldled by programmed I/O subroutines.

6.3.2.4 Program for Variable Point Spacing (Epipolar Mode)

The functions of this program are to:

(a) Provide capability to vary profile spacing along scan line (PRFLSP)

(b) Provide scan line spacing

Changes are required to the programs initializing the geometric address modification program and the plotting velocity program in the control computer. Certain parameters such as profile spacing and plotting velocity must be set to correspond to the selected profile and scan line spacing. The address modification scaling must also be revised accordingly. No significant change other than the addition of the initialization programs is required. Several program changes would probably also be required in the minicomputers to permit operation at the revised spacing.

6.3.2.5 Programs for Recording Figure-of-Merit (Epipolar Mode)

In order to record a Figure-of-Merit with each model point, program additions are required in both the correlation computer and the control computer. The correlation computer programs must send 58 values of correlation and signal power (C's and Sp's) to the control computer every 120 ms. The approach is to sum C's and Sp's over 6 scan lines and load buffers with data to be transferred using subroutines similar to those used for the monitor scope display. A DMA transfer to the control computer is initiated every 6 scan lines.

The control computer requires that a program receive C's and Sp's over link and output them on magnetic tape with model coordinate data.

It is therefore necessary to:

(a) Modify minicomputer input program to receive C's and Sp's along with parallaxes

(b) Modify coordinate output program to store C's and Sp's on magnetic tape output buffer along with X_p, Y_p, and E_p in a fourth word (8 bytes for C, 8 bytes for Sp).

6.3.2.6 Program to Evaluate Epipolar Data

The Version 4 ACE will normally transfer output data over the communicator link to the MODCOMP system processor in real-time rather than recording it on magnetic tape. It will therefore be necessary to modify the epipolar evaluation program to obtain data from the communicator link instead of from magnetic tape. Modifications are required to call the link control subroutine instead of the magnetic tape update routine to read data back from the system processor when evaluation is required. The AS-11B-X evaluation program would still be used for evaluation of data optionally recorded on magnetic tape.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

The ACE design study has resulted in the preparation of two primary alternative ACE design configurations: the Strawman design, which is based on dual PDP-11/45 computers and a Bendix-built viewer; and the Version 4 design, which is based on a GFE AS-11B-1 viewer and computer. Either design will probably meet the near-term digital data collection needs of the DMA Centers; however, there are certain advantages and disadvantages to each approach, considering criteria such as capabilities, flexibility, maintainability, development time, cost, and risk.

Concerning development time, cost, and risk, the Version 4 ACE definitely has an advantage. Very little new development is required since the Version 4 ACE is essentially an AS-11B-X with minor hardware and program revisions. The development time and cost will be significantly less and the technical risk practically nill.

As for maintainability, the Version 4 ACE will not be optimized for maintenance purposes; however, its similarity to the AS-11B-X will obviate developing a maintenance capability for a completely new system. Extensive new training and additional spare parts will not be required.

As stated above, the Version 4 approach will probably meet the DMA's near-term needs. It is cheaper, faster, has less development risk, and offers certain maintenance advantages. Therefore, if near-term needs are the primary considerations, the Version 4 ACE is the most appropriate choice.

If, however, long term needs are of primary consideration, a system with more capability and flexibility may be desired. The ACE Strawman design provides a number of capabilities not available on the Version 4 ACE. These include:

- Fortran Programming
- Modular Programs
- Modern operating system
- Single type of computer
- 9-track, 1600 BPI magnetic tape
- Electrostatic plotter
- Alphanumeric display terminal
- Computer prompting of manual operations
- Larger format viewer stages

The Strawman design also provides considerably more flexibility. This includes the ability to conveniently modify old programs or add new programs and the ability to add new standard peripherals without large development cost.

If DMA's needs change after a few years or if the production cycle is modified, the ACE Strawman will be more easily adapted to the new requirements. The ACE Strawman is therefore the most practical choice on a long-term basis.

APPENDIX A

VERSION 4 - ADVANCED COMPILATION EQUIPMENT SPECIFICATION

PROJECT NO.		CODE IDENT.	SPECIFICATION NO.	REV.
4561	BENDIX RESEARCH LABORATORIES SOUTHFIELD, MICHIGAN	11272	DS 880	X1

ENGINEERING SPECIFICATION

TITLE

VERSION 4 - ADVANCED COMPILATION EQUIPMENT SPECIFICATION

CUSTOMER	CONTRACT NO.	DATE RELEASED
Rome Air Drvelopment Center Griffiss A r Force Base, New York 13441	F30602-74-C-0260	23 February 1976

REVISION STATUS OF SHEETS

IT IS THE RESPONSIBILITY OF THE RECIPIENT TO DESTROY ALL PREVIOUS ISSUES OF THIS SPECIFICATION IN HIS POSSESSION

SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
REV.	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1

SHEET	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
REV.	X1	X1																							

SHEET	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
REV.																									

NOTES

PREPARED BY	DATE	CHECKED BY	DATE
[illegible signature]	1-5-76	[illegible signature]	1-6-76

APPROVALS – PER PROJECT AUTHORIZED SIGNATURE LIST

DESIGN LEADER		R AND QA	
MECH/ELEC ENGR		PROGRAM MGR	
PROJECT ENGR		PROGRAM DIRECTOR	
CONFIGURATION MGR.		CHIEF DRAFTSMAN	

REVISIONS

THE REVISION LETTER OF THIS TITLE SHEET SHALL BE UPDATED EACH TIME A CONTINUATION SHEET IS REVISED. SEE ENGINEERING CHANGE NOTICE (ECN) IDENTIFIED BY THIS SPECIFICATION NUMBER FOR DESCRIPTION OF EACH REVISION.

BRL-910-31 2171994 ORIGINAL FILED IN PRODUCT DESIGN SECTION

PROJECT NO.	BENDIX RESEARCH LABORATORIES	CODE IDENT.	SPECIFICATION NO.	REV.
4561	SOUTHFIELD, MICHIGAN	11272	DS 880	XI

ENGINEERING SPECIFICATION

VERSION 4 - ACE SPECIFICATION

1 SCOPE

1.1 This specification establishes the performance, design, development and test requirements for the Advanced Compilation Equipment (ACE) system.

2 APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement

SPECIFICATIONS: Bendix Specification DS 881, Version 4, ACE Viewer Specification, Issue XI
Bendix Specification DS 856, AS-11B-1 Viewer and Coordinatograph

DRAWINGS: None

OTHER PUBLICATIONS: None

3 REQUIREMENTS

3.1 System Definition

3.1.1 General Description

The ACE system shall rapidly and automatically measure point elevations in stereo aerial photography. This shall be done by automatic measurement of corresponding image areas along corresponding epipolar lines on the photographs. The points measured shall be recorded digitally in ground or model coordinates. In order to perform its functions, the system shall use pre-determined photograph and stereomodel data which is entered digitally.

REVISIONS
WHEN THIS CONTINUATION SHEET IS REVISED, THE REVISION LETTER SHALL ALSO BE RECORDED ON THE TITLE SHEET. SEE ENGINEERING CHANGE NOTICE (ECN) IDENTIFIED BY THIS SPECIFICATION NUMBER, FOR DESCRIPTION OF EACH REVISION.

PROJECT NO.	BENDIX RESEARCH LABORATORIES	CODE IDENT.	SPECIFICATION NO.	REV.
4561	SOUTHFIELD, MICHIGAN	11272	DS 880	X1

ENGINEERING SPECIFICATION

3.1.1.1 Manual Measurements

Although the ACE system will make most measurements automatically, the system operator shall be permitted to manually make the following measurements on the photographs:

(a) Interior orientation reference points

(b) Elevations of stereomodel check points

(c) Elevations or parallaxes of initial points in corner of areas to be measured automatically

(d) Elevations or parallaxes of restart points when automatic measurement is completely lost

(e) Elevations of automatic-measurement-accuracy evaluation points

The computer shall provide some assistance for most manual measurements, including

(a) Automatic drive to nominal locations

(b) Automatic typing and/or recording of measured locations and deviations from nominal locations

3.1.1.2 Operation Sequence

The ACE system operating sequence shall be basically as follows:

(a) Read computer programs from paper tape or magnetic tape.

(b) Read orientation and correction data in digital form (from magnetic tape or computer link).

(c) Manual measurement of two to four interior orientation reference points. These points are measured in photo coordinates.

(d) Manual elevation measurement of some stereomodel check points. These points are measured in model coordinates.

(e) Manual elevation or parallax measurement of initial point. This point is in the corner of the stereomodel area to be automatically measured.

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(f) Automatic measurement of epipolar points

(g) When automatic measurement operations become lost, manual elevation or parallax measurement of a few points for restart of automatic measurement.

(h) Manual elevation measurement of some points to evaluate automatic measurement accuracy.

3.1.2 Missions

The mission of the ACE system is collection of digital point elevations in large volume from stereo aerial photography, for a wide variety of ultimate uses, including:

(a) Digital terrain data bases

(b) TERCOM

(c) Computation of contours for line maps

3.1.3 Threat

Not Applicable.

3.1.4 System Diagrams

The ACE system shall consist of four major functional parts: the viewer, scanner, correlator, and control system as shown in Figure 1. This diagram shows in simplified form the four main parts of the ACE system and its main inputs and outputs. As indicated, the system inputs shall include two photographs, stereomodel data, and operator inputs. The operator inputs shall include the optical controls, monitor display controls, and system controls. The system outputs shall include epipolar points and operator outputs. The operator outputs shall include eyepiece views, monitor displays, and system control displays. Although separate functional parts of the system, the viewer and scanner will be one mechanical assembly and may use some common components. Similarly, the correlator and control system may be one mechanical assembly and may share some common components, such as computers.

The major inputs and outputs of each major part are also shown in Figure 1. The heavy arrows in the diagram indicate items with the highest data rate.

3.1.5 Interface Definition

3.1.5.1 Photographs

3.1.5.1.1 General

The ACE system shall accept vertical frame or convergent panoramic photography. Photographs shall be accepted with the air base in any stage direction; however, the panoramic photo air base will be approximately parallel to the axis of the panoramic cylinder.

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3.1.5.1.2 Photograph Format

The ACE system shall accept photograph segments with sizes up to 9 x 18 inches. Photographs will be on film with a base between 2 and 7 mils thick or on glass plates up to 0.250 inches in thickness.

3.1.5.1.3 Parameter Ranges

The ACE system shall accept photographs within the following parameter ranges:

(a)	Effective focal length:	75 to 6000 mm (300 to 6000 mm for normal speed)
(b)	Convergence angle phi:	$\pm 45^{\circ}$
(c)	Kappa and omega angles:	$\pm 20^{\circ}$
(d)	Panoramic sweep angle theta:	$\pm 60^{\circ}$
(e)	Base to height ratio:	0.25 to 1.5
(f)	Model to photo scale ratio:	0.5 to 2.0
(g)	Photo to photo scale:	0.8 to 1.2

3.1.5.1.4 Photogrammetric Corrections

The ACE system shall computationally perform the following photogrammetric corrections:

(a) Reseau correction

(b) Vehicle motion correction

(c) Lens distortion for frame photography

(d) Photograph rotation, offset, and shrinkage (for interior orientation)

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3.1.5.2 Operator Controls and Displays

3.1.5.2.1 General

The ACE system shall include the following operator controls and displays:

(a) Two handwheels and one footwheel
(b) Viewer control panel
(c) Typewriter keyboard
(d) Printer or typewriter output
(e) Viewing optics controls. See following section.
(f) Monitor displays. See following section.
(g) Scanner alignment controls.

3.1.5.2.2 Viewing Optics Controls

The ACE system shall provide the following operator controls of the viewing optics:

(a) Eyepiece focus, separate for each eyepiece
(b) Viewing brightness, separate for each stage
(c) Viewing illumination on-off, separate for each stage
(d) Inter pupillary distance
(e) Stereo parallax adjustment, vertical and horizontal
(f) Rotation, separate for each stage
(g) Magnification, separate for each stage

3.1.5.2.3 Monitor Displays

The ACE system shall include the following displays for monitoring system operation:

(a) CRT display (monitor oscilloscope), capable of displaying measured parallax profiles, cross correlation quality, covariance curves, or photo transmission.

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3.1.5.3 Input Data

The ACE system shall be capable of reading the following input data in digital form from magnetic tape or from a central computer via a communication line:

(a) Orientation data for both interior and relative or exterior orientation

(b) Photogrammetric correction data

(c) Evaluation point data, up to 100 points

The choice between magnetic tape and communication line shall be an operator option at the time of data entry for each stereomodel.

3.1.5.3.1 Communication Line

The input communication line shall be a standard type providing for data transfer at a rate of at least 2400 baud. The input communication line should be the same bidirectional line as the output communication line if this is not more costly. Input and output of data will not be interleaved.

3.1.5.3.2 Format

All input data shall be recorded or transmitted using alphanumeric ASCII Characters. Each quantity value shall be preceded by an alphanumeric quantity label or identifier of 3 to 6 characters.

3.1.5.4 Output Data

The ACE system shall be capable of outputting the following data:

(a) Epipolar point data in digital form, on magnetic tape or transmitted to a central computer via communication line. The choice between magnetic tape or communication line shall be an operator option at the time of data recording for each stereomodel.

(b) Steromodel evaluation data in typed form.

(c) Automatic operation evaluation data in typed form, including evaluation point measurements, evaluation point errors, overall measurement errors, area plotted, time taken, and average speed.

3.1.5.4.1 Magnetic Tape Format

The magnetic tape recording shall be in an industry standard, 9-track tape format with 800/1600 BPI, NRZ encoding.

3.1.5.4.2 Communication Line

The output communication line should be a standard type and shall provide for data transfer at a rate of at least 50,000 baud to a central processor.

3.1.5.4.3 Epipolar Data Format

For each output data point three model coordinate values shall be recorded or transmitted. The values recorded should be differential values from a reference point, whose whole coordinate values are recorded with each group of points. In addition, a measurement figure of merit shall be recorded with each point. This figure of merit may be the measured correlation and/or signal power. Differential coordinate values and the figure of merit shall be recorded or transmitted in fixed point, single precision, binary form.

3.1.6 Government Furnished Property List

The Government shall furnish a complete AS-11B-1 system including control computer, viewer, coordinatograph, teletype, and all interconnecting cables. A magnetic tape unit may or may not be included.

3.1.7 Operational and Organizational Concepts

The ACE system shall use the epipolar scan stereomapper principal and most principals incorporated in the AS-11B-X stereomapper system.

3.2 Characteristics

3.2.1 Performance Characteristics

3.2.1.1 Speed

The ACE system shall operate with an average overall speed of at least 50 points a second, when the points are spaced 0.3 by 0.32 mm apart. This overall speed shall include all required system time, from the time photographs are placed upon the stages until they are removed from the stages. This overall speed shall be obtained when an average area of 20,000 square millimeters is measured on each stereomodel. The average system speed during full automatic operation shall be at least 100 points per second or 10 square millimeters per second. It shall be a design objective that the average automatic speed be at least 25 square millimeters per second or 250 points per second. These speeds may be reduced when the focal length is less than 300 mm.

3.2.1.2 Accuracy

The ACE system shall have an automatic correlation parallax error of $\sigma(\Delta P_M)$ = 0.015 mm or less with respect to static manual measurements. (This is equivalent to the accuracy obtained by the AS-11B-1 in automatic profiling). The error shall be determined by manually measuring elevations at randomly selected points on the ACE system with the same stereomodel setup: the elevation error measure shall be the standard deviation of the elevation errors found, after exclusion of all points with elevation errors greater than 0.100 mm in photograph scale. This elevation error shall be converted to parallax error by multiplication of the elevation error by the base-to-height ratio of the stereo model, and conversion of the error into average photograph scale.

The correlation error and speed shall be measured and averaged over the following AS-11B-1 test stereomodels:

(a) Ft. Sill (frame)

(b) Arizona (panoramic)

(c) California (frame)

(d) Classified (SECRET) frame model

In addition to the automatic correlation error, the ACE system shall have a static position error of 0.005 mm rms or less on each stage axis.

3.2.2 Physical Characteristics

The ACE system shall occupy no more than 600 square feet of floor space.

3.2.3 Reliability

The ACE system should have a reliability characterized by a mean time between failures of 150 hours or more. This shall be demonstrated by recording of all failures and remedial actions beginning with preliminary acceptance testing at the contractor's plant and continuing through completion of installation and acceptance at DMAAC.

3.2.4 Maintainability

The ACE system shall be designed for ease of maintenance. The mean time to repair should be 4 hours or less. The time required for scheduled maintenance (for calibration, checking and preventive maintenance) should be no more than 2 shifts out of 40 working shifts plus two hours out of 10 working shifts. Maintenance procedures, facilities, and/or computer programs should be provided for the following:

(a) Checking correct system operation upon every stereomodel by evaluation of measurement accuracy at check points

(b) Periodically checking correct system operation by operating with a standard stereo model.

(c) Diagnosis of improperly operating system components

(d) Performing and checking system calibration

3.2.5 Availability

Not applicable

3.2.6 System Effectiveness

Not applicable

3.2.7 Environmental Conditions

3.2.7.1 Temperature

The ACE system shall operate over a temperature range of 21° to 24°C. The room temperature shall be within this range both during and 4 hours prior to system operation, and change at a rate less than 1°C per hour. The ACE system shall tolerate a non-operating temperature range from 18 to 28°C.

3.2.7.2 Relative Humidity

The ACE system shall operate with a relative humidity between 40 and 60 percent. The relative humidity shall be in this range during the 4 hours prior to system operation. The ACE system shall tolerate a non-operating relative humidity between 10 and 80 percent.

3.2.7.3 Vibration

There shall be no degradation of performance when the ACE system, during operation, is subjected to floor vibrations in the X,Y, and or Z directions that result in accelerations less than or equal to 0.01 g's peak in the frequency range of 2 to 200 Hz.

3.2.8 Nuclear Control Requirements

Not applicable.

3.2.9 Transportability

The ACE system shall be capable of being transported by air ride moving van between the place of construction and place of operation, when suitably disassembled and packed for shipment.

3.3 Design and Construction

3.3.1 Materials, Processes, and Parts

3.3.1.1 Correlator Computer

The ACE correlator shall use Microdata 1600 computers.

3.3.1.2 Control System Computer

The ACE control system shall use a Bx-272 computer.

3.3.1.3 Viewer

The ACE viewer shall be a modified AS-11B-1 viewer (see DS 881, Version 4 ACE Viewer Specification).

3.3.1.4 Scanner

The ACE scanner shall be an AS-11B-X type scanner (see DS 881 Version 4 ACE Viewer Specification).

3.3.1.5 Correlator

The ACE correlator shall be essentially the same as that used in the AS-11B-X.

3.3.1.6 Coordinatograph

The ACE coordinatograph shall be an AS-11B-1 coordinatograph (see DS 856, ACE Viewer and Coordinatograph).

3.3.2 Electromagnetic Radiation

The ACE system shall be designed for RFI suppression such that no component, circuit, or module shall malfunction or be adversely affected by interfering electromagnetic energy originating within the system. The term "No Malfunction" means that the performance of the equipment is not degraded beyond specified limits.

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3.3.3 Minimum Cost

The ACE system should be designed and constructed in such a manner as to minimize development time and cost. In addition, cost should be minimized for system production, operation, and maintenance. In order to do this, the system should be designed so that it has minimum system complexity and it uses existing designs and computer programs whenever this is practical. In particular, the system should use standard commercial components such as computers where this is practical.

3.3.4 Materials Processes, and Parts

Construction of all components shall be in accordance with good commercial practice.

3.3.5 Safety

The contractor shall comply with safety provisions per attached governing documentation.

The system shall be designed so as to minimize the danger from electrical, radiation, or mechanical hazards. Warning signs shall be employed where necessary to warn personnel of potential hazards. The system shall conform to the safety requirements of a Class 5 laser system as specified in ANSI Z136-1-1973.

3.3.6 Human Engineering

The system should be designed to minimize the difficulty of system operation. The system should require a minimum number of manual operations by providing good computer aids to necessary manual functions.

The operator shall be able to comfortably operate all controls and view all displays, including:

(a) The operator shall be able to comfortably operate handwheels and footwheel, illumination controls, focus and parallax adjustment controls, magnification and rotation controls, and control panel while looking through the viewer eyepieces.

(b) The operator should be able to observe the typewriter keyboard and printout with minimal change in head position from the normal viewing position.

(c) The eyepieces should be at a convenient height and angle for the operator. An adjustable head rest should be provided for the operator.

(d) Sufficient leg room shall be provided under the viewer for the operator in normal operating position.

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3.4 Documentation

The ACE system shall be provided with manuals and drawings suitable for operation and equipment maintenance of the system by skilled personnel. The contractor shall provide two sets of documentation per instrument in his own format, of good commercial quality. The manuals shall cover general theory of operation, operating procedures, calibration procedures, and maintenance procedures.

3.5 Logistics

Per paragraph 4.1.8 of S.O.W. for ACE.

3.6 Personnel and Training

3.6.1 Personnel

The ACE system shall be operable by one DMA operator skilled in the operation of an analytical stereoplotter. The ACE system shall be maintainable by maintenance personnel skilled in computers, digital electronics, and precise photogrammetric mechanical-optical equipment.

3.6.2 Training

The ACE system shall be operable by a skilled stereoplotter operator after about two weeks of specific formal training using the system. The entire system shall be maintainable by skilled maintenance personnel after about six weeks of specific formal training using the system.

3.7 Functional Area Characteristics

3.7.1 Viewer Characteristics

The following subsections summarize major viewer characteristics.

3.7.1.1 Functions

The viewer for the ACE system shall provide facilities for holding the two photographs of a stereo pair, independently manual viewing of the photographs in stereo, and permitting the scanner to scan the two photographs. The functional elements of the viewer are as shown in Figure 2. Major information flowing in and out of the various functional elements is as shown in the diagram.

For the purpose of this specification, the viewer includes the eyepiece views and operator controls of the viewing optics. All other operator controls and displays are considered a part of the correlator or control system. The viewer shall provide support and mounting space for the scanner and for many of the other controls and displays although they are not part of the viewer.

3.7.1.2 Interfaces

3.7.1.2.1 Operator

The viewer interfaces with the ACE system operator shall include:

(a) Placement of photographs upon the viewer stages, and their removal

(b) Controls for the viewing optics

(c) Eyepiece views of the photographs and stereomodel

3.7.1.2.2 Other Interfaces

The viewer interfaces to other parts of the ACE system shall include:

(a) Stage position control from the control system

(b) Stage position feedback to the control system, including limit switches for end of stage travel

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(c) Optical viewing rotation control from the control system

(d) Effective aperture through each stage platen, through which the scanner scans each photograph

(e) Mounting spaces and supports for the scanner and for various controls and displays associated with the correlator and control system.

3.7.1.3 Stages

The viewer shall contain two stages, each having a mechanical motion with respect to the optics of at least 9.35 by 18.4 inches. The total static position error of each axis after calibration shall be 0.005 mm rms or less. The maximum positioning speed obtainable with normal operating accuracy shall be at least 3 mm per second. The maximum slewing speed obtained (without accurate position) shall be at least 10 mm per second.

3.7.1.4 Viewing Optics

The ACE viewer shall include provisions for viewing the photographs optically as a stereo model with the following features:

(a) Rotation range: $\pm$ 190°

(b) Rotation accuracy: 0.5° rms

(c) Rotation under computer and manual control

(d) Zoom magnification under computer and manual control: 8X to 30X

(e) Photograph field of view: 8.5 mm at 14X magnification

(f) Resolution: 100 line pairs per millimeter for 1000 to 1 contrast target at maximum magnification

(g) Interpupillary distance adjustment: 50 to 75 mm

(h) Eye relief: 20 mm

(i) Stereo parallax adjustment range: $\pm$ 0.04 radians vertical and horizontal

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(j) Eyepiece focus: ± 4 diopters each eyepiece

(k) Reference mark: 0.020 mm black dot

3.7.1.5 Stage Optics

The ACE viewer shall include stage optics which permit simultaneous scanning and optical viewing of each photograph.

3.7.1.6 Reference Photo Viewer (Optional)

As an option available at the time of instrument purchase, the ACE system shall include a reference photo viewer. This reference viewer shall show the general location of the current operating point upon a copy of the photograph which is on the left stage. The entire photograph shall be visible to the operator from his position in front of the viewer, with the general area currently under the viewing optics being so indicated.

3.7.2 Scanner Characteristics

The following subsections summarize major scanner characteristics.

3.7.2.1 Functions

The scanner for the ACE system shall provide for scanning the two photographs of a stereo pair mounted upon the viewer stages. The photos shall be simultaneously scanned along straight lines, with the photo transmissions being detected and electronically sent to the correlator. The functional elements of the scanner are as shown in Figure 3. Major information flowing out of the scanner are the photo transmission of each photo and the scanner sweep position, both going to the correlator. Information coming into the scanner includes the scanner controls from the control system, providing control of scan line rotation and drive of the line sweep generator.

3.7.2.2 Interfaces

The ACE scanner interfaces with the other parts of the ACE system shall include:

(a) Effective aperture through each stage platen, through which the scanner scans each photograph, provided by the viewer

(b) Photo transmission of each photo to the correlator

(c) Scanner sweep position to the correlator

(d) Scan line rotation from the control system

(e) Scanner sweep drive from the control system (or correlator)

(f) Scanner alignment controls from the system operator, for scan centering, etc.

3.7.2.3 Performance

The ACE scanner shall have the following performance characteristics:

(a) Useable line length: 1 inch (25 mm)

(b) Sweep frequency: 50 lines per second desired objective, fixed

(c) Spot size range, manually controlled: 0.010 to 0.040 mm diameter

3.7.2.4 Accuracy

The accuracy of the ACE scanner, after calibration and computer correction, shall be sufficient to produce the following maximum errors:

(a) Position along line: 0.005 mm rms relative to the position indicated to the correlator

(b) Straightness of line: 0.008 mm rms

3.7.2.5 Scan Line Rotation

The ACE scanner shall include two rotators for independently rotating the scan line on each photograph. These rotators shall have the following characteristics:

(a) Independently computer controlled

(b) Rotation range: $\pm$ 190°

(c) Rotation accuracy: $\pm$ 1.5 minutes

3.7.3 Correlator Characteristics

3.7.3.1 Functions

The correlator for the ACE system shall correlate image transmission data, produce the elevations of epipolar points, and provide automatic operation monitor displays. The functions of the correlator shall be as diagrammed in Figure 4. Photo transmission data is accepted from the scanner and processed to produce epipolar point data which is recorded for output. Correlation control data is received from the control system and correlation status data is returned to the control system. In addition, monitor displays are generated for the benefit of the system operator, with operator controls of these displays. Although separate functional parts of the system, the correlator and control system may be one mechanical assembly and may share some components, such as computers.

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3.7.3.2 Interfaces

The correlator shall contain monitor displays to the system operator as specified in Section 3.1.5.2.3. In addition, the correlator shall include suitable means for operator control of the information being displayed. The correlator shall digitally record ACE output epipolar point data upon magnetic tape or transmit it to a central computer by communication line.

The correlator shall include interfaces to the scanner for:

(a) Photo transmission of each photo

(b) Scanner sweep position

The correlator shall provide necessary status data to the control system to indicate current status of the correlator. The correlator shall accept the following correlation control information from the control system:

(a) Correlation control parameters

(b) Photograph geometry along each scan line

(c) Epipolar geometry information needed for converting measured parallaxes to ground or model coordinates of output points.

3.7.3.3 Performance Characteristics

The ACE correlator shall have performance characteristics sufficient to provide the specified overall system performance. To do this, the correlator should provide at least the following performance capabilities:

(a) Maximum area correlation rate: 40 square mm per second with nominal point and density sample spacing

(b) Nominal spacing of measured points (at normal speed): 0.320 mm along epipolar lines and 0.300 mm between epipolar lines.

(c) Nominal density sample spacing correlated (at normal speed): 0.020 mm along epipolar lines and 0.050 mm between epipolar lines, at photograph scale

(d) Minimum density sample spacing correlated (at reduced speeds): 0.010 mm along epipolar lines and 0.025 mm between epipolar lines,at nominal photograph scale.

(e) Maximum density sample spacing correlated (at reduced accuracy): 0.040 mm along epipolar lines and 0.100 mm between epipolar lines, at nominal photograph scale

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3.7.3.4 Adaption to Image Detail

The ACE correlator shall automatically adapt its operation to the quality of image detail on the photographs by expansion of the image area which is correlated when poor image detail is present. A limited degree of expansion shall be provided.

3.7.3.5 Address Modification

The ACE correlator shall shape image sample data between scanning of epipolar lines and correlation of the image samples. This shall be done by modifying the effective address (and hence position along the scan line) of image samples in order to account for the following:

(a) Corrections for scanner calibration

(b) Photo-to-model coordinate transformation geometry

(c) Approximate terrain shape, as determined from recent automatic correlation measurements.

3.7.3.6 Automatic Y Parallax Adjustment

The ACE correlator shall automatically measure and compensate for small amounts of Y parallax.

3.7.4 Control System Characteristics

3.7.4.1 Functions

The control system portion of the ACE system shall control the other parts of the system to perform all the functions specified herein. The system control functions shall be as shown in Figure 5. The viewer and scanner are controlled to view and scan corresponding epipolar lines. This is done using feedback from the correlation process and information input by the operator. Information is also sent to the correlator to control its operation and proper processing of the data scanned. Although separate functional parts of the system, the correlator and control system may be one mechanical assembly and may share some components, such as computers.

3.7.4.2 Interfaces

The ACE control system shall contain interfaces to the other portions of the ACE system as specified herein. The control system shall provide for the input of system data as specified in Section 3.1.5.3. The control system shall provide for typing stereomodel evaluation data and automatic operation evaluation data as specified herein. The control system shall provide the following operator controls and displays for operator use in overall system control:

(a) Two handwheels and one footwheel

(b) Viewer control panel

(c) Typewriter keyboard

(d) Printer or typewriter output

3.7.4.3 Performance

The ACE control system shall have performance characteristics sufficient to provide the specified overall system performance. To do this, the control system should provide at least the following performance capabilities:

(a) Maximum scan line control rate: 50 lines per second

(b) Model-to-photo transformation update rate sufficient to maintain system accuracy at maximum automatic operation speed.

3.7.4.4 Variable Sample Spacing

The ACE control system shall provide operator variable spacing of measured points: 0.160 mm to 0.640 mm along the scan line and 0.150 mm to 0.600 mm between scan lines, in nominal photo scale. This shall be done by varying the spacing of density samples correlated over the ranges specified herein. The output point spacing shall be a fixed multiple of the density sample spacing correlated.

3.8 Precedence

The precedence of stated requirements ("shall be") and stated objectives ("should be") shall be in the following order:

(a) Meet all stated requirements

(b) Obtain good reliability and maintainability, approximately as specified

(c) Minimize development time

(d) Minimize development and production cost

(e) Minimize operation and maintenance cost

(f) Maximize speed and cost-effectiveness

4 QUALITY ASSURANCE PROVISIONS

4.1 General

The ACE system shall be tested to assure that the system performs all specified functions and provides specified speed and accuracy under nominal conditions. Preliminary acceptance tests shall be performed prior to delivery, and be witnessed by government representatives. Final acceptance tests will be performed by the government after delivery and installation.

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4.2 Quality Conformance Inspections

The system shall be given a thorough mechanical and visual inspection to determine that the quality of all material and workmanship is in accordance with good commercial practice.

System performance shall be tested using the following standard AS-11B-1 test models:

(a) Ft. Sill (frame)
(b) Arizona (panoramic)
(c) California (frame)
(d) Classified (SECRET) frame model

The average system speed and accuracy shall be determined using the averages obtained in testing these stereomodels under nominal conditions:

(a) Density sample spacing correlated: 0.020 mm along epipolar lines and 0.050 mm between epipolar lines; at nominal photo scale.

(b) Output point spacing: 0.300 mm by 0.320, at nominal photo scale.

(c) Average area measured automatically: 20 000 square millimeters per stereomodel.

(d) Manual point measurements made by an experienced operator of AS-11B-1 stereoplotters, capable of obtaining required ACE accuracy on an AS-11B-1 system.

System functional operation shall be verified with a sampling of different stereomodel characteristics. The contractor need not test the system:

(a) Under all possible combinations of allowed stereomodel characteristics

(b) to evaluate speed or accuracy except under the nominal conditions stated

5 PREPARATION FOR DELIVERY

The following provisions shall be made in preparation for shipping and delivery:

5.1 Delicate components and assemblies shall be removed and packed in boxes.

5.2 Padding shall be placed around corners and protrusions which are subject to damage during shipment.

5.3 A shipper listing all parts and components shall be prepared and delivered with the system.

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6 NOTES

6.1 This specification was prepared under Contract F30602-79-C-0260, ACE Design Study and Experiments, in accordance with Item A005, System Specification.

6.2 The capability for using adverse area data during automatic operation is not included in this specification.

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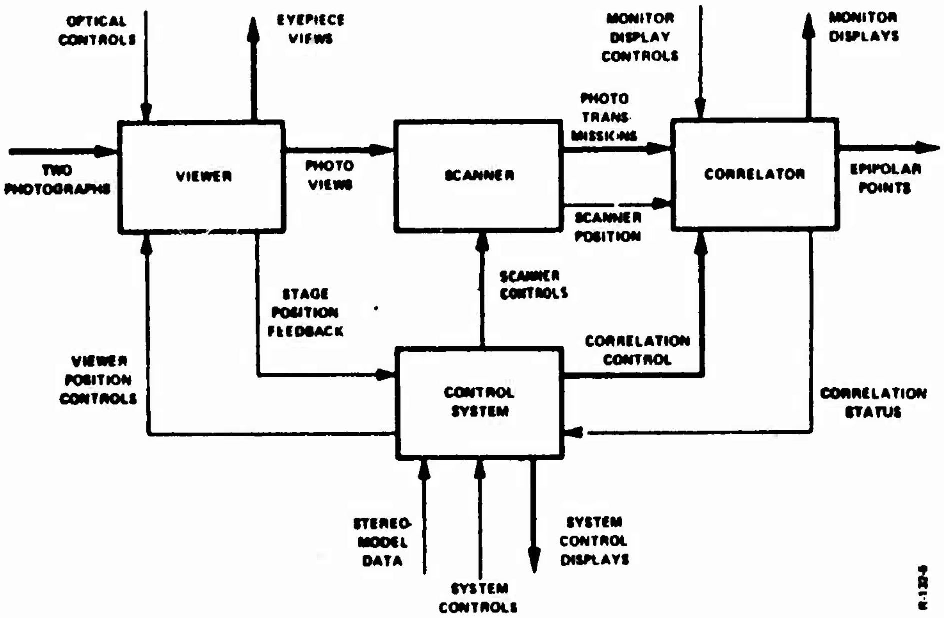

Figure 1 - ACE System Diagram

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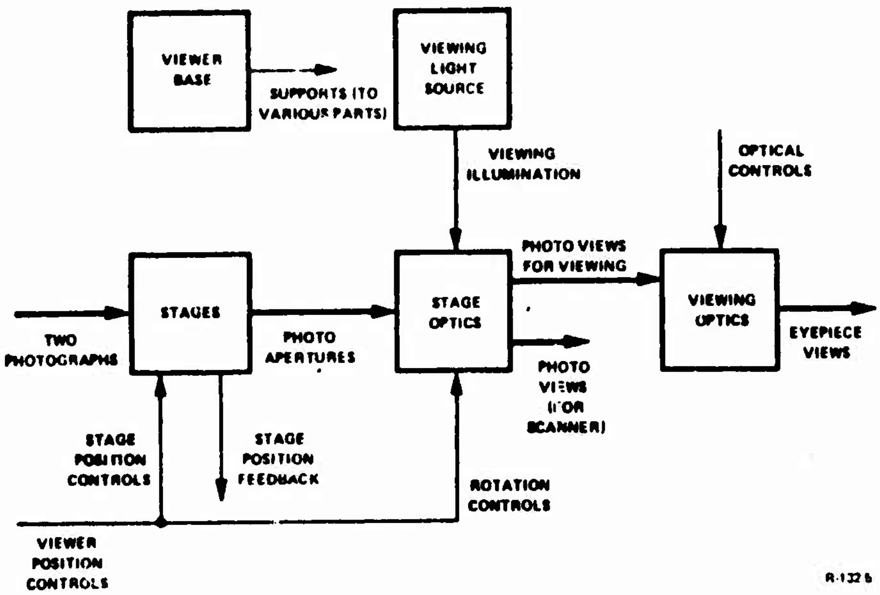

Figure 2 - ACE Viewer Diagram

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4561		11272	DS 880	X1

ENGINEERING SPECIFICATION

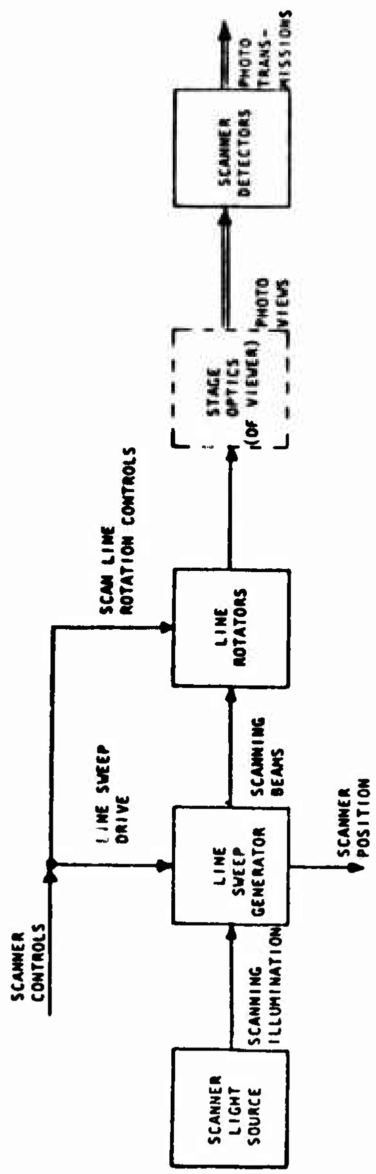

FIGURE 3 - ACE SCANNER DIAGRAM

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4561		11272	DS 880	XI

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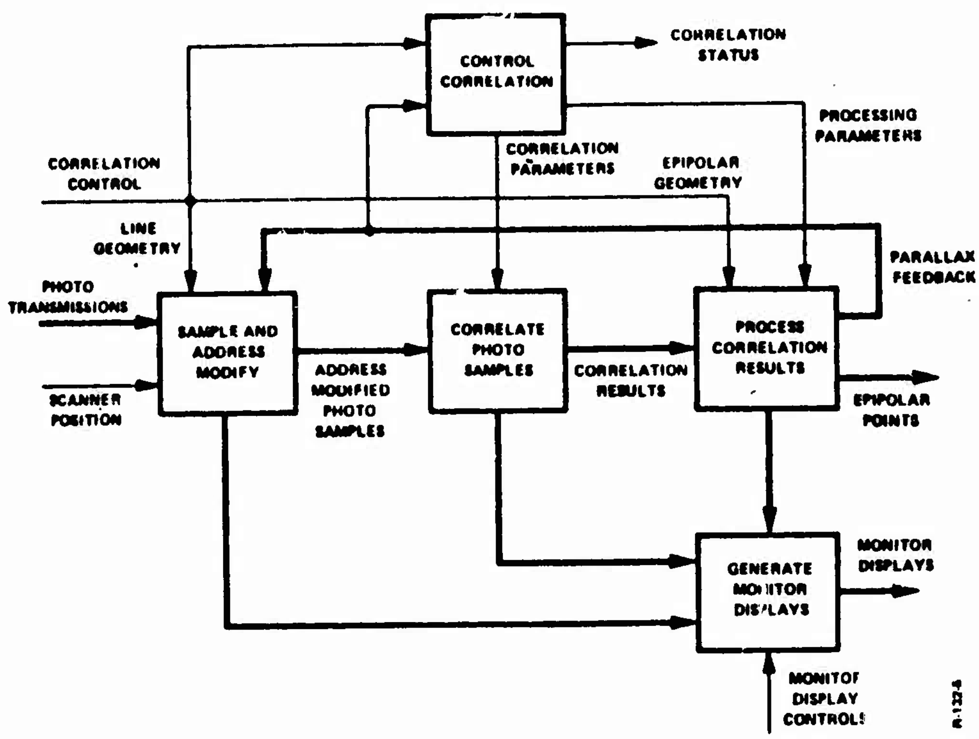

Figure 4 - ACE Correlator Design

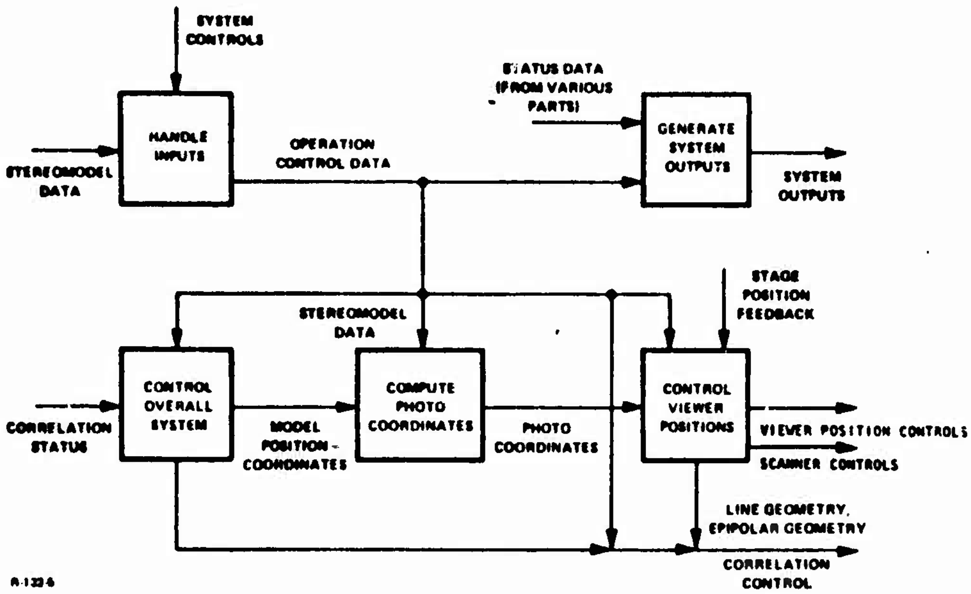

Figure 5 - ACE Control System Diagram

APPENDIX B

VERSION 4 - ACE VIEWER SPECIFICATION

PROJECT NO.		CODE IDENT.	SPECIFICATION NO.	REV.
4561	BENDIX RESEARCH LABORATORIES SOUTHFIELD, MICHIGAN	11272	DS 881	X1

ENGINEERING SPECIFICATION

TITLE

VERSION 4 - ACE VIEWER SPECIFICATION

CUSTOMER	CONTRACT NO.	DATE RELEASED
Rome Air Development Center Griffiss Air Force Base, New York 13441	F-30602-74-C-0260	23 February 1976

REVISION STATUS OF SHEETS

IT IS THE RESPONSIBILITY OF THE RECIPIENT TO DESTROY ALL PREVIOUS ISSUES OF THIS SPECIFICATION IN HIS POSSESSION

SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
REV.	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1														

SHEET	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
REV.																									

SHEET	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
REV.																									

NOTES

PREPARED BY	DATE	CHECKED BY	DATE
G.A. Brumm		L.J. Meyers *L.J. Meyers*	11-5-76

APPROVALS – PER PROJECT AUTHORIZED SIGNATURE LIST

DESIGN LEADER		R AND QA	
MECH/ELEC ENGR		PROGRAM MGR	
PROJECT ENGR		PROGRAM DIRECTOR	
CONFIGURATION MGR.		DESIGN DOCUMENT RECORDS	

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PROJECT NO.	BENDIX RESEARCH LABORATORIES	CODE IDENT.	SPECIFICATION NO.	REV.
4561	SOUTHFIELD, MICHIGAN	11272	DS881	X1

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ACE VIEWER SPECIFICATION

1 SCOPE

1.1 This specification covers the performance, design, developments, and test requirements of the viewer to be used in the Advanced Compilation Equipment (ACE) as defined in the ACE System Specification.

2 APPLICABLE DOCUMENTS

Bendix Specification DS 881, Version 4 ACE Specification
Bendix Specification DS 856, AS-11B-1 Viewer and Coordinatograph
Bendix Specification PS-1143, AS-11B-X Epipolar Scanner

3 REQUIREMENTS

3.1 Viewer Definition

The viewer for the ACE system shall provide facilities for holding the two photographs of a stereo pair, independently positioning the photographs with respect to viewing and scanning optics, manual viewing of the photographs in stereo, and scanning the two photographs of a stereo pair mounted upon the viewer stages. The photos shall be simultaneously scanned along straight lines, with the photo transmissions being detected and electronically sent to a correlator.

The ACE viewer shall be a modified AS-11B-1 Viewer. (See DS-856, AS-11B-1 Viewer and coordinatograph).

The viewer shall include the following components:

a. Viewer Base
b. Photo Stages
c. Optical System for Viewing
d. Scanner
e. Servo Drive System
f. Manual Controls
g. Enclosure
h. Chair

3.1.1 Viewer Base

The viewer base shall be of a dimensionally stable material mounted on a support structure having four legs with level adjustments and a stiffness sufficient to enable maximum stage motions without contributing to loss of performance.

3.1.1.1 Openings shall be provided in the viewer base where required for optical paths, electrical wiring, and mechanical linkages, access, etc.

3.1.1.2 The viewer base shall include provisions for mounting a wiring junction box and connector panel.

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3.1.1.3 Means shall be provided to support a control panel at the front of the viewer base and below the eyepieces.

3.1.2 Photo Stages

Two photo stages shall be provided for holding and translating input photographs. The stages shall have the following characteristics:

3.1.2.1 Each stage shall provide mechanical motion of 9.35 x 18.4 inches.

3.1.2.2 Each stage shall have a clear view of 9 1/2 x 18 1/2 inches.

3.1.2.3 Each stage shall be capable of normal operation of 3 mm/second with accurate position control in any direction.

3.1.2.4 Each stage shall be capable of slewing at 10 mm/second.

3.1.2.5 Each stage shall be capable of the following positioning accuracies (after calibration and with computer corrections).

Total static error 0.005 mm rms (each axis)
Stability over one hour of 0.003 mm rms

3.1.2.6 Each stage shall have a glass platen of optical quality to support photography and be capable of maintaining the photography at a focal plane within 0.001 inches at the scanning optical axis, while transporting this photography over the 9.35 x 18.4 inch stage motion.

3.1.2.7 Each stage axis shall have double limit switches at each end of its travel.

3.1.2.8 Each stage shall accommodate film segments up to 9 x 18 inches and film base thickness from 2 to 7 mil, and have a glass cover plate of optical quality to hold the film to the platen.

3.1.2.9 Each axis of each stage shall employ a d.c.-motor-tachometer and quantizer

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3.1.3 Optical System for Viewing

The viewing system shall comprise binocular optics with two optical paths for direct orthogonal viewing of stereo photographs. The viewer system shall meet the following performance requirements:

3.1.3.1 There shall be two independent viewing systems, one for each photograph.

3.1.3.2 Each viewing system shall permit the operator to view a 8.5 mm diameter at the photograph at 14x magnification.

3.1.3.3 Each viewing system shall permit the operator to resolve 100 line pairs per mm on a 1000:1 contrast target on the photograph stage platen when viewing at 30x magnification.

3.1.3.4 Each viewing system shall enable the operator to manually zoom the magnification over a range from 8x to 30x.

3.1.3.5 Each viewing system shall be capable of rotating the image $\pm$ 190 degrees under computer control.

3.1.3.6 The viewing system shall provide vertical stereo parallax adjustment of $\pm$ .04 radians.

3.1.3.7 Each viewing system shall have a reference mark 0.020 mm diameter which appears in the center of the field of view at the input photograph.

3.1.3.8 Each eyepiece shall provide for $\pm$ 4 diopter focus adjustment and have an eye relief of 20 mm.

3.1.3.9 The viewer shall have an interpupillary distance adjustment from 55 to 75 mm.

3.1.3.10 Each optical path shall be provided with an independently variable illumination source adjustable by controls on the viewer.

3.1.4 Scanner

A scanner shall be provided which scans two small light spots simultaneously along straight lines on each of two stereo photographs. The scanner shall employ counter-rotating glass wedges to generate the scan lines and a beam splitter to split the scan for two photos. The wedges shall be driven by a common motor through precision gears and fitted with an encoder to accurately indicate scan position. The scanner shall also include means of independently rotating the scan lines on each photo under computer control and have detectors in each optical path for sensing light transmissions through the photographs. The layout of the scanner configuration is shown in Figure 2.

The ACE Scanner shall be a modified AS-11B-X Scanner (See PS-1143, AS-11B-X Epipolar Scanner, 23 November 1971, Issue X2)

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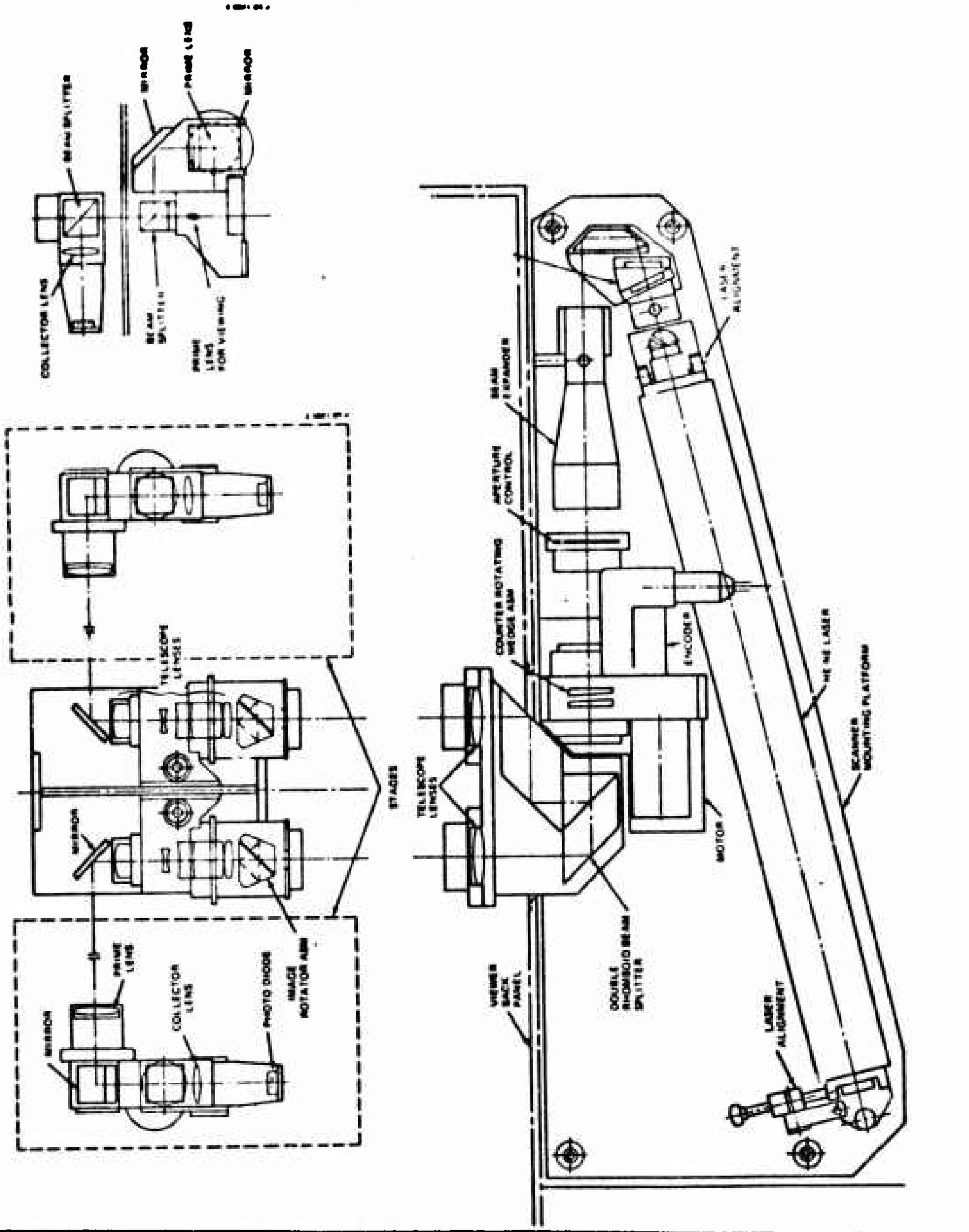
ENGINEERING SPECIFICATION



ACE SCANNER CONFIGURATION

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3.1.4.1 Scanner Performance

The scanner shall meet the following performance requirements:

3.1.4.1.1 The effective length of each scan line shall be 25.6 mm at the photograph. This length shall correspond to ± 30° of scanner wedge rotation.

3.1.4.1.2 Scan velocity must be smooth and continuous.

3.1.4.1.3 The scanner shall operate at sweep frequencies up to 50 scan lines per second.

3.1.4.1.4 The scan line shall be straight within 0.008 mm rms.

3.1.4.1.5 The scan line shall be stable relative to a designated sweep direction within 0.005 mm rms.

3.1.4.1.6 The scan spot position along the scan lines shall be indicated to the computer and true to the indicated position within 0.005 mm rms.

3.1.4.1.7 Each scan line shall be independently rotatable about its center ± 190 degrees. The scan rotation mechanism shall have a positioning accuracy of ± 1.5 minute.

3.1.4.1.8 The center of rotation of the scan line shall make an excursion no greater than 0.005 mm while the scan line is rotated ± 30°.

3.1.4.1.9 Provisions shall be included in the scanner path to permit simultaneous illumination and viewing of the photograph, with protection in the viewing path to prevent possible eye damage from the laser energy, and to prevent viewing illumination from producing a signal on the scan detector.

3.1.4.1.10 The scan spots shall be generated by a 15 mw Helium-neon laser (.6328 μm wavelength).

3.1.4.1.11 Provisions shall be made for manually varying spot size between 0.010 and 0.040 μm.

3.1.4.1.12 Provisions shall be made for manually varying spot intensity over a range of 1×10^{-6}:1 by means of selectable fixed attenuators.

3.1.4.2 Scanner Alignment Requirements

The scanner shall be provided with the following alignment facilities:

3.1.4.2.1 Scan Centering - Controls shall be provided on the front of the viewer for aligning the center of the scan line and the optical floating mark. Two axes of adjustment shall be provided for each photo. Facilities should also be provided for locating the scan line center.

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3.1.4.2.2 Nutation - Adjustment screws shall be provided for adjusting nutation. The adjustments screws should be non-interactive, have minimal backlash, and provide a stable adjustment. Means shall be provided to allow a maintenance person to observe the scan line and reference mark while performing the nutation adjustment.

3.1.4.2.3 Scan Rotation Zero Reference - Means shall be provided for approximately aligning the quantizer zero reference pulses with the zero rotation position of the scan rotators. Cam actuated switches shall be provided on the scan rotators to facilitate computer seeking of the zero reference pulse.

3.1.4.2.4 Laser Alignment - Means shall be provided for aligning the position and direction of the laser beam.

3.1.5 Servo Drive Systems

Servo drives are to be provided for the photo stages (4 axes), image-rotation optics (2 axes), scan-rotation optics (2 axes), and the counter-rotating wedge scan generator (1 axis). For each axis, the viewer shall include the required servo motors, tachometers, quantizers, potentiometers, and other components. The viewer shall also include the required gear trains and mountings for all components.

The servo drive interfaces shall be servo motor leads, quantizer connectors, potentiometer terminals, etc. Servo electronics are not part of this specification.

3.1.6 Manual Controls

The viewer shall have the following controls in such a location that an operator can use them while viewing into the eyepieces or while in the operating position:

3.1.6.1 On-Off Switches

The system shall have on-off switches for the scanner motor, laser, and overall viewer power. The switches shall be of the pushbutton type with indicator lights.

3.1.6.2 Handwheels

Two handwheels coupled to quantizers shall be provided for manual model position control.

3.1.6.3 Elevation Foot Treadle

A foot treadle coupled to a quantizer shall be provided for manual entry of model elevation.

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3.1.6.4 Foot Switches

A foot switch assembly shall be provided with two momentary foot switches.

3.1.6.5 Viewing Optics Controls

The following viewing optics controls shall be provided:

Eyepiece focus for each eyepiece
Interpupillary distance adjustment
Viewing intensity for each optical path with an off position
Stereo parallax adjustment for vertical parallax
Image rotation for each stage
Image magnification for each stage

3.1.7 Enclosure

An enclosure shall be provided for enclosing the sub-components mounted on the viewer base. The enclosure shall have the following characteristics:

3.1.7.1 The enclosure shall exclude external light and shall confine laser emissions.

3.1.7.2 Hinged covers shall be provided to allow photos to be mounted on the photo stages and to permit routine maintenance and adjustments.

3.1.7.3 Interlock switches shall be provided on all covers to extinguish the laser when the covers are opened. The interlock switches shall be of the type which can be defeated by pulling out the actuator.

3.1.7.4 The enclosure shall be equipped with fans and/or vents where necessary to remove excess heat.

3.2 Characteristics

3.2.1 Physical Characteristics

The viewer should be as compact and light as possible consistent with the requirements for performance and format size stated herein.

3.2.2 Reliability

The reliability of the viewer shall be consistent with a MTBF of no less than 150 hours for the ACE.

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3.2.3 Maintainability

The maintainability of the viewer shall be consistent with a MTTR of less than 4 hours for the complete ACE system.

3.2.4 Environmental Conditions

3.2.4.1 The instrument shall operate within the specified limits in a room temperature of 21 to 24 degrees centigrade, and this room shall be within this temperature range 4 hours prior to operation, and change at a rate less than 1°C per hour.

3.2.4.2 The relative humidity shall be maintained between 40 to 60 percent during and 4 hours prior to operation.

3.2.4.3 There shall be no degradation of performance when the viewer, during operation, is subjected to vibrations in the X, Y, and/or Z directions that result in accelerations less than or equal to 0.01 g's peak in the frequency range of 2 to 200 Hz.

3.2.4.4 The instrument shall withstand nonoperating temperatures of 18 to 28 degrees centigrade with no adverse effects.

3.2.4.5 The instrument shall withstand nonoperating humidity of 10 to 80 percent with no adverse effects.

3.3 Design and Construction

Construction of all components shall be in accordance with best commercial practice.

3.3.1 Radio Frequency Interference (RFI)

The viewer shall be designed for RFI suppression such that no component, circuit, or module within or outside of the viewer shall malfunction or be adversely affected by interfering electromagnetic energy originating within the viewer. The term "No Malfunction" means that the performance of the equipment is not degraded beyond specified limits.

3.3.2 Safety

3.3.2.1 Laser Safety

The viewer shall conform to the safety requirements of a Class 5 laser system as specified in ANSI Z136-1-1973.

3.3.2.2 The viewer shall be designed so as to minimize the danger from electrical, radiation, or mechanical hazzards.

3.3.2.3 Warning signs shall be employed where necessary to warn personnel of potential hazards.

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3.3.3 Human Engineering Features

The operator shall be able to comfortably operate handwheels and footwheel, illumination controls, focus and parallax adjustment controls, magnification and rotation controls, foot switches, and control panel while looking through the viewer eyepieces.

The operator should be able to observe the control panel display with minimal change in head position from the normal viewing position.

The eyepieces should be at a convenient height and angle for the operator. An adjustable headrest should be provided for the operator.

Sufficient leg room shall be provided under the viewer for the operator in the normal operating position.

3.4 Documentation

3.4.1 Drawings

The contractor shall provide two complete sets of drawings on his own format, of good commercial quality, to facilitate installation and maintenance.

3.4.2 Manuals

Two sets of operating and maintenance manuals shall be provided with each instrument. This manual shall also provide instructions for conducting preventive maintenance and inspection with diagnostic information to help quickly define the source of problems that may not be obvious.

4 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The supplier is responsible for the performance of all inspection requirements as specified herein.

4.2 General Inspection

The viewer shall be given a thorough mechanical and visual inspection to determine that the quality of all material and workmanship is in compliance with the requirements of this specification.

4.3 Performance Test

The viewer shall be given a test that demonstrates compliance with the performance specifications stated herein, under normal operating conditions and environment.

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5 PREPARATION FOR DELIVERY

The following provisions shall be made in preparation for shipping and delivery:

5.1 Delicate components and assemblies such as lasers, image rotators, counter-rotating wedge scanners, etc. shall be removed from the viewer and packed in boxes.

5.2 The stages shall be removed from the viewer and packed in separate boxes.

5.3 Padding shall be placed around corners and protrusions which are subject to damage during shipment.

5.4 A shipper listing all parts and components shall be prepared and delivered with the viewer.

6 NOTES

6.1 This specification was prepared under Contract F30602-74-C-0260, ACE Design Study and Experiments in accordance with Item A006, Viewer/Scanner specification.

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APPENDIX C

MODCOMP COMPUTER STUDY

The impact upon the Strawman design of substituting Modcomp computers for PDP-11 computers was studied. Comparison was made between using dual Modcomp IV computers versus dual PDP-11/45 computers, with semiconductor memory. The Modcomp IV computer was selected for this comparison because it is the fastest Modcomp computer and has the closest speed to the PDP-11/45 computer.

Comparison of PDP-11/45 and Modcomp IV computer features shows that they have essentially the same capability in many respects. As might be expected, each computer is better in some respects and worse in others. Some significant feature differences are tabulated in Table C-1. Some speed comparisons are tabulated in Table C-2, limited to speed capabilities which are significant to the ACE Strawman design.

Table C-1 - Comparison of PDP-11/45 and Modcomp IV Features

FEATURE	PDP-11/45	MODCOMP IV
• MAIN MEMORY SIZE, 16-BIT WORDS DIRECTLY ACCESSIBLE	29K-32K	64K
• CPU REGISTERS, 16 BITS		
• NUMBER OF SETS	2	16
• NUMBER PER SET	7	15
• USER MICROPROGRAMMABLE (TO ADD INSTRUCTIONS)	NO	YES
• MEMORY MANAGEMENT SUPPORTED BY SOFTWARE		
• NUMBER OF 16-BIT WORDS SIMULTANEOUSLY MAPPED	64K	256K
• NUMBER OF TASKS SIMULTANEOUSLY MAPPED	2	7

Table C-2 - Comparison of PDP-11/45 and Modcomp IV Speed Capabilities

CAPABILITY	PDP-11/45	MODCOMP IV
o ADD/SUBTRACT, REGISTER TO REGISTER TIME IN MICROSECONDS		
o 16-BIT FIXED POINT	0.3, 0.5, 0.9 (1)	0.56
o 32-BIT FIXED POINT	0.9, 1.5, 2.7 (1)	0.64
o 32-BIT FLOATING POINT	$\approx$ 6	6.3
o MULTIPLY, TIME IN MICROSECONDS		
o 16-BIT FIXED POINT	3.5	2.3
o 32-BIT FLOATING POINT	$\approx$ 8	5.2
o MOVE BYTE, MEMORY TO MEMORY, TIME IN MICROSECONDS	1.1, 1.7, 3.0 (1)	3.2 (2)
o ACE ADDRESS MODIFICATION INNER LOOP, MILLISECONDS PER LINE	3.9	5.7 (2)
o CONTEXT SWITCHING TIME, BETWEEN USER TASKS, MICROSECONDS	250	30

NOTES - (1) Depends upon speed of memory being utilized: Bipolar, MOS, of CORE
(2) Could be faster if used microprogrammed special instructions

Because of the high degree of similar capability, Modcomp IV computers could be directly substituted for PDP-11/45 computers in the ACE Strawman design. Some minor design changes would be required, including:

(a) Use only core memory, since only core memory is available.

(b) Include more memory because the operating system takes more memory. About 16K more words (16-bit words) of memory would be required on one computer.

(c) Use a different viewer interface design, since the existing design is specific to the PDP-11 computer.

(d) Interface the scanner to the computer using the separate high-speed I/O bus available for the Modcomp IV computer.

(e) Use the Modcomp MAXNET IV multi-processor operating system.

(f) Add a few instructions to the Modcomp instruction set, by special microprogramming. These additional instructions would be tailored for address modification computations, to improve computer speed.

The advantages of Modcomp IV computers for ACE include:

(a) Modcomp computers are the same series of computer as used on other DMAAC stereoplotters, although not the same model.

(b) Multicomputers are more common applications of Modcomp computers, so such usage is better supported. In particular, more multicomputer software has been available at any time (similar software has been available sooner).

(c) Modcomp computers would be somewhat easier to program, because Modcomp IV computers have only one speed of memory, larger physical address space, and non-continguous page memory allocation.

(d) Modcomp computers have higher speed for certain features, including task switching, double precision fixed point computation, and can be microprogrammed to add special instructions for critical functions.

The disadvantages of Modcomp IV computers for ACE include:

(a) Additional development work would be required to (1) rewrite some computer programs already written for the PDP-11 and (2) redesign some viewer interfaces already designed for the PDP-11.

(b) Increased risk and less support available, since Modcomp is a smaller, less established company. For example, fewer standard peripherals, fewer service personnel, and less documentation are available.

APPENDIX D

MAP 300 PROCESSOR STUDY

Potential replacement of the special design correlation processor by the Map 300 processor was briefly studied. Such a replacement was considered in order to reduce cost; it might also improve maintainability and reliability. Actually, several commercially available signal processors could be considered, including:

(a) Map 300, made by Computer Signal Processors Inc. (CSPI) of Burlington, Mass.

(b) SPS 81, made by Signal Processing Systems Inc. (SPS) of Waltham, Mass.

(c) Flexible Processor, made by Control Data Corp. (CDC) of Minneapolis, Minn.

(d) STARAN, made by Goodyear Aerospace Corp. of Akron, Ohio

Of the above-listed processors, the Map 300 clearly has the best performance-to-cost ratio. It most nearly approaches the performance-to-cost ratio of the AS-11B-X parallel processor.

The MAP 300 is a fast peripheral processor for use with a host minicomputer. It is designed for high speed processing of arrays of data. A measure of its speed is that in 0.42 microseconds it can simultaneously perform <u>all</u> of the following:

(a) Two multiplies, using 2 multipliers.

(b) Four adds or subtracts, using 2 adders.

(c) Twelve moves between arithmetic registers, using 2 buses to move data between 32 registers.

(d) Six data memory accesses, using 3 memory buses.

(e) Fourteen program memory accesses, using 4 program memories (and buses).

All of the above data operations are performed on 32-bit floating point numbers. The design appears to be quite effective for operating on arrays of data, such as 1000 items of input and output data. The multiply speed is often the effective speed, within about 20 percent. However, there is some overhead time required for each array operation; this time is claimed to be on the order of 50 μs per array operation.

The unit is fully programmable. Programming appears to be straightforward, despite six separate programmable sections. The unit comes with standard programs for many common array operations. Indeed, programs are claimed to be available for both the MAP unit and a PDP-11 host computer. However, the standard programs handle primarily linear arrays of input and output data, and not matrices or array of arrays, as would be desirable for ACE.

A typical MAP 300 configuration is claimed to cost about $35,000. CSPI is now building the first batch of 25 units. As of July 1975, they did not have a working unit. CSPI claims to have orders for about 25 units and plans to deliver about 10 units by January 1976.

Based upon a preliminary evaluation, using claimed MAP 300 capabilities, it is likely that a MAP 300 could replace the special correlation processor in the ACE Strawman design. Furthermore, one MAP 300 might also replace one of the two general purpose computers. (PDP-11/45 or Modcomp IV). Use of the MAP 300 might thus reduce both development and production costs by $50,000 to $200,000. More study is necessary to reduce the uncertainties and risks, and to evaluate the cost saving.

APPENDIX E

DESIRABLE FEATURES OF ACE POST PROCESSINC

Some desirable features of the post-processing (system and computer programs) for ACE and AS-11B-X point data are described in this appendix. Although post-processing was not extensively studied under this contract, some post-processing features are clear from these studies and previous AS-11B-X development work. Some of these features are quite essential, and the rest are highly desirable. Some of these features would be rarely used, but are critical under certain circumstances which arise from time to time.

Many of these features would require significant computer time. However, we believe all are technically feasible at reasonable cost. Indeed, several were implemented in the Bendix-written programs for AS-11B-X off-line processing. Remember that some features would not be used all the time, or not applied to all points processed.

This appendix deals with post processing to interpolate grid point elevations from surrounding epipolar point elevations. This material does not treat two other areas where the ACE system requires off-line support·

(1) Manual editing and fill-in of the data produced by ACE. In large measure, this is a problem with any method of producing digital grid data, and is not peculiar to the ACE or AS-11B-X system.

(2) Stereomodel setup and orientation prior to measurement on the ACE system.

These other areas also need careful study, planning, and development if the ACE system is to be adequately supported in DMA production.

E.1 REQUIRED FUNCTIONS

The functions which must be performed during post-processing are indicated by the data flow diagram of Figure E-1. Epipolar points are received from the ACE or AS-11B-X system, and grid points are produced. In between, the following functions are required:

(1) Input epipolar point data into the computer, and convert its format.

(2) Coordinate conversion of point coordinates, when necessary.

(3) Sort and store point data as needed to permit interpolation.

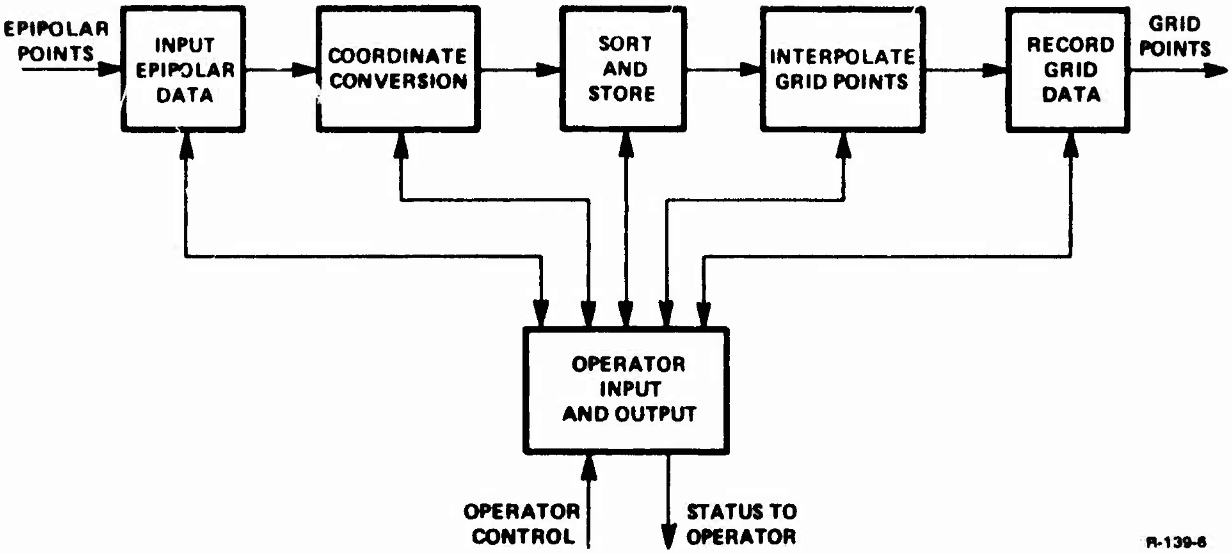

Figure E-1 - ACE Post-Processing Functions

(4) Interpolate output grid points from surrounding epipolar points.

(5) Record output grid data, including formatting of output data.

These functions are not necessarily performed in the order shown. In particular, "sort and store" might be done following interpolation, or between two stages of interpolation.

In addition, operator input and output is required to:

(1) Input data from the operator needed for control of various processing operations.

(2) Output status data from various processing operations, for operator monitoring.

E.2 DATA QUANTITY

An ACE system will operate at an overall rate of at least 50 epipolar points per second, at the nominal point spacing of 10 points/mm^2. One ACE system can thus produce at least 180,000 points per hour, or about 3 million points per working day if operated two shifts.

The number of grid points depends upon grid point spacing, which depends upon photo scale and data usage. The grid point density referred to the photograph might reasonably vary from 1 to 100 points/mm^2. This would mean grid point numbers from 0.1 to 10 times the number of epipolar points.

The area measured on a single stereomodel is also variable. The maximum stereomodel area is about 200,000 mm^2 (300 by 700 millimeters). The typical stereomodel area might be about 20,000 mm^2 (100 by 200 millimeters or 50 by 400 millimeters). There may thus be 2 million epipolar points measured from one stereomodel.

One post-processing system might be designed to handle data from more than one ACE system, perhaps 2 or 3 systems.

It is thus seen that the post-processing (system) must be designed to handle:

(1) Interpolation, input, and output of very many points per day.

(2) Sorting of very large numbers of points in one ground area.

E.3 VARIABLE SMOOTHING AND INTERPOLATION

A variable amount of data smoothing and/or variable interpolation methods are required. That is, the interpolation surface (effective surface) must be fitted to more points than necessary to define the surface. The surface should be fitted to points over a variable distance, or with a variable weighting of points as a function of distance.

Smoothing is required to improve resultant accuracy by filtering (or averaging) out random ACE measurement errors. Variable smoothing is needed to account for the variability of:

(1) Magnitude of random measurement errors

(2) Roughness of ground terrain

(3) Input and output point spacing (number of points per unit area)

(4) Degree of terrain generalization needed in the output data. (For most uses, the grid elevations should represent a specified function of the ground elevation taken over a specified area, rather than discrete point elevations.)

The amount of smoothing should be separately variable in two directions. In the ACE system, the error statistics are different along and across a scan swath, because of different degrees of smoothing within the ACE system. Also, the point spacing produced by ACE can be made significantly different in the two directions, at operator option.

E.4 VARIETY OF POINT SPACINGS

The post processing must accept a variety of input point spacings, or number of points per unit area. Similarly, it should be capable of producing a variety of output point spacings. A point density range of at least 1000:1 is needed (points per unit area on the ground).

Input points can be measured by ACE on a variety of photograph scales, ranging at least 10:1 in a given geographical area. In addition, the ACE system will be capable of measuring points with a photograph scale spacing ranging from about 0.100 to 1.000 mm. Futhermore, it is probably useful to measure the photographs two or more times with the ACE system, and combine the results in the post processing; this will produce more accurate data through averaging out some system errors, when higher accuracy is worth the additional instrument time.

Similarly, post processing should be capable of producing a variety of output point spacings, to meet a variety of grid data uses. An input/output ratio range from about 100 input points per output point to about 1000 output points per input point is desirable (100,000:1 range).

E.5 FLEXIBLE COORDINATE TRANSFORMATION

A flexible capability to convert input data (or output data) to another coordinate system is required. The input data might not be in the desired "normal" coordinate system because it comes from a different source, such as an AS-11A or a digitized map. Alternately, production of input data in exactly the desired coordinates may not have been done due to mistake or to unavailability of the needed ground control information at the time the points were measured. The output points might not be desired in the normal output coordinate system, in order to meet the requirements of a particular user.

For flexibility, an optical coordinate transformation using second- or third-degree polynomials might be used. The polynomial coefficients could be either pre-computed or computed on-line by least-squares fitting to actual and specified desired coordinates of a number of points.

E.6 FLEXIBLE INPUT AND OUTPUT FORMATS

A flexible capability is desirable to accept input data recorded in other recording formats, and produce output data recorded in other recording formats. The input data may be in a different format because it comes from a different source, such as an AS-11A. The output data may be desired in a different format, in order to directly meet the requirements of a particular user.

Format flexibility might include some of the following features:

(1) Number Base: Decimal or binary

(2) Quantity Precision: Number of bits or digits.

(3) Fixed Point or Floating point.

(4) Character Set: Binary, ASCII, EBCDIC, RCA 501, or other

(5) Number of quantities per point (1 to 10), and quantity position of X, Y, and E coordinates.

(6) Whole quantity recorded or change from reference point.

(7) Choice of parity, check sums, error correcting codes, etc.

(8) Number of points recorded per logical record.

(9) Number of logical records per physical record.

(10) Header formats for:

   (a) Logical record.

   (b) Physical record.

   (c) Tape reel.

(11) Point order: Specification of grid sections within which points are to be recorded in row or column order.

E.7 SPECIAL HANDLING OF GAPS

Gaps in the input data which are much larger than the usual point spacing should be handled specially, not just interpolated across in the normal manner used between input points. Gaps up to some specified gap area may be interpolated across in normal fashion, unless the gap has been designated as needed special handling (see Section E.10). The maximum gap area or size for normal interpolation must be selectable by the operator. Gaps larger than a specified area should be called to the operator's attention in some way. This is because all gaps larger than some threshold must be filled in before post processing, in order to obtain desired output accuracy. Thus any gap larger than this threshold which remains at the time of post processing is probably an error which should be detected.

In addition, gaps larger than some minimum size and smaller than some maximum size may need to be interpolated across in a different manner than smaller gaps. For example, second-order interpolation (see Section E.9) is probably optimum for small gaps, but linear interpolation is probably optimum for larger gaps.

As a particular case, output points must not be extrapolated beyond the area covered by the input data. These will appear as "edge gaps" of indeterminate size. Any form of extrapolation (beyond about one input point spacing) surely produces doubtful data, and must be avoided or called to the attention of the operator.

E.8 VARIABLE POINT WEIGHTING

There should be provision in the interpolation for giving different weights to data at different points. The ACE system will record a "figure-of-merit" of each point, which is somewhat indicative of the accuracy of the elevation measured and recorded. Some allowance should be made for use of this information (present or future). Similarly, different data to be combined may be of different accuracies, due to use of different photography or different measuring instruments. The quality may not be readily representable by use of a higher point density for higher quality data, or it may be undesirable to increase the number of points and thus the amount of computation required.

E.9 SECOND ORDER INTERPOLATION

Interpolation should usually be done by fitting a second-order polynomial, or equivalent, or better. Any form of first-order interpolation will "round off" the tops of peaks and bottoms of sharp valleys. This will increase the error in the output data, sometimes exactly where accuracy is most important. Some degree of this "rounding" is unavoidable, and some degree is inherent in the measurements produced by the ACE system. Use of second-order interpolation will avoid doing too much additional "rounding", and might compensate for some of the "rounding" done in the ACE system, if properly implemented.

Second-order interpolation is not necessary at all points, but only where the ground is curved or rough. If this roughness could be reliably detected, the second-order interpolation could be used only in those areas.

E.10 AUTOMATIC EDITING

The post processing should perform some automatic editing functions, and some semi-automatic editing functions. Occasional large errors (blunders) are produced in both manual measurements and in automatic measurements. Similar large errors are sometimes produced by equipment malfunctions.

Most of the largest of such errors can be detected reliably by a suitable computational algorithm. For example, any elevation differing greatly from nearby elevations is questionable, whether the values are nearby in time of measurement or in ground position. If the point also has a lower figure-of-merit recorded by the ACE, the point can be considered invalid and discarded. Some automatic editing algorithm should be included, and provision should be made for changing this algorithm as better algorithms are found, or different data sources and/or uses require.

Efficient editing also requires a degree of semi-automatic operation, where the operator makes some decisions and/or measurements and a computer takes care of the mechanical details. For example, open water areas (lakes and large rivers) could be effectively handled by manual outlining of the boundaries. The computer could then assign the same elevation to all points within that area, using either an operator-specified elevation or the average elevation of the lowest nearby points. Similarly, moderate size barren areas detected and outlined by the operator may be suitably approximated by an inclined plane computed to fit the nearby surrounding measured points.

When joining data from two or more sources, one of the most common errors is a shift of elevation reference. When data is identified as coming from two sources, a computer program can compute the average elevation difference between nearby points. If the difference is large, this should be indicated to the operator, and/or one set of data should be computationally adjusted for the average difference before the data is combined.

E.11 FLEXIBILITY FOR FUTURE MODIFICATION

Where considerable flexibility is not initially provided, provision should be made for easy modification later. Computer program changes would be made later as needed to meet new, changing, or special requirements. Changes would also be made to use new and improved algorithms as they are developed and proven. Careful program modularization would be very desirable to facilitate later changes.

At this time, DMA has limited experience in producing grid data, both from AS-11B-X measurements and from other sources. Similarly, users of the grid point data have limited experienced in its use. It is thus highly likely that desirable changes will be discovered as experience is accumulated.