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INVESTIGATION OF A SPACE DATA TECHNOLOGY FACILITY (SDTF) FOR SPACELAB

FINAL REPORT

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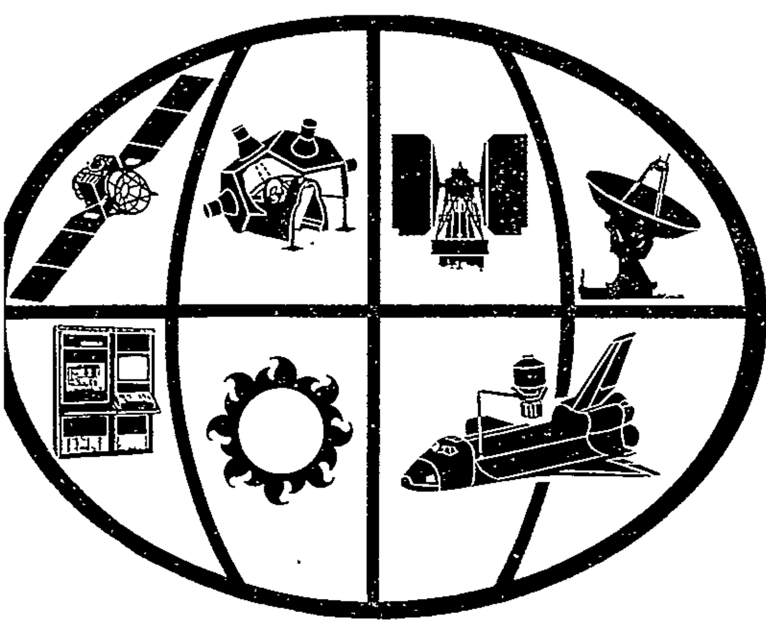

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16. Abstract

A preliminary design of a Space Data Technology Facility (SDTF) for Spacelab is described. It would have the role of supporting a wide range of data Technology related demonstrations which might be performed on Spacelab. The SDTF design is incorporated primarily in one single width standardized Spacelab rack. It consists of various display, control and data handling components to-gether with interfaces with the demonstration-specific equipment and Spacelab. To arrive at this design a wide range of data related technologies and potential demonstrations were also investigated. One demonstration concerned with on-line image rectification and registration was developed in some depth.

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1.0 INTRODUCTION

Spacelab offers the potential to evaluate or demonstrate the viability and value of space data systems technologies and techniques in a space environment at far lower costs than possible by other approaches. This potential will be realized if the demonstrations so performed require a space environment which would be difficult to simulate, and if the cost of the flight support equipment can be minimized by the shared use of a facility specifically designed to support such missions.

This study designed such a facility based on the requirements for the evaluation or demonstration of four technologies and applications.

The necessity to anchor the facility design to real requirements was satisfied by an in-depth development of a single, albeit complex, demonstration requiring several new technologies and techniques. The demonstration jointly selected by GE and NASA was an Onboard Image Registration technique. In the process of developing this demonstration some novel imaging techniques utilizing Charge Injection Devices were devised.

The study has thus produced both the design for a facility to support data technology demonstrations and a viable demonstration in advanced techniques which is a candidate for early shuttle flight.

Readers who are most interested in the SDTF design may wish to concentrate on the discussions of Section 7 whereas those most interested in the image registration demonstration may wish to concentrate on Section 5.

2.0 APPROACH, SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

2.1 SUMMARY AND CONCLUSIONS

In order to provide a basis for design of the SDTF this investigation has identified a wide range of data system related technologies having potential applicability in space. This technology aspect of the study considered the following:

- o Future uses of Space.
- o Present Data System Shortcomings.
- o Trends in Sensors and Spacecraft Systems.
- o Trends in Data Systems.
- o Near Term and Long Term technology requirements.
- o Advanced Technologies in development.

A significant result of this technology survey is the reconfirmation of high data rates and large volumes of data (up to 10^{15} bits/day by year 2000) which can be expected to be collected from space platforms. It is concluded that advances in data handling beyond what is presently planned will be needed.

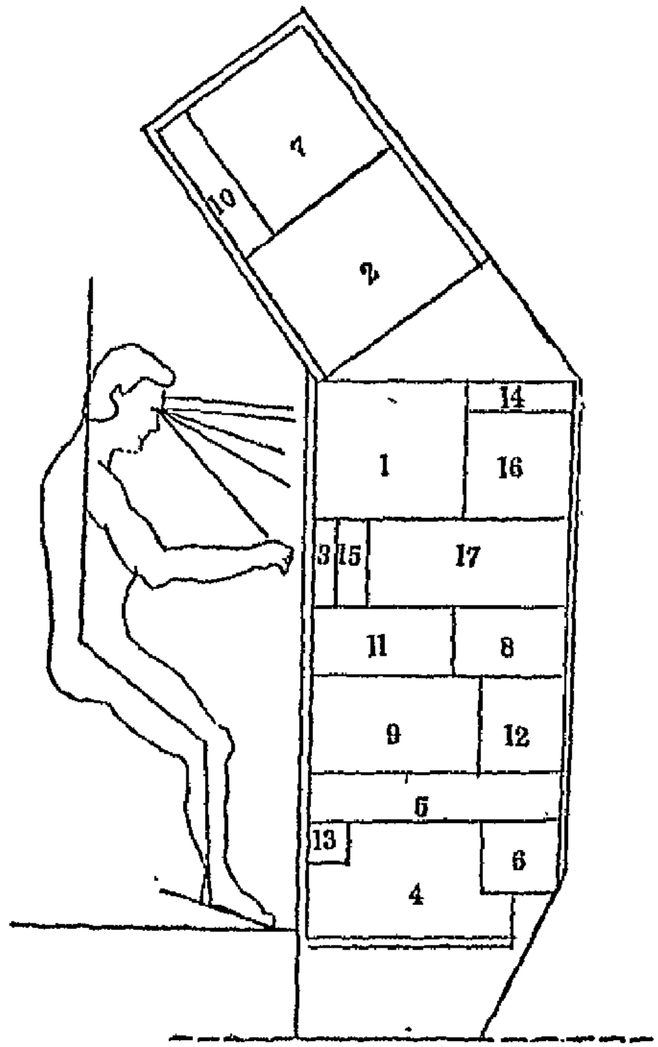
These and other needed technology advances provide a basis for identification of data technology-related demonstrations in Spacelab. An unculled listing of some 44 such demonstrations are presented. One of the most promising of these is a proposed real time image registration demonstration. This would be a demonstration of a technique having significant potential in simplifying the data handling needed for advanced Earth observation systems. This demonstration, which is described briefly below, provides the primary design requirements for the SDTF.

SPACE DATA TECHNOLOGY FACILITY (SDTF)

A PROPOSED SPACELAB FACILITY PAYLOAD TO PROVIDE:

- o DATA PROCESSING
- o DISPLAY
- o CONTROL
- o DEMONSTRATION INTERFACE

IN SUPPORT OF DATA TECHNOLOGY RELATED DEMONSTRATIONS



Based primarily on the needs of this demonstration the SDTF requirements are defined as being related to data handling and display and various control, electrical and mechanical interfaces. The SDTF is conceived as a facility capable of supporting demonstrations conducted either within the pressurized module or on the instrument pointing mount or elsewhere on the pallet. It is proposed that the SDTF be designed chiefly about a standardized single width Spacelab rack. Its primary components and their functions would be:

Components	Function
o Two 19 tri-color CRT soft displays.	o To display presently sensed and pre-stored imagery and also alpha-numeric data
o Digital Data Processor	o To provide up to 750,000 equivalent ADDs per second and 3 x 10^9 bits of High Speed Storage.
o One main and one "ancillary" control and data transfer panel.	o To provide analog and digital controls in form of keyboard and other controllers and displays.
o Remote Acquisition Unit (RAU) and data multiplexer	o To provide data transfer between STDF and demonstrations and also other Spacelab subsystems.
o Electrical power switching panel and power conditioner	o To provide power for demonstrations and other STDF components.

In addition the SDTF rack provides up to 110 x 10^3 cubic cm's for demonstration - specific hardware. Even more volume can be made available by removing one or more modularized components which may not be needed during any given mission. The STDF baseline complement of components would have an estimated weight of 131 kg occupying a volume within the rack of 560(10^3) cubic centimeters. A normal power requirement is estimated to be 700 watts to support the SDTF and the image registration demonstration.

The image registration demonstration is conceived as imaging an Earth surface scene such that each picture element has the same registration as that of some previously obtained imagry of the same scene. It would generally be based on application of precision ephemeris data from Global Positioning System (GPS), precision stellar inertial pointing data as well as Earth-referenced Ground Control Point (GCP) data. A goal of limiting maximum mis-registration error of 26 meters is proposed when the Spacelab is operation at a 750 km attitude. Such a capability could, for example, have future applicability in detection of changes in an Earth observation mission.

It is shown that an approach based on the application of more conventional line scan sensors would have computational requirements of about 50 x 10^6 equivalent ADDs/sec which is judged to be near the maximum capabilities of planned spacecraft data processors. For this reason a different approach to real time image registration based on a more advanced sensor having random access readout capability is proposed. The sensor is a Charge Injection Device (CID) which is an advanced solid state sensing array which has direct Hadamard transform readout capability as well as the random access readout capability. Because this sensor has, in effect, significant built-in data processing capability it has potential to greatly simplify the otherwise extremely formidable data processing requirement needed by more conventional approaches to real time image registration.

Application of CID types of sensors are shown to also have unique potential to simplify processing of image data, to reduce buffer storage and to relax sensor pointing and stability requirements when performing real time image registration as well as other real time image sensing operations. Use of random readout of pixels in a "dewarping" sequence combined with some degree of image oversampling has potential for eliminating image resampling which, in more conventional image processing, is by far the most extensive of the data processing operations. Uniformity of the sensor's elements may avoid the necessity for radiometric corrections which typically are the second most demanding operation. In addition the (Hadamard) transform readout capability of the CID may provide an advantageous means for registration of sensed imagery with pre-stored ground control points (GCPs).

An alternative less precise and more simple image registration demonstration is also conceived. It would be based on use of high quality GPS ephemeris data and high accuracy pointing determination (e.g. 0.0025°) but not using GCP ground reference data as used in the primary demonstration discussed above. It is predicted to have a performance as follows:

Altitude	Misregistration Error
265 km	25 to 35 meters
750 km	70 to 90 meters

Some of the other demonstrations which have been identified having significant potential promise are:

- o "Heads-Up Display" Demonstration
- o Laser Ranging Demonstration
- o Low Light Level Imaging Demonstration

The head's up display demonstration can have function, for example of providing display of imagery presently obtained in non-visible spectral bands or prior imagery or collaterial data superimposed over imagery presently sensed in the visible spectral band.. This capability, if adequately demonstrated, can be expected to have significant potential in assisting the crew in the difficult problem of orienting themselves relative to Earth surface features.

The laser ranging experiment, if adequately demonstrated, is expected to have significant applicability, for example, in making the precise measurements needed for physical geology investigations or in refining of the gravity model.

The low light level demonstrations would make use of image intensifiers and would be expected to extend man's capability for twilight and night viewing of Earth surface features. This can have future applicability for search and rescue operations, for example, or for monitoring of shipping or fishing operations.

2.2 RECOMMENDATIONS

Any recommendation to proceed with development of a SDTF is contingent upon the complement of data technology related demonstrations to be performed on Spacelab. If a sufficient number of demonstrations, each having significant support requirements which can be satisfied by a SDTF, are to be performed, then the development of such a facility can be a cost effective way to proceed. Therefore, a program is recommended which would result in a decision for or against a STDF development. The steps of such a program would be:

- Obtain committments, or at least, best estimates, of which demonstrations will be performed. This can be based on the listing of demonstrations included in this report plus other newly suggested demonstrations, coupled with their level of development and priorities.

- Develop a schedule of possible ensembles of demonstrations (i.e. mission planning) to determine which might be performed on the same or different missions in order to optimize sharing of possible SDTF equipment.

- Summarize the aggregate support requirements which might be provided by an SDTF for these specific combinations of demonstrations to be flown.

- Perform a cost effectiveness analysis comparing the relative costs of performing the selected combination of demonstrations with support provided by SDTF as compared to the alternative of using equipment provided by each specific demonstration supplemented by existing Spacelab subsystem hardware.

There are also recommendations concerning specific demonstrations which are nearly independent of the outcome of the SDTF development decision. Real time image registration capability can enhance the capability of an Earth sensing mission in data analysis especially in the matter of detection of changes which may occur over a period of time in an observed scene (e.g., changes in conditions of flooded areas or forest fires). Therefore, a recommendation is made to proceed with the development of a real time image registration demonstration.

Because a demonstration based on the CID random access readout type of sensor appears to have the most promise in achieving accurate geometric correction and registration without unrealistic data handling requirements, an approach based on that sensor is recommended. Two specific initial steps in development of such a demonstration are now recommended.

- Use existing image handling simulation capabilities to evaluate more completely the approach to using random access and oversampling as well as possibly using direct (Hadamard) Transform correlation of GCPs. Simulation would provide evaluation of image quality of registered imagery and would identify specific potential problem areas such as artifacting.

- Produce preliminary design layouts of CID chips in the image plane of an optical system so as to identify problem areas in placement and construction of sensing chips.

Results of these two steps should serve as a basis for further development of the demonstration.

2.3 TECHNICAL APPROACH

The study consists of three tasks which are derived from the original contract work statement as follows:

Task 1:

Investigate data system technologies that can have meaningful demonstrations aboard Spacelab.

Task 2:

Draw up a baseline list of useful data technology orbital demonstrations and experiments.

Task 3:

Define a Spacelab facility that would support selected demonstrations from that baseline list as well as other similar demonstrations and experiments. Such a definition will include the dimensions of the facility, its power requirements, types and area of windows, and special electrical requirements.

The study approach details are illustrated in the flow diagram of Figure 2-1.

Task 1 investigates technologies applicable to data systems in various disciplines of interest including: On-board data processing and storage, data communications, spacecraft control and navigation, data sensing and man-machine interfaces. The intent of this task is to identify and define those technologies which either in their present state or advanced state or by forecast or trend analyses offer potential utilization in future space-related data systems. As such this technology forecast serves as a basis for the definition of demonstrations of Task 2.

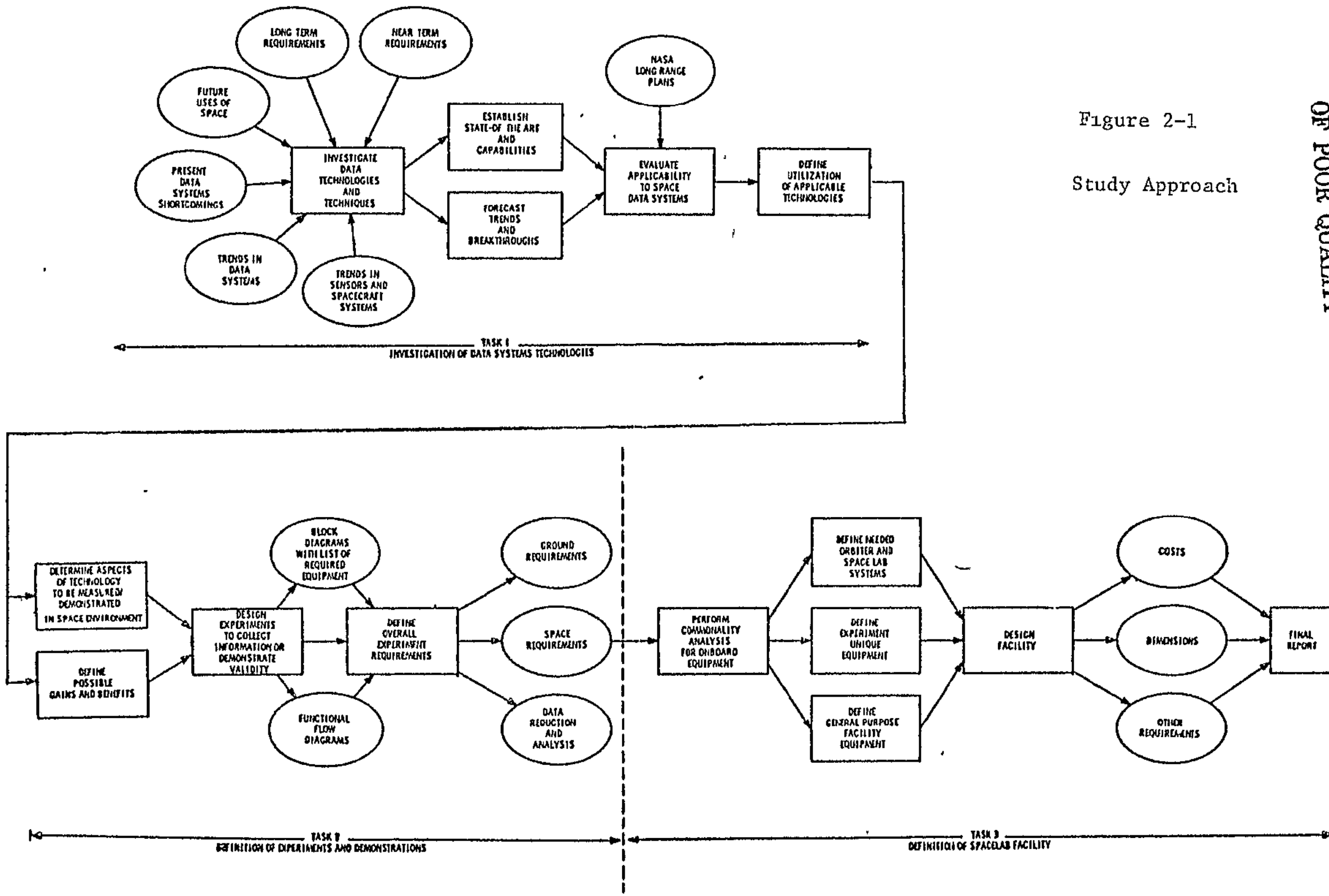


Figure 2-1

Study Approach

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Task 2 has the intent of defining meaningful data technology related demonstrations in space which can serve as a basis for specifying SDTF design requirements and which also have unique merit as space flight demonstrations. It proceeds from the results of the technology investigation of task 1. A primary source of unique and promising demonstrations is a panel of in-house consultants which the contractor organized specifically for purposes of generating ideas on demonstrations. A further source of ideas here is the NASA technical monitor and other NASA GSFC personnel who provided ideas and especially encouragement in pursuring development of one specific selected demonstration concept (a real time image registration demonstration).

Task 3 has the intent of developing design requirements for the SDTF based on results of the two proceeding tasks. As the study progressed it was agreed that one specific proposed flight demonstration (real time image registration) serve as the primary basis for specifying initial design requirements for the SDTF. This initial design is then further evaluated relative to its capability for serving the needs of three other selected proposed demonstrations. Finally the SDTF design requirements are appropriately modified so as to meet these needs.

During an early phase of the investigation an agreement was made with the contract technical monitor to place a major effort on the conceptual development of a real time image registration demonstration. This provided not only a primary basis for development of SDTF design requirements but also the basis for a demonstration which, in itself and by virtue of the ultimate applicability of its technology is judged to have a high degree of merit.

2.4 CONTRIBUTERS TO THIS REPORT

The primary author and chief technical contributer to this report is J. D. Welch, G. Frippel was the project manager. Technical contributions in various disciplines

and demonstration suggestion were made by: J. Avery, W. Guard, D. Peters, K. Stow, D. Bonello, R. Sergo, C. Cheeseman, T. Aepli, D. Hoeshle and D. Nicholson as well as G. Frippel and J. Welch. The image correction concepts as applied to the scanner types of sensors is based, to a significant extent, on prior work of T. Greene, D. Nicholson, R. Hicks, W. Guard, G. Liebling and R. Sergo. All of the above are with GE's Space Division

The CID (Charge Injection Device) is a development of GE's Corporate Research and and Development based on work of G. Michon, H. Burke et al. The specific proposed applications techniques of that sensing device for real time image registration and "analytic stabilization" as described in this report were originated by J. D. Welch Related discussions by H. Brown on CID applications are also acknowledged.

The NASA technical monitor, D. Schaffer, as well as M. Maxwell, et al, of GSFC made several suggestions and directions particularly in regard to the selection of real time image registration as a demonstration to be emphasized.

3.0 DATA SYSTEM RELATED TECHNOLOGIES

The data system related technologies are generally related to the six fields as listed in the request for proposal:

a. Communications

b. Spacecraft control

c. On-board data processing

d. Telemetry

e. Display

f. Man-machine interactions

Several reference sources were employed as an aid to identify technologies of interest. These include:

1. Research and Technology Objectives and Plans ("RTOP book") NASA - Fiscal year 1977.
2. OAST Summer Workshop (1975) Final Report - NASA Grant NSG 1186 (especially Volumes I, II and III of this 12 volume report).
3. "A Forecast of Space Technology 1980-2000" January 1976, Prepared by a multi-center NASA Task Group. (NASA-SP-387).

One significant input, for example, was the extraction of current or recent RTOP's from reference (1) above which primarily relate to the six advanced technologies listed above. These are significant in that they are indicative of NASA's specific interest and needs in technology development. These RTOP's are summarized in Appendix A of this present report.

As a further means of investigation of technologies and techniques related to data handling certain pertinent technology requirements, trends and shortcomings were evaluated. The evaluations which are summarized here relate to these considerations:

- Future Uses of Space (Table 3-1)
- Present Data System Shortcomings (Table 3-2)
- Trends in Sensors and Spacecraft Systems (Table 3-3)

- o Trends in Data Systems (Table 3-4)
- o Near Term and Long Term Technology Requirements (Table 3-5)

Based on a review of the above, a review of the references listed above and also on inputs from the team of consultants assigned by the contractor of this study some significant technologies and techniques which are in various stages of availability, development or planning can be summarized. These are presented in Table 3-6.

TABLE 3-1 FUTURE USES OF SPACE

- o Increased operational use of space platforms/systems for remote sensing of earth for worldwide operations such as:
  - o Crop and Forest Inventories
  - o Crop Stress Surveys/Predictions/Rainfall Surveys.
  - o Earth Natural Resources and Geological Surveys including Search for Petroleum and Critical Minerals.
  - o Long and Short Term Weather Prediction, Climatological Studies.
  - o Oceanographic and Ice Flow Surveys.
  - o Monitoring and Control of Fishing and Shipping Operations.
  - o Monitoring and Prediction of Natural Disasters including Floods, Forest Fires and Earthquakes.
  - o Improved Geodetic Mapping, Interconnection and Densification of Geodetic Monumentation Systems.
  - o Urban Land Use and Growth Studies
  - o Air and Water Pollution Monitoring.
  - o Search and Rescue Operations.
- o Increased use of space platforms for communication links:
  - o Direct and Indirect Television Transmissions.
  - o Commercial Telecommunications Services.
  - o Educational Programs in Developing Countries.
  - o Administration and Monitoring of Health Care Service.
  - o Communications with Remote Site Monitoring Platforms.
  - o Emergency Service Communications.

TABLE 3-1 FUTURE USES OF SPACE (CONTINUED)

- o Application of space for space processing and energy generation
  - o Metalurgical processing including crystal growth, containerless melting, fiber formation.
  - o Biological/Pharmaceutical processing.
  - o Ceremic processing.
  - o Chemical and fluid processing.
  - o Generation and transmission to earth of solar derived energy.
- o Increased use of space platforms for astronomical observations
  - o Investigation of origins and evolution of stars, quasars, "black holes".
  - o Search for extraterrestrial life.
  - o Investigation of universality of physical laws.
  - o Planetary and solar studies.

TABLE 3-2 PRESENT DATA SYSTEM SHORTCOMINGS

- o Difficulties in extracting meaningful information from large volumes of sensed data and transmitting this information in a timely manner to interested users.
- o Problems in defining classification algorithms for a wide range of observable Earth materials and conditions. Difficulties in defining "Ground Truth Data".
- o Problems in keeping track of collateral data (e.g. ephemeris data, attitude data, previously sensed data, maps, time) with corresponding sensed data.
- o Complexities of present sensed data correction operations (e.g. rectification, radiometric correction).
- o Non-standardization of software languages and computer peripherals.
- o Difficulties in Man-machine interfaces.
- o Limitations in capacity, access time, and reliability of mass data archival data storage.

TABLE 3-3 TRENDS IN SENSORS AND SPACECRAFT SYSTEMS

- Utilization of Shuttle as Launch and Recovery Vehicle and also as an Operational Platform.
- Use of Multi-spectral sensors having improved spectral resolution and wider spectral bandwidth.
- Replacement of beam addressed types of imaging sensors (e.g. vidicons) with solid state arrays (e.g. linear and area CCD and CID sensors).
- Increased Recovery/Resupply/Refurbishment of sensors, spacecraft subsystems and entire spacecraft.
- Availability of higher power and higher efficiency space-qualified lasers for use in active sensing (e.g. ranging) and for wideband data links.
- Continued increases in spatial and radiometric resolution of various types of sensors and optical systems.
- Introduction of lightweight erectable structures to increase capability of various sensors and subsystems (e.g. erectable antennas having tens of thousands of square meters in area, large optical mirrors and solar arrays having areas up to hundreds of thousands of square meters.)
- Reduced launch costs and greater power availability associated with Shuttle Operations Launch to low altitude (Costs may be as little as $100 per kilogram.)
- Reduced component and subsystem costs resulting from concepts of Reuseability/Refurbishment.
- Low cost power available in space from advanced nuclear generators.
- Increased autonomy and self-adaptivity of spacecraft systems such as navigation, guidance and attitude control.
- Availability of High Accuracy Navigation in space by use of Global Positioning System providing navigation uncertainty in neighborhood of 10 meters.
- Improved attitude sensing and control with attitude determinations as good as, or better than, 0.01 arc sec.
- Improved space-qualified cryogenic systems to improve performance of a wide range of sensors (e.g. IR sensors, nuclear and gamma-ray detectors) and also devices based on superconductivity.
- Improved resolution (e.g. 5 meters) of Shuttle-borne imaging radars.

TABLE 3-4 TRENDS IN DATA SYSTEM

- Increased Data Volume and rates produced by new generations of sensors from about 10^{10} to 10^{11} bit/day in 1977 to 10^{13} to 10^{15} bits/day by year 2000.
- Increased interest in on-board and/or real time data processing.
- Increased interest in more efficient ground data processing and distribution systems to handle large masses of data expected.
- Introduction of parallel data processing techniques to cope with increased data processing needs.
- Increased application of fault tolerant programmable and/or dedicated microprocessors in distributed systems.
- Increasing component densities of LSI constructions (approaching one million transistors per chip).
- Application of wideband data links making use of TDRSS and other advanced space communications systems and possible corresponding relative decrease in application of on-board data storage.
- Increased capacity, storage densities and read/write accessability of mass data storage. Mass memories of 10^{12} bits per cubic meter can be expected before year 2000.
- Increased storage density and address accessability of archival storage. Densities of 10^{13} to 10^{14} bits of permanent data storage per square meter expected before year 2000.
- Major improvements in automated data processing including data compression, image data correction and information extractions.
- Data systems having a mix of high bandwidth data links and improved data compression techniques.
- Greatly improved and simplified man-computer hardware and software Interfaces, displays and other peripherals leading to expanded applications for computer utilization.
- Extremely large aperature and highly directional antennas achieved by phasing of electronic elements.
- Increased data processing functions incorporated in advanced sensing instruments having combined sensing and data processing functions.
- Early rejection of non-useful sensible data (e.g. imaging sensors deactivated when cloud sensors/mappers indicate a high level of obscuration.)
- Increased design effort in end-to-end information management as an integrated system (e.g. from space-borne sensors to Earth-based users).

TABLE 3-4 TRENDS IN DATA SYSTEM (CONTINUED)

- Reduced wideband bit error probability (e.g. by factor of 10^{12} to 10^3) by means of improved error detecting and correcting encoding.
- Greatly increased processing rates of space qualified computers (e.g. 10^6 to 10^7 operations/sec)
- Development of optimal algorithms for image data processing (e.g. enhancement, pattern recognition, cross-correlation).

TABLE 3-5 SUMMARY OF NEAR TERM AND LONG TERM TECHNOLOGY REQUIREMENT

- Data Processing Needs

  - Near real-time precision ephemeris computation based on GPS and/or other available navigation data and making use of optimum recursive filter techniques (e.g. Kalman).

  - Near real-time attitude computation based on sensed star and gyro data.

  - Scan conversion computation of sensed data which is compatible with display and/or computational needs.

  - Improved image data correction techniques including rectification, restitution and radiometric correction.

  - Computation of sensed target location in a geocentric frame based on precision ephemeris and attitude data.

  - Multi-spectral classification of image data on an individual pixel basis based on intensity in each spectral band.

  - Autonomous adaptive computation of experiment plan based on measurements and computations to date (e.g. re-direct experiment time line profile based on sensed cloud cover).

  - Payload sensed data compression.

  - Payload sensed data pattern recognition (including digital and optical techniques).

  - Data compression (e.g. DPCM) and error correction encoding of data prior to transmission.

  - Computation of needed inputs to control adaptive optics and/or electronically controllable antennas.

- Data Storage Needs

  - Storage of raw or processed sensed data prior to its transmission or transfer to Earth.

  - Collateral data (e.g. locational data, previous imagery, maps) of targets and images to be sensed.

  - Storage of pre-known "false alarm" data (e.g. water bodies such as lakes not to be included as flood areas).

  - Refresh data storage used in conjunction with on-board soft displays.

  - Storage of computed attitude and ephemeris data as a function of time into flight.

  - Storage of data needed for correction computations (e.g. pre-determined sensor radiometric correction data).

TABLE 3-5 SUMMARY OF NEAR TERM AND LONG TERM TECHNOLOGY REQUIREMENT.

(CONTINUED)

- o Storage of star catalog identification data (e.g. locational, spectral radiometric).
- o Storage of flight and experiment plan data.
- o Storage of operational procedural and specification data on subsystems and components (i.e. operational manual data).

o Soft Image Type Displays Needed

- o High resolution ($\sim$ 1000 lines) monochrome and/or color displays of raw and/or processed corrected sensed image data (in near real time).
- o Display of pre-stored or pre-sensed image and/or map data in monochrome or color. (e.g. for cue purposes).
- o Superimposed display of both of above simultaneously (e.g. a "heads up" display application).
- o (Superimposed) display of pre-known "false alarms" (e.g. lakes which are not flood area or "hot areas" which are not forest fires).
- o Display of cloud cover from cloud cover sensor superimposed on map and/or sensed imagery data (e.g. a "heads up" display application).
- o Display of measured and/or predicted laser and/or microwave propagation patterns.
- o Graphic display of spacelab attitude/ephemeris.
- o Interactive displays for near real time image data interpretation by the crew in space.
- o Superimposed image registration display of present and prior imagery of same Earth surface areas.

o Alpha-Numeric Displays Needed

- o Display of computed ephemeris, attitude, time etc.
- o Display of collateral (image) data (e.g. location data, maps)
- o Display of flight and experiment plan and timeline profile data as well as present status of planned program which is completed.
- o Display of updated command and/or advisory data obtained via up-link.
- o Display of operational characteristics and present status of key demonstration equipment, expendables and subsystems.

TABLE 3-5 SUMMARY OF NEAR TERM AND LONG TERM TECHNOLOGY REQUIREMENT

(CONTINUED)

- Data Communication Needs
  - Down-link transfer of raw and/or processed sensed data at rates of hundreds of megabits/sec.
  - Up and down link of command control and telemetry.
  - Up link of new collateral data (e.g. independent up-date of cloud cover and weather prediction).
  - Up link and down link of experiment verification data.
  - Up link and down link transfer of attitude and ephemeris data.
  - Experiment data transfer within spacelab.
- Data Sensing Needs
  - Wide spectral band sensing extending from IR to U.V.
  - Lightweight Adaptive Optical Systems.
  - Combined image sensing and data processing functions.
  - Lightweight, low power high resolution radar imaging systems.

TABLE 3-6 SIGNIFICANT TECHNOLOGIES AND TECHNIQUES IN VARIOUS STAGES OF AVAILABILITY, DEVELOPMENT OR PLANNING

- Alternative Data Processing Hardware and/or Techniques
  - Modular Parallel Pipeline Processor
  - MATRIX (OEDSF) Digital Data Processor
  - MPP (Massively Parallel Processing Computer)
  - Advanced Spaceborne Digital Processor
  - Distributed non-dedicated programmable microprocessors/microcomputers
  - Distributed dedicated microprocessors/microcomputers
  - Artifical Intelligence Machines
  - Surface Acoustic Wave (SAW) Devices
  - Coherent optical data processing
  - Non-Coherent optical data processing
- Alternative Memory Hardware Techniques
  - CCD and other Solid State Memories
  - Bubble Memories
  - Holographic Memories
  - BEAMOS - Beam addressable mass memory developed by GE with data storage of 10^7 to 10^9 bits.
  - Advanced Archival Memory 10^{15} bit archival memory being developed by GE for DARPA.
  - Photographic film (color and/or monochrome) storage of image and collateral data including possible on-board film processing (e.g. BIMAT).
  - Other hard copy data storage.
  - Optic-Acoustic Devices.
  - Wideband Magnetic Tapes.
  - Magnetic Disks, Drums.
  - Extended Core Memories
  - Notebooks, Handwriting, printing, etc.
  - Plated wire memory.

TABLE 3-6 SIGNIFICANT TECHNOLOGIES AND TECHNIQUES IN VARIOUS STAGES OF AVAILABILITY, DEVELOPMENT OR PLANNING

(CONTINUED)

- Alternative Display Hardware
  - Direct view and projection types of CRT displays.
  - Light valve (e.g. liquid crystal type) projection displays.
  - LED alpha-numeric displays.
  - Liquid crystal alpha-numeric displays.
  - Electro-phoretic and other types advanced alpha-numeric displays.
  - Hard copy displays of data including laser beam, ink spray and advanced impact printer.
  - "Heads up" projection display techniques.
  - Man-machine interactive display techniques.
- Data Transmission Alternatives
  - Microwave link (direct or via relay)
  - Laser link (direct or via relay)
  - Transfer of stored data (e.g. film) via Shuttle down flight.
  - Fiber optic data links (within spacecraft).
  - Advanced error correction and data compression encoding.
- Alternative Payload Data Sensors
  - CCD solid state director arrays (linear and area types) including those with TDI (Time Delay Integration) Mode.
  - CID solid state detector arrays (linear and area types) in random access and Transform readout mode.
  - Advanced multi-spectral scanners (e.g. Thematic Mapper)
  - Solid state IR detectors (linear and area arrays)
  - Photographic sensors (silver halide)
  - Cloud cover detectors
  - Active and Passive radiometric sensors
  - Laser radiation sensors
  - Adaptive optics and antennas

TABLE 3-6 SIGNIFICANT TECHNOLOGIES AND TECHNIQUES IN VARIOUS STAGES OF AVAILABILITY, DEVELOPMENT OR PLANNING

(CONTINUED)

- o Electronically controllable antennas. (e.g. for SAR)
- o Large Telescopes
- o Spectrometers
- o Graviometers

o Alternative Reference Sensors

- o Solid state star sensors
- o Landmark identifiers/trackers using various electronic or optical correlation techniques.
- o Verticality and horizon sensors
- o Cryogenic lasers
- o Laser gyros
- o "Tuned Rotor" gyros
- o High accuracy radar altimeters
- o High accuracy Laser Rangers

4.0 PROPOSED DATA TECHNOLOGY - RELATED DEMONSTRATION AND MISSION CONCEPTS

4.1 DEMONSTRATION CONCEPTS

Criteria for selection of candidate demonstrations of interest to the Data Technology Facility have been generated and are outlined in Table 4-1. Based on these criteria, the technology inputs outlined in Section 3, as well as recommendations of the review panel of consultants, and further suggested inputs from NASA personnel, a listing of proposed demonstration concepts has been generated. The candidate demonstrations include those based primarily on a single technology as well as those which are mission-oriented and which typically involve several technologies.

Following this generation of demonstration concepts the review panel of consultants were requested to provide some ranking of merit of the proposed demonstration concepts. This review was further augmented by suggested recommendations by NASA personnel. As a result of these inputs one demonstration, "Real-Time Image Data Registration", has been selected for the primary basis for development of STDF design requirements. This proposed demonstration is discussed in some detail in Section 5 of this report.

Three other demonstrations (i.e. numbers 2, 3 and 4 below) have been selected to provide a basis for evaluation and expansion of the initial design of the SDTF. These three demonstrations and their relation to SDTF design are discussed in Section 6. Characteristics of these four demonstrations are briefly summarized in Table 4-2. The remaining 40 demonstration concepts of the original listing of 44 concepts are outlined in the table appendix B. In compiling this table effort was made to order the list sequence relative to their merit in meeting the selection criteria outlined in Table 4-1.

Table 4-1. CRITERIA FOR SELECTING CANDIDATE DEMONSTRATIONS TO BE USED AS BASIS FOR SDTF DESIGN REQUIREMENTS

- The demonstration must clearly depend upon, or significantly benefit from, performance in the space environment.
- Significant level of near real-time data handling on-board spacecraft must be essential to conduct of experiment.
- Complexity, volume and /or rate of data handling must be great enough so as to insure that data handling capability will also meet requirements of other experiments having equal or lesser degree of data handling needs.
- Experiment must have significance relative to NASA's current interests.
- Level of data handling requirements should be representative of a range of other experiments and should neither be trivial or unrealistically complex.
- The status of the experiment definition in terms of objectives and procedures should be sufficiently well developed to serve as a basis for the design of the SDT facility.
- The demonstrations should support the development of one or more key technologies typified by those outlined in Section 3.

TABLE 4-2

DEMONSTRATIONS SELECTED FOR DEFINITION OF SDTF DESIGN REQUIREMENTS

	TITLE OF DEMONSTRATION (RELATED TECHNOLOGIES)	OBJECTIVES OF DEMONSTRATION	APPLICABILITY OF TECHNOLOGY/MISSION TO SPACE SYSTEM	REASONS FOR SPACE DEMONSTRATION
(1.)	On-Board Precision Image Registration (Sensing, Data Processing, Display Control)	• Demonstrate capability to maintain unchanged image registration on a picture element by picture element basis during the imaging of a given scene of an Earth surface area	• This technology could provide capability to perform real time data processing of various kinds on each and every pixel of an observed scene. Such processing includes image rectification, radiometric correction, etc. • It also provides subsequent relative true registration on a pixel-by-pixel basis with image of the same area obtained in previous orbital passes so as for example, to more readily detect changes over periods of time.	• It is expected that the most convincing demonstration of this capability would be that which is conducted in space • In most Earth viewing operations atmospheric conditions, which are difficult to predict and simulate, are important

Table 4-2 (CONTINUED)

TITLE OF DEMONSTRATION (RELATED TECHNOLOGIES)	OBJECTIVES OF DEMONSTRATION	APPLICABILITY OF TECHNOLOGY/MISSION TO SPACE SYSTEM	REASONS FOR SPACE DEMONSTRATION
(2.) "Heads-up Display" of collateral data such as imagery sensed in UV or IR (DISPLAY, MAN MACHINE INTERACTIONS)	• To demonstrate effectiveness of alternative approaches to providing displays of UV or IR sensed Imagery super-imposed on direct visible image observed by crew considering alternative display technologies, etc. • To compare man-operated and automated means for image registration • To evaluate heads up super position means for displaying non-image collateral data in alpha-numeric and /or graphic form	• Provides crew with expanded spectral view capability with some increase in cloud penetration and night viewing and also with improved capability for interpreting Earth-based phenomena • Provides crew with improved and more rapid means for locating and orienting themselves relative to specific Earth features.	• Effects of atmosphere on viewing by astronaut and also by UV and IR sensors cannot be adequately modeled or simulated • Superposition precision of heads up displayed imagery is dependent on imagery characteristics and fidelity (which depend on atmospheric effects). This is true whether super-position is manual function or depends on computed correlation. • Attitude and orbit dynamics may be difficult to simulate • Display effectiveness will be dependent on external and internal lighting conditions which may be difficult to simulate

Table 4-2 (CONTINUED)

(3) Precision laser Ranging (Sensing, Data Processing, Data Storage)	• Demonstrate capability to range from Spacelab to cooperative targets on Earth and/or other satellites with accuracies of a few centimeters (e.g., 2 to 5 cm)	• Precision ranging to Earth can have major application to geophysics (e.g., in Tectonic plate motion investigations, earth quake prediction studies, glacier flow studies) • Precision space-to-space ranging can be used in refining Earth's gravity model	• Atmospheric effects which are difficult to predict and to model have significant effect on laser ranging • No convincing Earth based experiment is likely to be developed NOTE: cf. NASA GSFC RTOP 645-40-01

Table 4-2 (CONTINUED)

(4) Low Light Level Sensing (Sensing, Display, Data Processing, Data Storage, man-machine interface)	• Demonstrate extended twilight and night-time Earth viewing with image intensifier-based system • Demonstrate in space capability of sensing system based on application on an Image Intensifier to detect very dim stars and other faint astronomical objects • Demonstrate operation with alternative intensifiers including micro-channel plate types and types with various photo-emitters having different spectral sensitivities • Demonstrate on-board real-time display of these sensed objects • Demonstrate use of image intensifiers to provide a direct view to operator (e.g., like "night vision goggles") and also an electro-optical readout for data storage and /or remote display	• Capability to view Earth under night conditions would extend operation of many space-based Earth observation programs such as search and rescue, monitoring of shipping, fishing, etc. • Image intensification techniques can extend capabilities for astronomical investigations in space	• Night time viewing of Earth may be difficult to simulate due to uncertainties in characteristics of existing atmospheric conditions. • Atmospheric conditions play a very major role in astronomical observations especially of faint objects. Ultimate capability for viewing can be expected to be limited by such atmospheric caused degradations as scintillation, back-scatter, attenuation, etc. • Evaluation of image intensifiers for space astronomy must ultimately be performed in space.

DEMONSTRATIONS SELECTED AS BASIS FOR SDTF DESIGN

DEMONSTRATIONS	REASONS FOR SELECTION
o <u>PRIMARY BASIS</u>	
o ON-LINE IMAGE REGISTRATION	o MEETS REAL NEEDS (e.g., RAPID CHANGE DETECTION) o HIGHER REQUIRED RATE OF DATA PROCESSING THAN MOST DEMONSTRATIONS o CAN PROFIT FROM EMERGING TECHNOLOGIES SUCH AS "SMART SENSORS", GPS.
o <u>SUPPORTIVE BASIS</u>	
o "HEADS UP" DISPLAY (HUD)	o MEETS REAL NEEDS SUCH AS CORRELATION OF SENSED AND COLLATERAL DATA o REQUIRES ADVANCED DISPLAY TECHNIQUES
o LASER RANGING	o MEETS REAL NEEDS (e.g., IN GEOLOGICAL INVESTIGATIONS) o REQUIRES PRECISION NAVIGATION AND POINTING
o LOW LIGHT LEVEL SENSING	o SATISFIES NEED FOR MONITORING OF OCEAN ACTIVITIES ETC. o REQUIRES ADVANCED SENSING TECHNIQUES

4.2 DEVELOPMENT OF OPERATIONAL MISSIONS BASED ON APPLICATION OF DEMONSTRATION CONCEPTS

In order to substantiate the value of the proposed demonstration concepts, preliminary plans for several operational space missions each based on one or more of these concepts have been developed. These mission developments are summarized in Table 4-3. The development of these mission ideas is based on identification of problem areas and potential solutions to these problems. As shown in the table, in many cases these potential problem solutions as well as alternative means of implementations take advantage of concepts the demonstration of which are being proposed during this investigation. Where applicable, the alternative on-board implementations are also related to the RTOP's listed in Appendix A.

PROPOSED OPERATIONAL SPACE MISSION EXAMPLE #1 AN ADVANCED EARTH OBSERVATION SYSTEM

MISSION OBJECTIVE	PROBLEM AREAS	POTENTIAL SOLUTIONS	PROBLEM AREAS	POTENTIAL SOLUTIONS	SELECTED ALTERNATIVE IMPLEMENTATIONS ON-BOARD (NUMBERS RELATE TO RTOP'S LISTED IN APPENDIX A)
COLLECT, PROCESS AND DISTRIBUTE EARTH OBSERVATION INFORMATION HAVING. HIGH RESOLUTION WIDE AREA COVERAGE, MULTI-SPECTRAL CHARACTERISTICS	• ACHIEVING HIGH SENSING RATES o ACHIEVING ULTRA-HIGH WIDEBAND RAW DATA TRANSMISSION RATES (UP TO 10^3 MBITS/SEC) • EXTRACTION ON GROUND OF USEFUL INFORMATION FROM LARGE VOLUMES OF RAW DATA o TIMELY DISSEMINATION OF USEFUL INFORMATION TO LARGE NUMBER OF USERS • GROUND STORAGE OF LARGE VOLUMES OF RAW AND PROCESSED DATA (NASA COLLECTS 10^{15} BITS/YR) • COLLECTION AND UP-LINK TRANSMISSION OF GROUND TRUTH DATA FOR CLASSIFICATION	• IMPROVED MULTI-CHANNEL SENSORS • INCREASED ON-BOARD COMPUTATION TO PROVIDE DATA COMPRESSION AND INFORMATION EXTRACTION	o HIGH RATE OF SENSED DATA RESULTS IN NEED FOR HIGH DATA PROCESSING RATES • PROGRESSIVE IMAGE MISREGISTRATION OF PIXELS DUE TO ORBITAL MOTION, ATTITUDE AND POINTING CHANGES • RADIOMETRIC ERRORS AND NOISE IN SENSED IMAGE DATA • ACHIEVING HIGH SPATIAL AND SPECTRAL RESOLUTION WITH HIGH RELIABLE SENSING CAPABILITY	• ON-BOARD PARALLEL IMAGE DATA PROCESSING TO. - PERFORM RADIOMETRIC CORRECTION ON INDIVIDUAL PIXEL BASIS (e.g GAIN AND "HAZE BACKOUT") - PROVIDE IMAGE REGISTRATION CORRECTION AND RESTITUTION ON INDIVIDUAL PIXEL BASIS BY SHIFTING OPERATIONS BASED ON PRECISION ORBITAL AND ATTITUDE DATA AND IMAGE (I E. GCP'S) - PROVIDE FEATURE AND CHARACTERISTIC SIGNATURE EXTRACTION BASED ON SPATIAL AND/OR SPECTRAL CONTENT OF IMAGES (e.g CLUSTER ANALYSIS, PATTERN RECOGNITION) - REJECT RAW DATA HAVING NO INFORMATION OF INTEREST (e.g. CLOUD COVERED) - HIGH DENSITY BUFFER STORAGE OF REDUCED DATA PENDING TRANSFER VIA DOWN-LINK • PROVIDE (TUNABLE?) MULTI-SPECTRAL SOLID STATE ARRAY DETECTORS • PROVIDE NEEDED PRECISION ATTITUDE REFERENCE AND CONTROL BY ADVANCED STELLAR-INERTIAL MEANS • PROVIDE PRECISION EPHEMERIS DATA BY AUTONOMOUS MEANS • CLOUD SENSING CAPABILITY TO PROVIDE REJECTION OF CLOUD COVERED IMAGES	• DATA PROCESSING (30), (18) - MASSIVELY PARALLEL PROCESSING COMPUTER (MPPC) (21) - MODULAR PARALLEL PIPELINE PROCESSOR (MPPP) - MATRIX (OEDSF) PROCESSOR • MASS MEMORIES - CCD MEMORIES (7) - BUBBLE MEMORIES (27) - HOLOGRAPHIC MEMORIES - ADVANCED ARCHIVAL DATA STORAGE - BEAM ADDRESSABLE SEMI-CONDUCTOR MEMORY • ADVANCED SENSING TECHNIQUES (7), (31) - CCD's (7), (15) - CID's (CHARGE INJECTION DIODES) - MULTI-SPECTRAL SOLID STATE SENSORS (32) - ADVANCED CLOUD SENSOR/MAPPER - THEMATIC MAPPER - SCANNING RADIOMETER (29) • NAV. & REFERENCE SENSING & CONTROL - SOLID STATE STAR TRACKERS (15) - LANDMARK TRACKERS (17) - CRYOGENIC GYROS - LASER GYROS (11) - ACS (13), (34) • COMMUNICATIONS (35) - WIDEBAND MICROWAVE LINKS (22), (24) - LASER COMM. LINKS (31) - DATA COMPRESSION (33), (36)

TABLE 4-3 OPERATIONAL MISSIONS DEVELOPED FROM SELECTED PROPOSED DEMONSTRATION CONCEPTS

PROPOSED OPERATIONAL SPACE MISSION EXAMPLE #2 ON-BOARD FOREST FIRE DETECTION

MISSION OBJECTIVE	PROBLEM AREA	SELECTED ALTERNATIVE IMPLEMENTATIONS ON-BOARD (NUMBERS RELATE TO RTOP'S LISTED IN APPENDIX A)	POSSIBLE DATA HANDLING TECHNOLOGY NEEDS (NUMBERS RELATE TO RTOP'S LISTED IN APPENDIX A)

• SURVEILENCE FOR, AND RAPID REPORTING OF, ON-BOARD FOREST FIRE DETECTION	• DETECTION OF LARGE AREA SOURCE OF FIRE
	• REJECTION OF "FALSE ALARMS" (e.g. LARGE STEEL MILLS OR OTHER LARGE SOURCES OF I.R. RADIATION)
	o MEASUREMENT OF AREA OF FOREST FIRE
	o CHANGE DETECTION TO ASSESS INCREASE OR DIMUNITION OF FIRE THREAT
	o LOCATING FOREST FIRE IN GEOMETRIC REFERENCE FRAME (i e. LAT. - LONG.)
	o CLOUD COVER
		• VISIBLE LIGHT SENSOR (NIGHT OPERATION) (4),(32)
		• IR SCANNER
		• IR SOLID STATE ARRAY (LINEAR OR AREA) OR DETECTOR (7),(32)
		• STORAGE OF LOCATIONAL AND DESCRIPTIVE DATA ON "FALSE ALARMS" (7)
		• AREA OF FIRE MEASURED BY INTENSITY THRESHOLDING IN SENSOR (7)
		• AREA OF FIRE COMPUTED BY INTEGRATION IN DIGITAL DATA PROCESSOR
		• VEHICLE LOCATION OBTAINED BY.
		  • GROUND TRACK NET
		  • GPS
		  • ON-BOARD AUTONOMOUS NAVIGATION (16)
		• VEHICLE POINTING OBTAINED BY. HIGH PRECISION STAR TRACKING HIGH RESOLUTION GYROS (14)
		• DISPLAY ON-BOARD OF SENSED IMAGRY (7)
			• SENSOR SCAN CONVERSION
			• EPHEMERIS COMPUTATION (e.g. FROM GPS DATA)(16)
			• ATTITUDE COMPUTATION (e.g. FROM STAR CROSSING AND GYRO DATA)
			• IMAGE RECTIFICATION/RESTITUTION/ RADIOMETRIC CORRECTION
			o DETERMINATION OF FIRE AREA OBTAINED BY INTEGRATION OF PIXEL EXCEEDING SOME PRE-SELECTED THERMAL INTENSITY THRESHOLD (18)
			• LOCATING FIRE FROM EPHEMERIS AND VEHICLE/SENSOR POINTING DATA
			o DISPLAY OF ON-BOARD SENSED IMAGRY WITH CRT OR PROJECTED LIQUID CRYSTAL LIGHT VALVE DISPLAYS
			• DISPLAY OF ALPHA-NUMERIC DATA BY LED OR LIQUID CRYSTAL DISPLAYS
			• IMAGE DISPLAY OF PRE-KNOWN "FALSE ALARMS" BY CRTS OR LIGHT VALVE PROJECTION
			• TRANSMISSION IN NEAR REAL-TIME OF REDUCED FOREST FIRE DATA TO GROUND
			• COMPUTATION OF CHANGE IN SIZE, SHAPE AND LOCATION OF FIRE (CHANGE DETECTION ALGORITHM MECHANIZED IN DIGITAL DATA PROCESSORS)

PROPOSED OPERATIONAL SPACE MISSION: EXAMPLE #3 ON-BOARD DETERMINATION OF FLOODED AREAS

MISSION OBJECTIVE	PROBLEM AREAS	ALTERNATIVE IMPLEMENTATIONS ON-BOARD (NUMBERS RELATE TO RTOP'S OF APPENDIX A)	POSSIBLE DATA HANDLING TECHNOLOGY NEEDS (NUMBERS RELATE TO RTOP'S OF APPENDIX A)
• TO MAKE RAPID DETERMINATION (ON-BOARD) OF ACREAGE UNDER WATER DUE TO FLOODING	• DISTINGUISHING WATER UNDER A WIDE RANGE OF ILLUMINATION, CLOUD AND VIEWING CONDITIONS FROM NON-WATER • INTEGRATING AREAS OF DETECTED WATER • *LOCATING OF FLOODED AREAS* • DISTINGUISHING FLOODED AREAS FROM PRE-EXISTING BODIES OF WATER (e.g. LAKES, RIVERS)	• MULTI-SPECTIAL SCANNER • MULTI-SPECTIAL SOLID STATE DETECTORS (4) • ACTIVE LASER HYDROLOGIC SENSING (6) • PARALLEL MULTI-SPECTIAL CLUSTER CLASSIFICATION ANALYSIS AND AREA INTEGRATION IN A MPP TYPE OF PROCESSOR (21) • MULTI-SPECTIAL CLASSIFICATION ANALYSIS AND AREA INTEGRATION IN A SERIAL TYPE DIGITAL DATA PROCESSER • ON-BOARD MEMORY TO STORE DATA ON PRE-EXISTING BODIES OF WATER • ON-BOARD DISPLAY OF REDUCED IMAGRY DATA SUPERIMPOSED OVER DISPLAYS OF MAPS OR PHOTO-MAPS • ON-BOARD STORAGE OF PRE-EXISTING MAPS AND/OR PHOTO-MAPS • UP-LINK OF UP-TO-DATE COLLATERAL DATA ON FLOOD CONDITIONS • ON-BOARD DISPLAY IN ALPHA-NUMERICFORM OF SUCH DATA	• SENSOR SCAN CONVERTERS • EPHEMERIS COMPUTATION (e.g. FROM GPS) • *ATTITUDE COMPUTATION FROM* STAR SENSORS AND GYROS • IMAGE DISPLAY WITH CRTs OR LIQUID CRYSTAL LIGHT VALVES (7) • ALPHA-NUMERIC DISPLAYS WITH LIQUID CRYSTAL OR LED DISPLAYS (7) • CHANGE DETECTION ALGORITHMS • BUBBLE MEMORIES (27)

PROPOSED OPERATIONAL SPACE MISSION. EXAMPLE #4 DEMONSTRATE ABILITY TO ORIENT SPACECRAFT TO ACQUIRE PRECISELY DEFINED IMAGES

OBJECTIVE	PROBLEM AREAS	ALTERNATIVE IMPLEMENTATIONS ON-BOARD (NUMBERS RELATE TO RTOP'S LISTED IN APPENDIX A)	POSSIBLE DATA HANDLING TECHNOLOGY NEEDS (NUMBERS RELATE TO RTOP'S LISTED IN APPENDIX A)
ORIENT SPACECRAFT TO ACQUIRE PRECISELY DEFINED TARGETS	o PRECISION EPHEMERIS DETERMINATION	o EPHEMERIS COMPUTATION BASED ON GPS AND AUTONOMOUSLY DETECTED FIX DATA (16)	o PRECISION MAN/MACHINE ATTITUDE CONTROL INTERFACES
	o PRECISION ATTITUDE DETERMINATION	o PRECISION ATTITUDE CONTROL AND DETERMINATION BASED ON SENSED STELLAR AND INERTIAL REFERENCE DATA	o GRAPHIC AND NUMERIC DISPLAY OF VEHICLE ATTITUDE IN INERTIAL OR LOCAL VERTICAL FRAME ON CRT DISPLAY (7)
	o TARGET DETECTION	o DIGITAL DISPLAY OF COLLATERAL DATA	o LIQUID CRYSTAL OR L.E.D. DISPLAYS OF COLLATERAL DATA (7)
	o PRECISION FINE CONTROL OF ATTITUDE	o IMAGE DISPLAY OF SENSED IMAGE DATA SUPERIMPOSED ON STORED MAP OR PHOTO-MAP DATA (i.e. "HEADS UP" DISPLAY)	o "HEADS UP" DISPLAY TECHNIQUES
	o INDEPENDENT CONTROL MEASUREMENTS FOR EXPERIMENT VALIDATION		

PROPOSED OPERATIONAL SPACE MISSION: EXAMPLE #5 ADVANCED HIGHLY DIRECTIONAL LASER COMM. SYSTEM

SYSTEM OBJECTIVE

- TO ACHIEVE VERY HIGH DATA RATE ($\sim 10^9$ BITS/SEC) IN SPACE - TO - SPACE OR SPACE - TO - GROUND DATA LINKS

PROBLEM AREAS

- TO ACHIEVE INCREASED EFFICIENCY OF LASER WHICH NOW RANGE FROM 2% TO 15%
- TO PROVIDE HIGH EFFICIENCY WIDE BANDWIDTH MEANS FOR LASER BEAM MODULATION
- TO SENSE AND ACQUIRE GROUND OR SPACE-BASED RECEIVER FROM LONG RANGES
- TO MAINTAIN TRACK DURING TRANSMISSION
- TO PENETRATE EARTH ATMOSPHERE UNDER A WIDE RANGE OF ATMOSPHERIC CONDITIONS
- TO PROVIDE STORAGE OF LARGE VOLUMES OF DATA WHICH CAN BE TRANSMITTED BY LASER LINK

POTENTIAL SOLUTIONS

- RECENT ADVANCES IN GLASS TECHNOLOGY MAY PROVIDE MORE EFFICIENT LONGER LIFE LASERS OPERATING IN VISIBLE SPECTRUM. CARBON DIOXIDE LASERS CAN HAVE EFFICIENCIES OF 15% AT 10.6 MICROMETERS.
- NEW ADVANCES IN LASER MODULATORS NEEDED TO IMPROVE BANDWIDTH AND EFFICIENCY
- DEVELOPMENT OF LARGER HIGH PRECISION ERECTABLE TRANSMITT AND RECEIVE ANTENNAS
- SELECTION OF VISIBLE LIGHT PRODUCING LASERS FOR BEST ATMOSPHERIC PENETRATION HAVING ACCEPTABLE BEAM DIVERGENCE
- APPLICATION OF HIGH PRECISION SOLID STATE STAR TRACKERS/MAPPERS PLUS HIGH RESOLUTION GYROS FOR VEHICLE ATTITUDE CONTROL AND STABILITY
- IMPROVED BEAM STEERING TECHNOLOGY

SELECTED ALTERNATIVE IMPLEMENTATIONS ON-BOARD. (NUMBERS REFER TO RTOP'S LISTED IN APPENDIX A)

- CO_2 LASERS OF IMPROVED EFFICIENCY FOR SPACE - TO - SPACE LINKS (25)
- GLASS LASERS OF HIGHER EFFICIENCY TO OPERATE IN THE NEAR VISIBLE RANGE FOR SPACE - TO - GROUND LINKS (25)
- ERECTABLE MIRRORS OF LARGER SIZE AND CONTROLLED FIGURE
- GPS AND/OR OTHER HIGH PRECISION NAV. AIDS (16)
- HIGH RESOLUTION STAR TRACKERS AND GYROS (11), (13), (15)

PROPOSED OPERATIONAL SPACE MISSION EXAMPLE #6 HIGHLY DIRECTIONAL MICROWAVE COMM LINKS

MISSION OBJECTIVE	PROBLEM AREAS	ALTERNATIVE IMPLEMENTATION ON-BOARD (NUMBERS REFER TO RTOP'S LISTED IN APPENDIX A)	POSSIBLE DATA HANDLING TECHNOLOGY NEEDS (NUMBERS REFER TO RTOP'S LISTED IN APPENDIX A)
DEMONSTRATE CAPABILITY TO ACHIEVE HIGHLY DIRECTIONAL COMM. LINK	• ACHIEVING NEEDED RADIATION BEAM PATTERN (e g NARROW BEAM AND/OR SHAPED BEAM) • PRECISION POINTING OF VEHICLE AND ANTENNA • PRECISION EPHEMERIS DETERMINATION	• ELECTRONICALLY DIRECTABLE AND SHAPABLE ANTENNAS (2),(22) • PRECISION ATTITUDE CONTROL AND DETERMINATION FROM STAR AND GYRO DATA (11),(12),(13) • EPHEMERIS GENERATION FROM GPS AND OTHER DATA (17) • MICROWAVE INTERFEROMETRIC ATTITUDE SENSING • ADVANCED MICROWAVE TECHNIQUES (23),(24)	• HIGH EFFICIENCY, RAPID CONVERGENCE EPHEMERIS AND ATTITUDE DETERMINATION ALGORITHM • LC OR LED ALPHA-NUMERIC DISPLAYS (7) • DATA COMPRESSION TECHNIQUES (33)

5.0 A PRELIMINARY DESIGN OF A SPACELAB MOUNTED PRECISION IMAGE REGISTRATION DEMONSTRATION

5.1 DEMONSTRATION OBJECTIVES

The overall objective is to establish in a real time on-line demonstration, the same registration, on an image cell by image cell basis, of a currently sensed "candidate" image of an earth surface area as was established with a previously obtained image of the same area. This previously established registration is referred to as the "reference registration" for that specific earth surface area. The reference registration data itself may have been established by ground processing of a prior imagery data obtained by some earlier satellite operation. Some even more advanced future demonstrations may obtain both the candidate and the reference image on the same space flight. This later demonstration is expected to be significantly restricted due to limitations on area image coverage available with the Spacelab's orbit during flight. (Subsequent application-oriented utilization of the technique when applied to the longer flight times and repetitive coverage of future unmanned earth observation spacecraft, however, will not necessarily have this limitation.)

As used here, the dimensions of the image cell are defined in terms of the registration precision which is established as a performance goal. It is defined in terms of dimensions on the earth surface and, as such, is independent of the viewing angle from which it is viewed from the spacecraft. The corresponding cell size at the sensor image plane in the spacecraft is, as a result, a function of viewing angle. Image cell size may not necessarily be related to pixel size (e.g. at maximum viewing angle measured up from nadir) which is usually related to sensor resolution rather than registration performance.

Here we will provisionally define the registration performance goal as being not less than 2/3 overlap in each of two dimensions of corresponding cells, corresponding to not less than 4/9 area overlap between each cell of the present image and each cell of the reference registration. As the demonstration concept matures further, it may become advantageous to revise this goal so as, for example, to permit some greater flexibility in its definition (e.g., 90% of image cells shall not have less than (TBD) % overlap in two dimensions, 100% of image cells shall not have less than (TBD) % overlap in two dimensions). It may also be both technically feasible and desirable from an applications point of view to set a tighter registration goal at high contrast bounds (e.g. well defined straight lines such as highways or land-water bounds). The corresponding "sharper" correlation function could facilitate such improved registration. The desire to avoid objectionable discontinuities in such bounds may provide motivation for establishing such additional performance goals.

Actual registration performance will be defined by the ground dimensions of the image cell. The performance of the most used Earth Resources type of image sensor, the Multi-Spectral Scanner (MSS) is presently recommended here as a basis for selection of an image cell dimension. At the standard Landsat altitude, the MSS has an image cell size of 79m x 79m. Since this instrument has been most useful for observation from space, the same image cell size is related for the present demonstration. The performance goal will then be restated as performing registration with a misregistration error in each of two horizontal dimensions of not more than 1/3 x 79 meters or 26 meters. The demonstration will include sensing of earth images in the visible spectrum by electro-optical means.

The extent and the location of Earth surface areas selected to be imaged should be such as to demonstrate registration with a wide range of topography and surface cover. Plans for imaging land areas should be in sufficient quantity to compensate for inability to obtain images due to adverse weather or other conditions. It is anticipated for the demonstration that the sensed image data should be geometrically corrected so as to provide the registration specified above in an ortho-rectified projection. It is expected that this real-time processing will be performed primarily by digital data processing means.

The primary output of the demonstration will be a near real time bit stream of digital data which contains the grey scale calibrated intensity level of each picture element. The ordering of this corrected bit stream will be such as to conform to that of the desired rectified and registered imagery.

This data may be either stored on high density digital tapes, if available, and returned to Earth with the Spacelab, or alternatively may be transmitted to Earth at real time sensing rates via the wideband data link provided by TDRSS. This data will be available on the ground in hardcopy and softcopy displays showing the extent of misregistration between the candidate image and the reference imagery.

5.2 DESCRIPTION OF THE PROBLEM TO BE SOLVED

It is expected that in order to perform the demonstration, some optimal combination of most or all of these functions will be performed:

- Precision determination of Spacelab ephemeris (with uncertainties in order of a few tens of meters).
- Precision determination and control of Spacelab attitude.

- Precision pointing determination of earth sensing instrument (with uncertainties of less than 10 arc seconds).
- Radiometric correction of image data.
- Manipulation of image data so that its geometry is compatible with that of the stored reference registration data (e.g., rectification).
- Real time registration of candidate image data relative to stored registration reference typically by some correlation-like function.

These functions would be expected to be part of the Spacelab demonstrations and also any subsequent application resulting from these initial successful demonstrations. Unique to the Spacelab demonstration, however, are also functions and procedures for demonstration validation.

Of the functions listed above, consider first the subject of geometric manipulation of the candidate image data so as to conform to the same geometric reference frame in which the reference registration is stored. The question exists: What should the reference frame (or grid) be? Alternative reference frames might, for example, be:

- Defined by the specific geometric characteristics of the present viewing geometry and sensor.
- Defined by a specific application convenience.
- Defined by a more general geodetic reference grid which has more general applicability to a variety of sensors and system applications.

The last alternative is judged to be most advantageous. Typically, it will involve the geometric correction of candidate image data by a rectification process and also storage of registration reference data (i.e., ground control points) in a reference frame which is everywhere ortho-normal to the local earth geoid vertical. In principle, such rectification can be accomplished by optical, analytic (i.e., digital), or hybrid optical/analytic techniques. Commercial optical rectifiers, of various types, for example, are widely available. However, it is presently expected that only the analytic (digital) techniques will provide the high operational speed, the precision and operational flexibility needed for the present demonstration. Hence, only digital techniques will be considered here.

Approaches to the present registration problem which do not incorporate rectification would likely be not only difficult to implement, but would also result in output image products which have limited utility to most image data users. Consequently, a significant part of the problem to be solved can be viewed as an extension of the much studied image rectification[1] problem. Some of the sources or modifying effects of image distortion which give rise to rectification needs are outlined in Table 5-1.

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(1) The term rectification is used here to refer to transformation of an image to a horizontal frame of reference so as to remove distortion effects of non-normal viewing angles.

Table 5-1. Image Distortion Causing Factors

- <u>Viewing Geometry and Vehicle (Platform) Related Causes</u>:

  <u>Static Causes</u>:

  - Off-Normal Perspective Errors (Obliquity)
  - Curvature of Earth
  - Attitude and Pointing Errors
  - Ephemeris Errors

  <u>Dynamic Causes</u>:

  - Uncompensated Image Motion Errors (uniform and oscillatory)
  - Dynamic viewing geometry (e.g. scene "blooming," scene "twisting")
  - Earth rotation

- <u>Sensor and Optics Related Causes</u>:

  <u>Statis Causes</u>:

  - Optical misalignment and distortions
  - Image plane curvature
  - Sensor misalignments and instabilities

  <u>Dynamic Causes</u>:

  - Dynamics of sensor sequential sampling

- <u>Ground Terrain Causes</u>:

  <u>Static and Dynamic Causes</u>:

  - Terrain relief

Note that the "dynamic" causes as listed in the table are of concern for images detected in some finite time sequencing mode (e.g., by line scanners or sequential readout solid state arrays), but would be of no concern to an ideal instantaneous parallel operating sensor (e.g., a high speed photographic framing camera).

Terrain relief as a cause of distortion is listed separately because of the unique rectification problem that it presents: In general, distortion due to terrain relief cannot be removed by monoscopic imagery only; rather, it requires stereoscopic image data. Some consideration should be given to limiting the initial Spacelab image registration demonstrations to relatively flat terrain so as to avoid this complication. This may not be as limiting as it may at first seem, since many scenes of earth observation interest have relatively featureless relief (e.g., prairies, agricultural flatlands, river estuaries). More advanced demonstrations could make use of stereoscopic imagery to compensate for terrain relief.

Consider next what capabilities the proposed demonstration might also require in addition to a near real time capability to rectify a candidate image to a horizontal plane. These additional near real time capabilities are:

- Radiometric correction of each pixel to remove variation in sensor responsitivity (if excessive for a specific sensor) and also adverse effects and variations in scene illuminations (e.g., haze, shadows, etc.)

- Rotation of image about an axis normal to horizontal reference plane to provide proper north-south alignment.

- Image scale factor adjustment to compensate for variations in ephemeris (especially altitude) of satellites.

- Image cell-by-image-cell registration of the current rectified image relative to the corresponding reference registration frame.

The second and third of these operations can be incorporated as part of the rectification function. The fourth operation represents the most unique aspect of the present demonstration and possibly its greatest technical challenge.

5.3 ALTERNATIVE SENSING TECHNIQUES AND THEIR IMPACT ON RECTIFICATION AND REGISTRATION

For the present demonstration, only electro-optical image sensing devices are considered appropriate. Photographic or other hard copy producing techniques are not sufficiently compatible to the real time needs of the demonstration. Furthermore, imaging tube techniques including vidicons and image orthicons generally have significant level of variable distortion which makes them unattractive for this demonstration. Consequently the sensors which are considered here are limited to the following types:

- Optical-mechanical scanners including Landsat's Multi-Spectral Scanner (MSS) and the more advanced Thematic Mapper.

- Solid State Detector Arrays such as CCD's and photo diode arrays having readout capability limited to conventional line sequence scanning.

- Solid State Detector Arrays of the Charge Injection Device (CID) type having other readout options in addition to conventional line scan sequence including random access readout and transform (e.g. Hadamard) readout capability.

Two general approaches to the demonstration will be discussed below. The first approach assumes a sensor having readout capability limited to a conventional line scan sequence. This general approach is applicable to the optical-mechanical scanners and also to the more conventional solid state array detectors such as CCD's and photodiode arrays. It will be shown that this approach has extremely high demands on data processing rates. Consequently there is increased interest in identifying an alternative approach which makes use of advanced sensors which can, in effect, process data in the image plane and hence relax the computer requirements. The second approach is based on the availability of a solid state array detection of the CID type which has this potential. This approach takes advantage of the random access readout capability of that device.

The general approach is based on performance of these data processing operations in near real time:

- Sense the image data in multispectral bands. Two alternative approaches are considered for the demonstration: a line scan instrument and a CID type of solid state detector array.

- Provide radiometric correction to compensate for variations in sensor performance (radiometric correction not expected to be needed for CID application).

- Rectify the currently sensed image based on available geometric data (e.g. ephemeris, attitude and pointing angles and sensor characteristics).

- Further reduce the geometric errors and register this rectified image relative to the appropriate reference registration by use of pointing and ephemeris data and/or ground control point data.

Certain potential alternatives for accomplishing these functions will be considered here. To a significant extent these alternatives are based on capabilities of alternative sensors. The material to follow in this section will describe the two alternative approaches considered for the demonstration.

5.4 IMPACT OF POINTING AND EPHEMERIS ERRORS ON IMAGE REGISTRATION

If the absolute pointing direction of the satellite-borne optics and sensor and the satellite ephemeris were continuously known and/or controllable without errors and if there were no land area mapping errors, then the potential would exist for achieving image registration without any need for extracting misregistration data (e.g., by cross correlation) from the sensed imagery. The purpose of this section is to explore the impact of such errors on registration.

One specific objective is to provide insight into the registration performance which is potentially possible without such data derived from the imagery itself. Image registration can, in principle, be obtained by either of two general methods:

- "Mechanical" - by precisely orienting the optics and sensor so that at least some one point on the image plane has the same x,y location that it had on some prior stored image data.
- "Analytic" - by appropriately ordering and/or "labeling" the imagery data (i.e., in digital form) so that its registration location is known in an "analytic" mode relative to the prior stored imagery.

The first of these methods requires some control of the sensor pointing if not control of the ephemeris (which is rather unlikely). The second method requires precise knowledge of ephemeris and pointing as well as significantly less precise control of pointing for image acquisition purposes.

It is judged that this second or "analytic" approach is an acceptable approach if the registration data is integrated into the imagery bit stream in the same manner as normal for transmission and storage of unregistered imagery data.

The alternative of providing registration correction data as a separate data stream (e.g., a registration correction tape) is judged to be unacceptable from a data users point of view.

The analytic approach is definitely favored as permitting more precise registration with less burden on incorporating ultra-high precision instrument pointing controls. It is also more compatible with the favored analytic techniques for rectification as contrasted with optical rectification methods.

Figure 5-1 shows how maximum allowable error in ephemeris knowledge varies as a function of the specification of misregistration and viewing angle measured from the vertical. This plot assumes no sources of error other than ephemeris. To a first order approximation (error less than 1%) the maximum allowable in-track and cross-track ephemeris errors are independent of viewing angle, whereas the maximum allowable vertical component of ephemeris error decreases significantly with viewing angle as shown.

Knowledge of ephemeris for Spacelab will depend upon specific navigation techniques employed. However, the expected potential accuracies are listed in Table 5-2. Based upon the performance as shown here, it is expected that ephemeris errors resulting from the use of the Spaceflight Tracking and Data Network (STDN) and the Tracking and Data Relay Satellite (TDRS) will be so great that some form of registration data extraction from imagery data will be necessary to reduce errors from the initial acquisition conditions. This is true for registration specifications which are less than about 500 to 1000 meters (which probably includes most realistic image registration application needs).

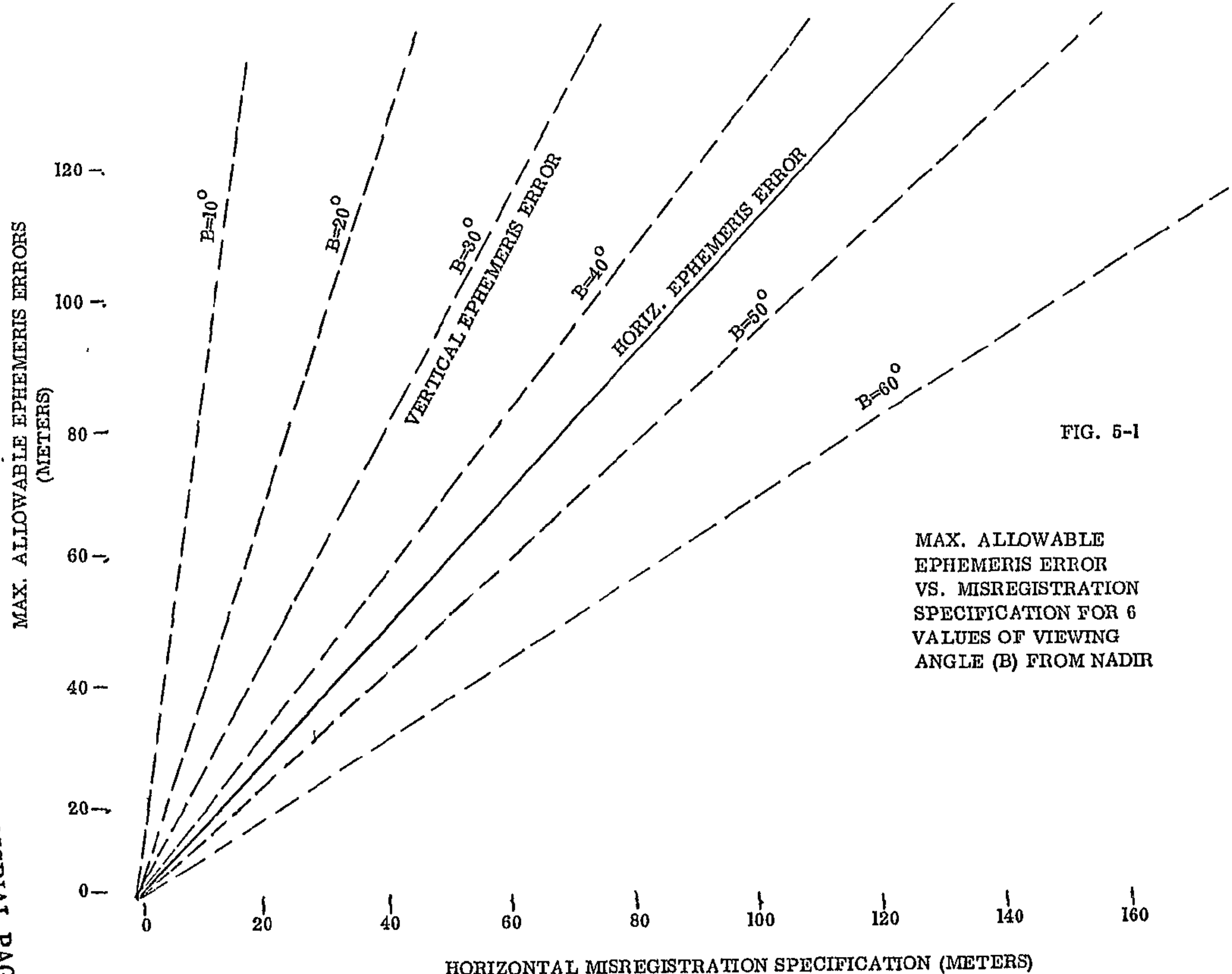


FIG. 5-1

MAX. ALLOWABLE EPHEMERIS ERROR VS. MISREGISTRATION SPECIFICATION FOR 6 VALUES OF VIEWING ANGLE (B) FROM NADIR

TABLE 5-2

EXPECTED ON-ORBIT NAVIGATION ACCURACIES (3 SIGMA)

FOR SPACE TRANSPORTATION SYSTEM (FOR 100 N.M. ALTITUDE)

NAVIGATION SYSTEM	Position (Meters)				Velocity (Meters/Sec)			
	Altitude	In-track	Cross-track	RSS	Altitude	In-track	Cross-track	R.S.S.
SPACEFLIGHT TRACKING & DATA NETWORK (STDN)	130-150	370-850	430	730-1030	1.2-1.3	0.5	0.6	1.3
TRACKING & DATA RELAY SATELLITE (TDRS)	90	430-610	460	630-740	0.5 - 0.7	0.1	0.15	0.5-0.7
GLOBAL POSITIONING SYSTEM (GPS)	7-15	7-15	7-15	12-25	0.05-0.08	0.05-0.08	0.05-0.08	0.09-0.16

* Adapted, in part, from Space Transportation Users Manual - Aerospace Corp.

However, the use of GPS. when fully operational in the mid-1980's can be expected to eliminate ephemeris errors as a source of registration error for many application needs (i.e., when 3 sigma registration needs are less than about 10 to 20 meters).

Figure 5-2 shows how maximum allowable error in pointing varies as a function of misregistration specification and viewing angle from vertical. This assumes no other source of misregistration and data is shown for an altitude of 265 KM and 750 KM. These represent the expected extremes of altitude at which this demonstration might be performed on Spacelab. Pointing errors of concern include pointing stability, knowledge of pointing angle and control of pointing. Stability has to do with the magnitude and rate of change of non-steady pointing errors and is typically of a relatively high frequency (i.e., jitter). The magnitude of jitter is to a large extent a function of the weight, torque and mechanical mounting technique of the sensor on its pointing system. Typical pointing stability capabilities are presently reported in "Space Shuttle Experiment Pointing Mount (EPM) Systems, An Evaluation of_Concepts and Technologies" (701-1) Jet Propulsion Laboratory, April 1, 1977, to be in the range of 0.4 to 3 arc secs (peak). Improvement in pointing control technology is predicted that will reduce such instability amplitudes to about 0.02 arc seconds by the early 1980s. These improvements are listed as in design of high bandwidth adaptive flexible body stochastic control technology, lower noise and lower drift gyros, improved linear drive motor and improved solid state array star trackers. Based upon these forecasts, as well as the allowable pointing error trade data of Figure 5-2, it is expected that sensor pointing probably can be sufficiently stabilized to meet the requirements of the demonstration. However, this should be reviewed again when angular ac-

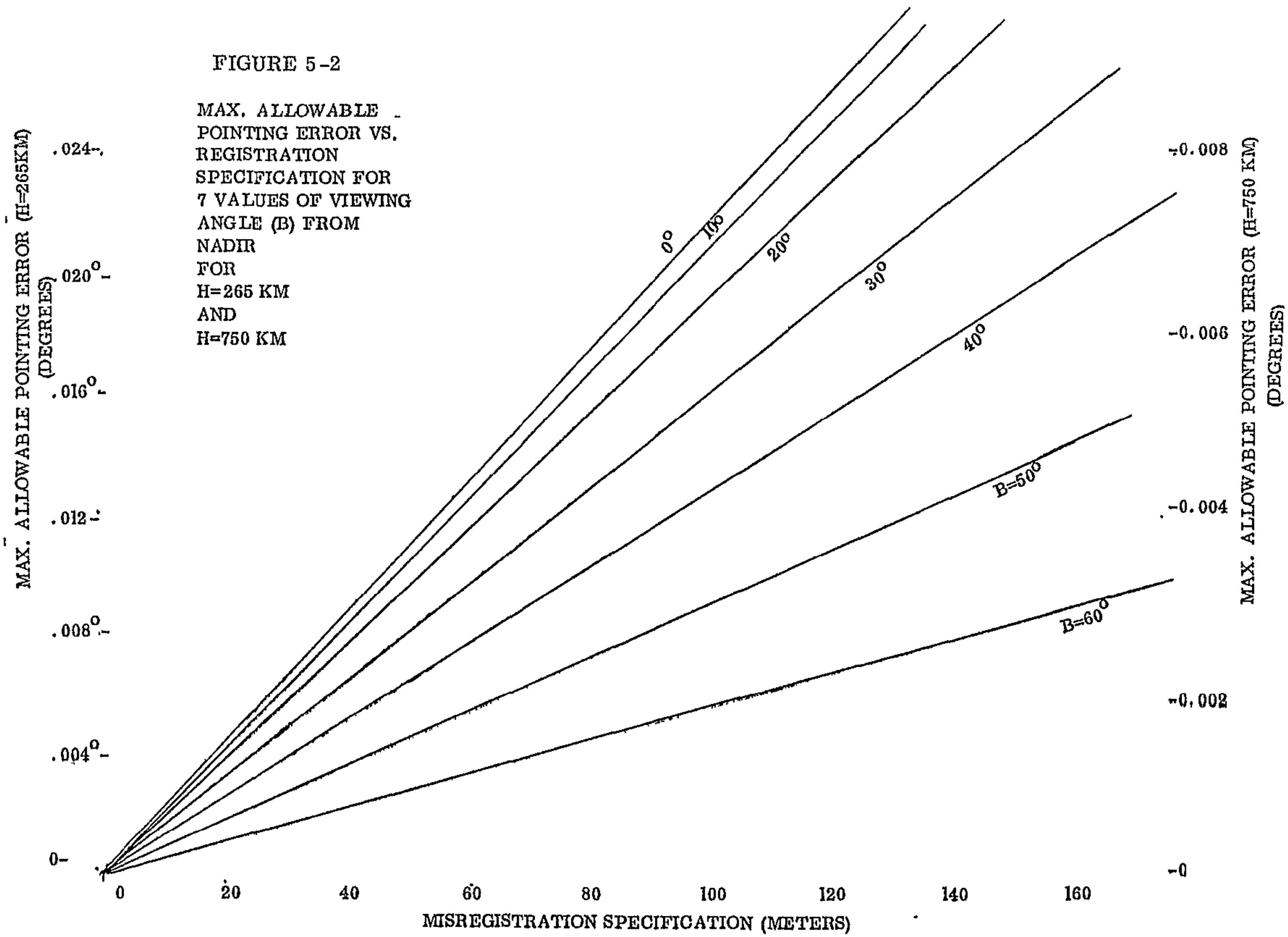


FIGURE 5-2

MAX. ALLOWABLE POINTING ERROR VS. REGISTRATION SPECIFICATION FOR 7 VALUES OF VIEWING ANGLE (B) FROM NADIR FOR H=265 KM AND H=750 KM celerations and setting time are further defined for the demonstration, since these will affect the jitter response.

Accuracy with which pointing will be determined primarily by performance characteristics of specific gyros (e.g., drift, resolution) and star trackers, as well as uncertainties in alignment of the payload sensor and the attitude reference sensors. The previously cited reference indicates specific NASA mission payload pointing determination requirements as follows:

- 7 payloads: 1 to 3 arc sec. pointing accuracy
- 14 payloads: 3 to 30 arc sec. pointing accuracy
- 80 payloads: 30 arc sec. pointing accuracy

Current attitude sensors can provide attitude information with resolution in the range of 0.01 arc seconds. A NASA proposal for developing a 0.001 arc second resolution sensor has been made. "Navigation, Guidance and Control" NASA-OAST Summer Working 1975 Vol. III, p. 70. This would be for use with the Large Space Telescope (LST) or other inertially stabilized experiment. For the presently planned demonstration, which has non-inertial stabilization requirements, an accuracy specification of attitude determination in the neighborhood of 0.0025° is judged as realistic.

In summary, these realistic assumptions are made:

- Spacelab incorporates GPS to provide 3 axis ephemeris errors (3 sigma) of 20 meters.
- A high accuracy stellar referenced inertial system can provide absolute attitude accuracy (3 sigma) directly at the sensor of 0.0025° (= 9 arc secs).
- Image sensing viewing angle from vertical is restricted to a maximum of 45°.

Then, for 265 Km altitude, error registration of at least one point on the image, with 3 sigma errors of 35 meters can be anticipated. Conceivably this might be reduced to a probable minimum value of about 20 to 25 meters if significant improvements in both BPS and attitude reference capability were assumed. A tentative conclusion is made that registration accuracy of about 25 to 35 meters can be achieved without extracting correlation type of data from the imagery when operating at 265 Km. Thus, the potential exists of meeting the registration goal of 26 meters based primarily on application of ephemeris and attitude data if the Spacelab were operating at 265 Km.

Operating at much higher altitudes (e.g., the near maximum altitude of 750 Km would lead to significantly increased misregistration errors due to attitude errors. The misregistration contribution of a 0.0025° pointing error and a 45° viewing angle would be 65 meters.

In order to meet misregistration performance specifications from 750 Km altitude, the error in pointing determination would have to be no greater than about 0.0008°.

Based on the above, the total (3 sigma) misregistration error contributed by sensor attitude and vehicle ephemeris errors is tentatively listed as:

at 750 Km:	70 to 90 meters
at 265 Km:	25 to 35 meters

TWO ALTERNATIVE APPROACHES DEPENDING ON REGISTRATION PERFORMANCE REQUIREMENTS

- PRIMARY INPUTS FOR MODERATE PERFORMANCE
  - EPHEMERIS
  - POINTING
- PRIMARY INPUTS FOR HIGHER PERFORMANCE (e.g. MISREGISTRATION <~30 M. AT 265 KM ALT. <~80 M. AT 750 KM ALT.)
  - EPHEMERIS
  - POINTING
  - SCENE DATA (i.e. GCP's)

NEED GCP's FOR MOST APPLICATIONS

5.5 AN APPROACH BASED ON SCANNER TYPE IMAGE SENSORS

5.5.1 Introduction

The first demonstration approach being considered would make use of scanning type sensors such as the Multi-Spectral Scanner (MSS) which is the primary sensor of the Landsat Earth Observation Program and the more advanced Thematic Mapper. The specific scanner to be considered will depend on the state of development and availability of the Thematic Mapper at the time of the planned demonstration. For the present demonstration, it is proposed that the scanning sensor be mounted on the instrument pointing system of the Spacelab such that its view can be centered about the nadir when the Spacelab is in its normal operational attitude.

These two types of scanning sensors and specific modifications considered for the present demonstration are described briefly in Appendices C and D. The most obvious differences between them are the higher resolution, greater number of spectral bands and the higher sensed data rate of the more advanced Thematic Mapper as compared to the MSS. However, because of significant similarities in their principles of operation, the same general approach to data processing can be assigned to systems using both sensors. Differences will exist in some details of correction algorithm and, most especially, in data throughput rates.

Since it is a more advanced instrument, there might be some tendency to favor the Thematic Mapper for the present demonstration. However, this interest is somewhat tempered by its significantly less mature level of its development and correspondingly less general availability of its operating characteristics and predicted performance. Hence, at this point it seems wise to consider both the MSS and the Thematic Mapper.

The proposed demonstration differs from current and planned future application of MSS in two respects: It requires real time data processing, and it requires the processing of all data on board the spacecraft.

The material of this section describes the approach based largely on the application of "pipeline" data processing, by which the real time operation would be accomplished.

5.5.2 An Overview of Processing of Scanner Data

As shown in Figure 5-3, the overall processing system can be conceived as being designed around a high throughput "pipeline" data processor which has the role of processing the sensed data. The term pipeline processor is used here to mean a data processor consisting of an interconnected chain of sub-processors each of which performs its own assigned function before transmitting its processed output data stream to the input of the next logically following sub-processor. It is characteristic of a pipeline processor that there be no "reverse" flow of data at any point in the processor. It is the planned requirements for the present pipeline processor that each sub-processor perform its assigned computational functions with a throughput rate which is consistent with the data collection rate of the sensor. No buffering of data should be required specifically to compensate for any computational function which operates at less than real time rates.

Pipeline processors of the type planned for the present demonstration are typically controlled and "serviced" by a "control and ancillary processor." The pipeline pixel processor, which is the heart of the system, is a synchronous

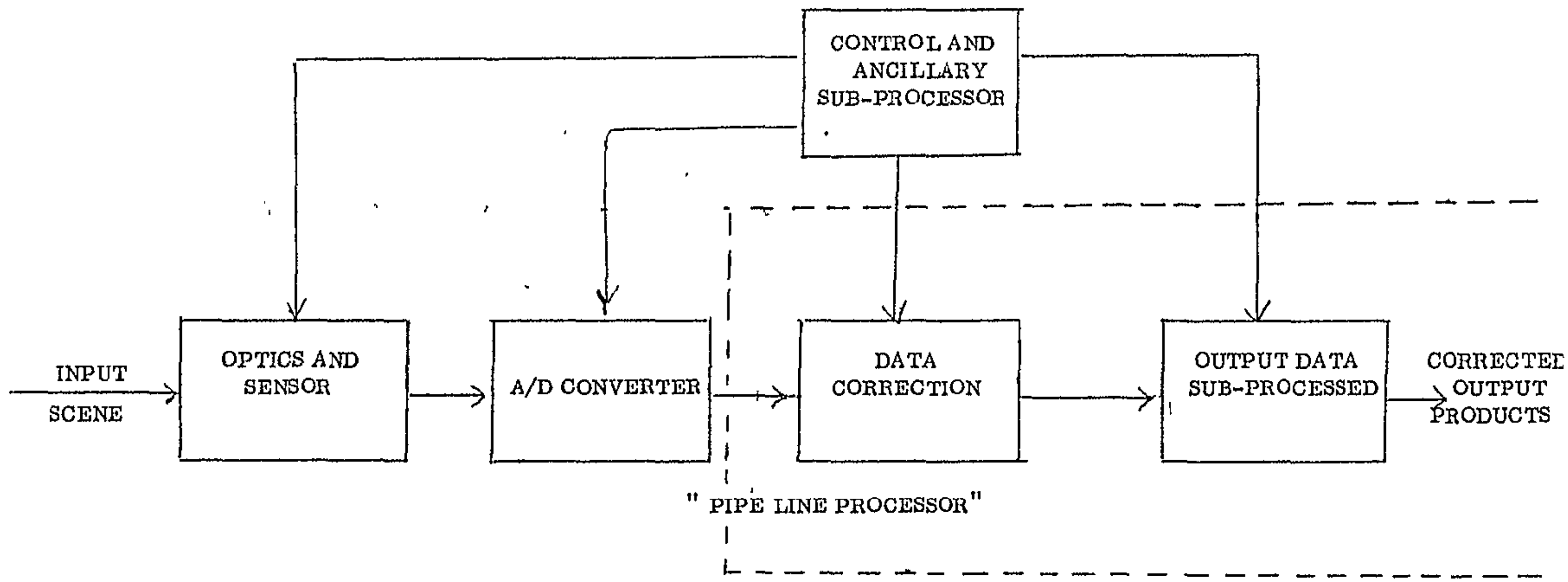


Fig. 5-3

OVERALL CONCEPT OF DATA PROCESSING BY THE PIPELINE PROCESSOR

processor in which each stage is clocked simultaneously at the sensed pixel rate. The basic system timing reference is the pipeline control clock. This results in the pipeline operating as the master and the remaining elements of the system as slaves from a timing standpoint. The pipeline controller consists of a shift register or synchronizer and a set of frequency scalers and counters which generate the necessary timing signals to all elements so that synchronization is maintained. Further, the data processing is structured around the picture element frequency with all remaining frequencies being scaled by integer multiples of the pixel rate.

In addition to providing basic control operations for the pipeline processor, the control and ancillary processor also provides computation of supportive data needed by the pipeline processor. As discussed below, such computations may be in principle, either pre-computed off-line or alternatively may be computed in real time. The inputs to the pipeline processor are derived, as shown in Figure 5-3, from the sensor and digitized at real time rates in the A/D converter. The outputs are formulated to meet output specifications by the output data sub-processor.

Figure 5-4 shows in somewhat more detail the function to be performed by a pipeline processor. The calibration function is designed primarily to compensate for variations in gain and bias which may exist from sensing element to sensing element. Calibration is needed to provide the image fidelity required not only by the ultimate user but also by the GCP correlation computation.

As discussed below, geometric correction (i.e., dewarping) may be designed as being performed in either one or two stages depending on whether or not attitude and ephemeris data is sufficiently accurate to preclude the need for

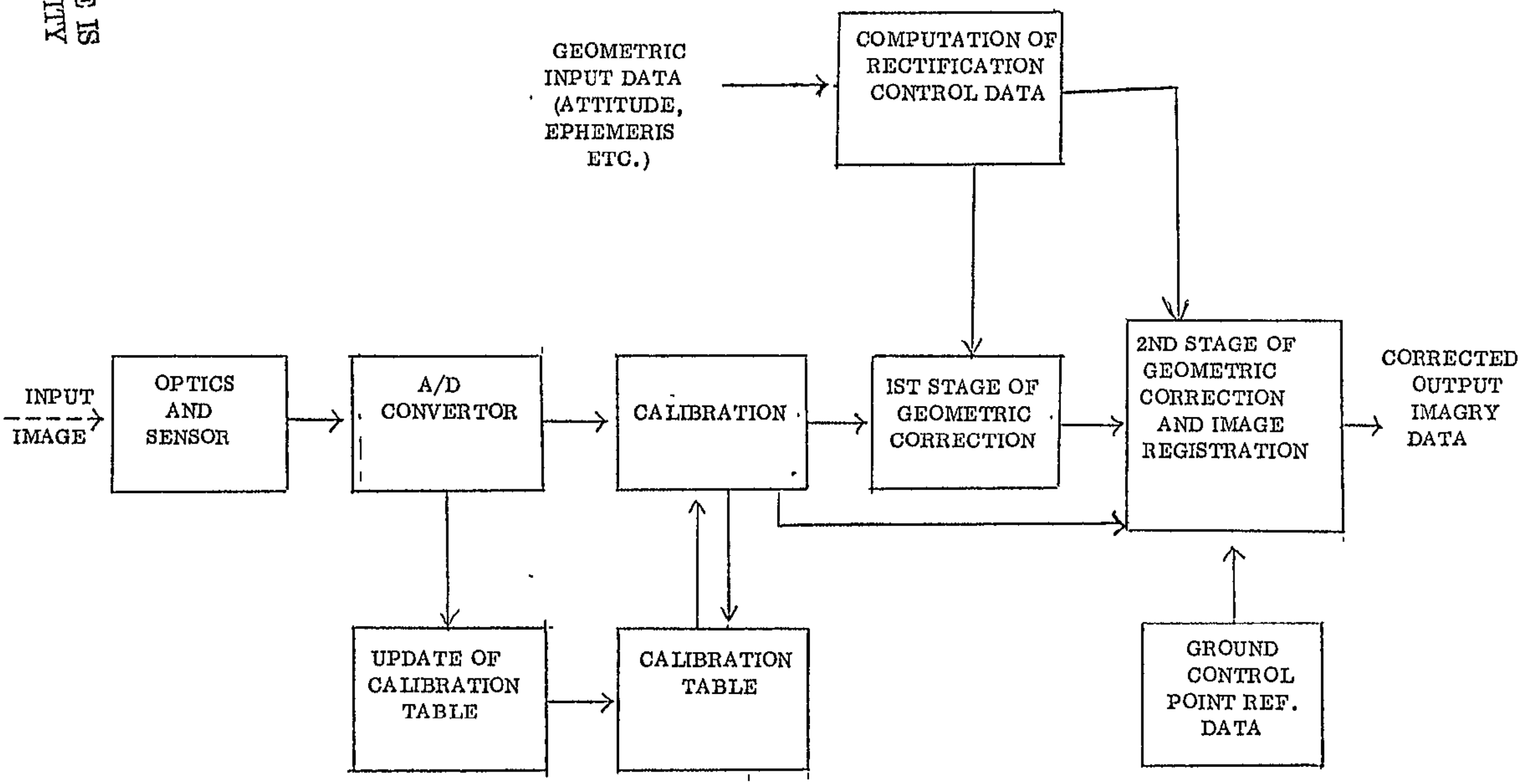


FIGURE 5-4

A MORE DETAILED DESCRIPTION OF THE FUNCTIONS OF A PIPELINE PRODUCER

GCP's (cf. discussion on impact of attitude and pointing errors in Section 5.4). In the baseline demonstration it is assumed that, primarily due to the effect of pointing errors, use of GCP's will be required for the present demonstration.

The first stage makes use of available geometric data including attitude and ephemeris data as well as scanner model data to compute geometric corrections. When two stages of geometric correction are needed, it is necessary to provide this first stage of correction only in the vicinity of the GCP's. This is so because the second stage of correction makes use of GCP's to correct the original non-geometrically corrected images. However, the first stage of correction is needed so as to permit correlation of the reference GCP's with the candidate image. If altitude and ephemeris data are sufficiently accurate for the altitude of the Spacelab, then this first stage of correction is the only stage and correction of the entire image is performed since GCP's are not needed.

The geometric correction coefficients derived from this geometric data may, in principle, be either computed on line in real time, or alternatively for a sufficiently well pre-planned mission, pre-computed off-line. Based on simulation results for similar corrections for another application, this first stage of correction is expected to reduce initial maximum geometric errors to the range of 2 to 10 pixels.

A second stage of geometric correction has the objective of further reducing geometric errors to the sub-pixel range and also to register the image to the ground control points (GCPs) and hence to achieve not only a high degree of geometric correction but also the desired pixel registration. The approach here is to make use of (GCPs) and pixel resampling techniques. The same type of GCP data obtained from prior "reference" imagery data is used to provide the needed registration and geometric correction of image data. The GCP's, when correlated with the candidate, provide a set of "anchor points" by which the image can be corrected of geometric errors by polynomial interpolation.

5.5.3 Radiometric Calibration

Radiometric correction must remove intensity errors introduced into the data by the scanner, and possibly also by the atmosphere, and other noise sources during the collection process. For these scanners, three types of calibration data may typically be utilized to remove errors in radiometry: (1) calibration wedge data contained in the video data stream for removing detector-to-detector variations (destripping);(2) sun calibration coefficients for absolute system response; and (3) area shading and illumination coefficients for removing errors caused by such sources as sun illumination angle, scan angle geometry and the atmosphere. Of these, stripping errors caused by the detector-to-detector variations are the most significant for scanning sensors. The initial emphasis for radiometric correction in both the hardware and software systems will be on destripping corrections. The coefficients to implement atmospheric and illumination corrections can be derived and these corrections can be implemented should that be necessary. The SDTF data processor should be sized to accommodate the radiometric calibration for the demonstration presently being considered. However, the most effective approach to achieving real time on-line operation for an operational system may be to provide separate parallel dedicated A/D conversion and calibration data processing for each sensing element (i.e., 24 parallel channels for MSS and 20 parallel channels for the Thematic Mapper). This can provide a simple approach to A/D conversion and calibration without a need for data interleaving or data buffering. For an operational system dedicated especially designed micro-processor chips should be considered to perform the calibration function.

The calibration procedure considered here is adapted from techniques previously developed for off-line radiometric correction. As in the case of present ground data processing procedures, a table look-up calibration technique is considered for present planning purposes. The table look-up function involves two functional operations:

- o Continued updating of the calibration look-up table.
- o Utilization of look-up table data for radiometrically correcting the sensed data in real time.

The operation of radiometric correction is summarized in the simplified schematic diagram of Figure 5-5. It is described in somewhat more detail in Appendix E.

It is recognized that there are also under development or in preliminary stages of utilization other more advanced calibration techniques which make use of scene dependent data. These should be evaluated further at some future time as to their suitability for the present application.

5.5.4 Geometric Correction - Principles of Operation

Following the calibration correction described in 5.5.3, the next correction operation in the pipeline sequence is the "first stage" of geometric correction. In the baseline demonstration the function of geometric correction is to reduce the image distortion (i.e., "dewarp" the image) in the vicinity of the GCPs caused by the various factors listed in Table 5-1. Specifically the "first stage" of geometric correction is based upon the utilization of available geometric reference data such as ephemeris, attitude and instrument

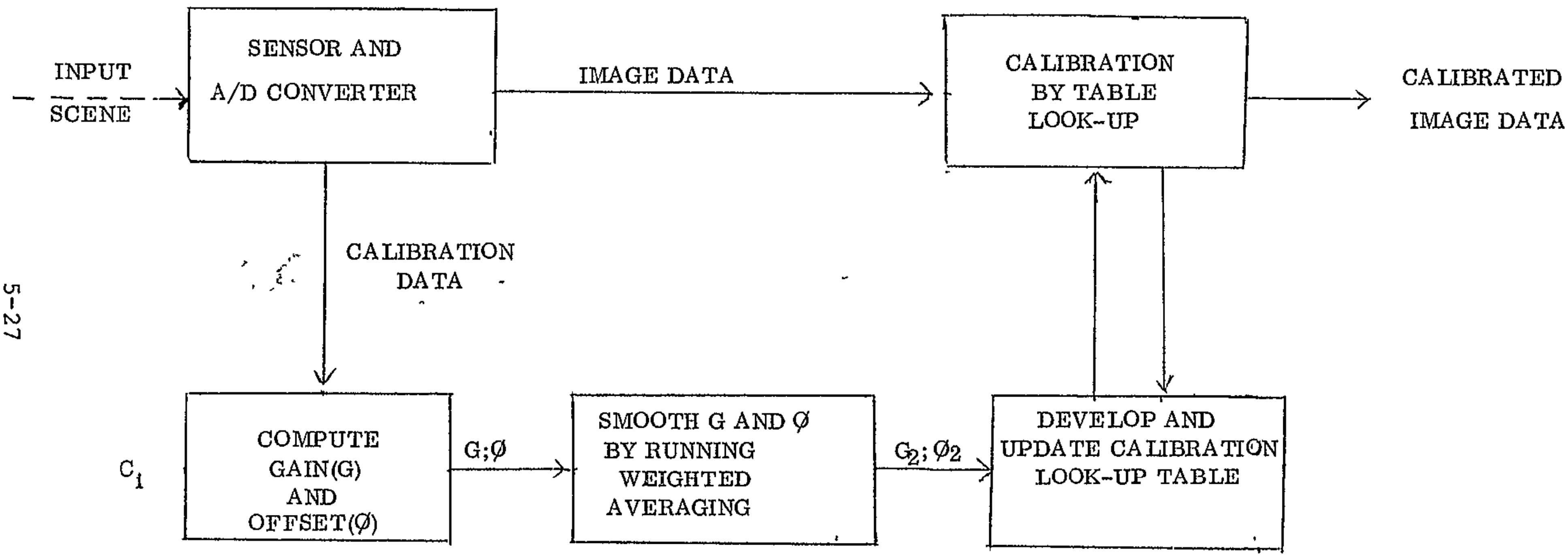


Figure 5-5

RADIOMETRIC CORRECTION - SIMPLIFIED SCHEMATIC pointing data. As discussed in Section 5.4, when operating at 750 Km altitude the potential exists for this stage of correction to reduce maximum geometric errors in the vicinity of GCPs to the range of 70 to 90 meters (3 sigma). If operating at 265 Km the potential exists for reducing this error to the range of 25 to 35 meters. Use of data which is incorporated in the imagery for a subpixel second stage of geometric correction is discussed in Section 5.5.6.

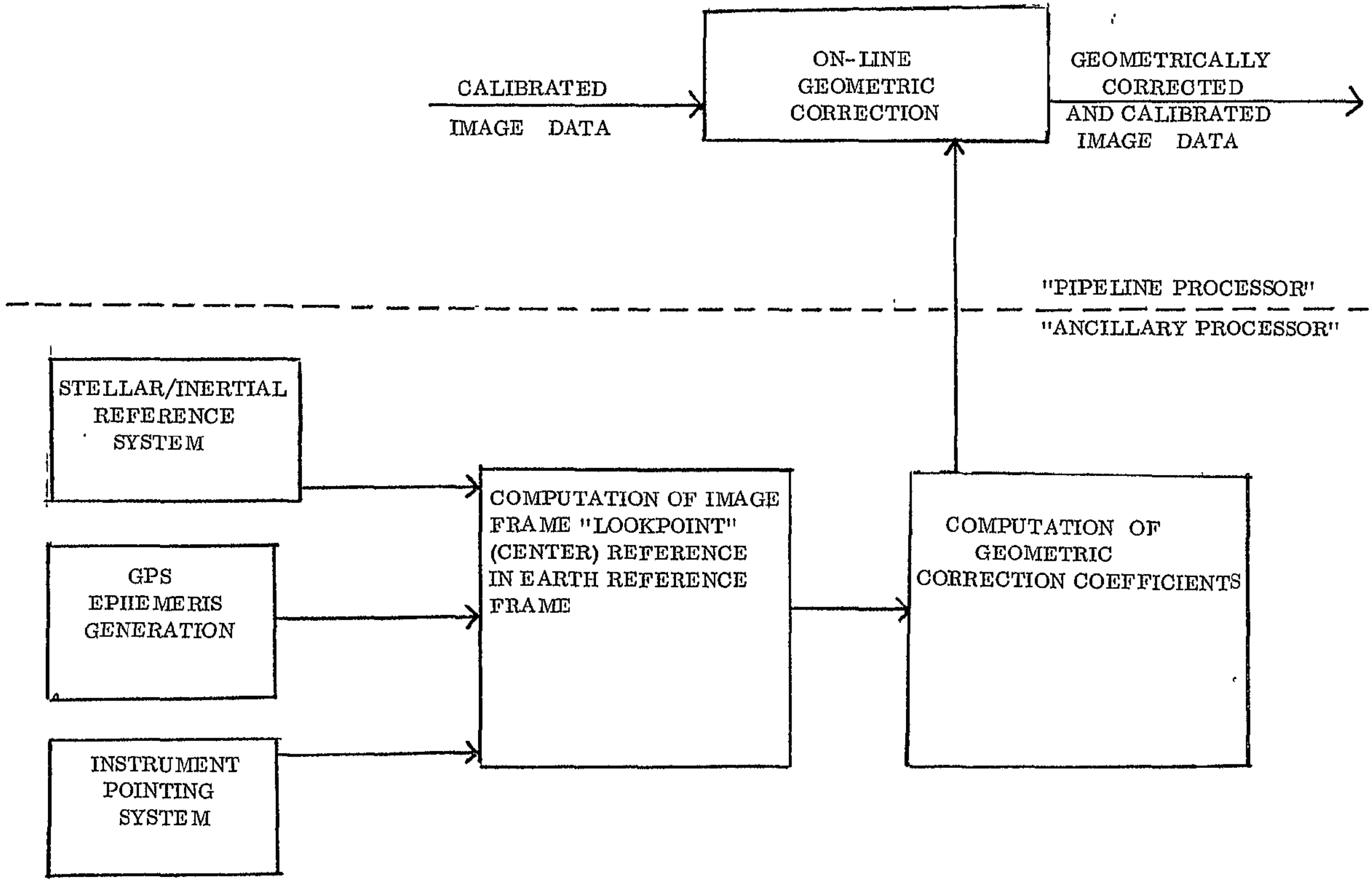
In a manner analogous to calibration correction geometric correction proceeds on the basis of two functional operations:

- Computation of geometric correction control data (correction function) in the form of correction coefficients.
- On-line application of these coefficients to dewarp the sensed imagery data in real time.

The correction function is a function which describes the geometric errors present in a given input scene and the corrections required to remove the geometric distortion in the output scene. It is generally a function of the viewing geometry and the operating characteristics of each specific sensor and its optics. In general it will be necessary to redefine the correction function for each new sensor being considered. This procedure, which is adapted from an approach previously developed for off-line operation, is described in the simplified schematic of Figure 5-6. This procedure is described in somewhat more detail in Appendix F. Typical approaches to generation of geometric correction functions are discussed in Appendix G.

5.5.5 Second Stage of Geometric Correction and Image Registration

This operation makes use of information which is contained in the imagery data to improve the geometric correction and also to provide registering of the imagery relative to prior stored reference imagery (the "reference scene").



FIRST STAGE OF GEOMETRIC CORRECTION

FIGURE 5-6

Registration here refers to location tagging certain key pixels in the imagery being corrected so as to be locatable relative to the reference imagery. This constitutes the third operational stage of the pipeline processor. As in the other operations, it consists of two functions:

- o Computing the registration error between the ground control points (GCP) of the reference and the image being corrected and registered (i.e., the "registrant").
- o Implementing the geometric correction and appropriately tagging the registrant image data to register it relative to the "reference."

The second of these operations is similar to the correction operation discussed for the first stage of geometric correction. The first operation, however, involves a correlation between the candidate image and the reference image GCP data. Based on previous work, the computational approach to image correlation which is favored is that of a modification of the Similarity Detection Algorithm (SSDA).* It computes the similarity of the reference GCP and each similarly sized sub-array of the candidate, lying within the expected error bound resulting from the first stage of correction. The similarity measure is given by:

$$SIM(\mu,v) = \min_{S} \left[\sum_{n=1}^{s} \left| GCP(RI(s), RJ(s)) - SRH(\mu+RI(s), v+RJ(s)) \right| > T(S) \right]$$

When RI and RJ form a random ordering of GCP pixel coordinating and T(s) is a monotonic increasing threshold function.

The results of the first stage of correction are expected to have errors of less than about eight pixels. Prior effort has also shown that GCPs which are defined in eight bits over an 8 x 8 array are effective in providing the needed similarity function. Therefore, the data storage for each GCP is only

*This algorithm is modified from the SSDA as described in: "A Class of Algorithms for Fast Digital Image Registration", D.I. Barnea, H.F. Silverman, IEEE Transactions on Computers, vol. C-21, No. 2, Feb. 1972, pp 179-186.

512 bits. For the planned flight demonstration it is expected that fewer than 50 GCP's would be needed. This is based on a total demonstration operating time of about 800 seconds. This discontinuous period of operation is selected as that necessary to collect and operate on imagery of a wide range of terrain types and under a wide range of viewing conditions. A preliminary evaluation indicates that providing a GCP on average of every 20 seconds would suffice to meet the demonstration objectives. This includes a contingency factor of 25% to compensate for non-availabili of certain GCPs due to adverse weather or other factors. Thus the total storage needed for GCPs will be less than about 10^4 bits. As a result of the first stage of geometric correction, candidate sub-array areas of 16 x 16 pixels will be defined. As discussed, the initial flight demonstration can be expected to be performed with 10 GCP correlation operations. For each sub-area a buffer storage of 2048 bits will be required.

The modified SSD similarity measure operates as follows: For each possible positioning of the 8 x 8 GCP matrix relative to the 16 x 16 candidate sub-array area a summation of intensity differences of corresponding pixel pairs is made. An identity of the reference GCP and a specific 8 x 8 sub-array of the 16 x 16 sub-array would provide a zero difference. In actual practice a minimum value in the similarity computation is used to indicate correlation. To improve registration to the sub-pixel level, a two dimensional curve fitting can be made in the vicinity of the minimum point. The minimum of the fitted curve indicates registration, ideally to within a fraction of a pixel.

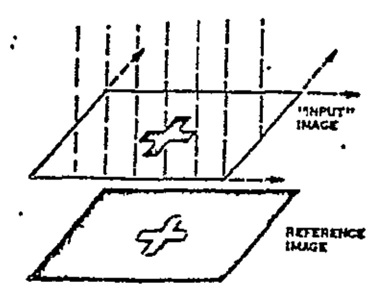
As in the case of the first stage of correction, the image geometric points between GCP correction are performed by linear interpolation in 2 axes (bilinear interpolation). Some question may exist as to the effectiveness of the modified SSDA to provide the needed sub-pixel registration. In the event that further analysis demonstrates its inability to meet this performance, then some further form of image correlation may be required.

5.5.6 Data Processing and Storage Needs

The real time data processing and storage needs are the most critical aspects of the proposed demonstration. Table 5-3 summarizes these needs for a demonstration based on application of the MSS. Table 5-4 summarizes the data storage needs. As expected, the most severe data handling requirements are associated with the two application stages of geometric correction. These two operations combined are shown as requiring some $4.6 \times (10^7)$ equivalent ADDS of 8 bit words per second for the MSS. For a demonstration based on the Thematic Mapper an arithmetic capability equivalent to $5 \times (10^8)$ ADDS is projected. These are massive computational capabilities which are well beyond the capability of any known existing or projected spaceborne data processor. By way of contrast, for example, very large ground-based central processing units are capable of performing in the neighborhood of 10^6 to 2×10^6 equivalent ADDS/sec.

It is concluded that the approach to demonstration of real time image registration as described here with MSS or thematic mapper types of sensors will begin to be promising only with the development of massively powerful spaceborne data processors which would likely be of the pipeline processor type of machine. For this and other reasons discussed below, it is appropriate to consider the applicability of a sensor, which in effect combines image sensing and some degree of image data processing in the sensing image plane. Such an approach is discussed next.

IMAGE REGISTRATION



MAIN CHALLANGE FOR ON-LINE REGISTRATION:

HOW TO HANDLE (OR AVOID) MASSIVE DATA PROCESSING REQUIREMENTS

Table 5-3
REGISTRATION DEMONSTRATION USING SCANNER TYPE OF SENSOR
PRELIMINARY ESTIMATE OF DATA PROCESSING NEEDS
(ASSUMES MSS TYPE OF SENSOR)

FUNCTION	COMPUTATION INPUTS	COMPUTATION OUTPUTS	COMPUTATION PERFORMED	FREQ. OF COMP. (PERIOD)	MIN. WORD LENGTH(B)	NUMBER OF MULTIPLICATIONS	NUMBER OF ADDS	EQUIV. NO. OF ADDS*	NO. OF EQUIV. ADDS/SEC.
GPS Ephemeris Generation	Inputs from NAV Stars: Timing Data, Navstar Epheridies, Etc.	Spacelab location in earth coord. (~5M Granularity)	Recursive Nav. Algorithm	Once per 10^{-3} Sec, to once per 10^{-4} Sec with GPS updates at 10^{-1} SEC	16 to 32	With GPS update 360 Orbit mechanics only 9	90 9	4,000 once per GPS fix 3,690 at 10^{-1} sec intervals	4,000
SIPS pointing data (Stellar inertial) Computation	Gyro data, star crossing data inertial ref frame	SIPS pointing angles in stellar reference frame	Recrusive pointing algorithm	5×10^{-3} Sec	12	40	100	500	100,000
Aimpoint Computation	Ephemeris data, pointing data	Earth aimpoint in geocentric coordinates for Sips acquisition and control	Geometric Transformation	10^{-3} SEC 2×10^{-3} Sec	10	15	20	180	90,000
Computation of aimpoint errors	Present aimpoint Aimpoint Commands	Same as above	Vector Subtraction (2 dimentions)	2×19^{-3} Sec	10		10	10	5,000
Computation of pointing commands	Aimpoint error in Stellar/ Inertial frame	Commands to Sipa Gimbal Controls	Geometric Transformation	4×10^{-3}	8 to 10	15	10	160	40,000
Radiometric Correction Calibration Table Update (not expected to be for CID)	Calibration Data	Updated Calibration Look-up Table	Compute Gain and Offset and Smooth Same by running weighted averages	$\frac{(1)}{(14)}$ Sec	6	14	4	144	10,000

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Table 5-3 (Cont'd)

REGISTRATION DEMONSTRATION USING SCANNER TYPE OF SENSOR

PRELIMINARY ESTIMATE OF DATA PROCESSING NEEDS

(ASSUMES MSS TYPE OF SENSOR)

FUNCTION	COMPUTATION INPUTS	COMPUTATION OUTPUTS	COMPUTATION PERFORMED	FREQ. OF COMP. (PERIOD)	MIN. WORD LENGTH (B)	NUMBER OF MULTIPLICATIONS	NUMBER OF ADDS	EQUIV. NO. OF ADDS*	NO. OF EQUIV. ADDS/SEC.
Radiometric Correction Application	Uncorrected image data	Corrected image data	Look-up table	10^{-5} Sec	8	2	1	21	2×10^{6}
Computation of rectification control data	Spacelab attitude data, SIPS pointing angles in inertial space, ephemeris in earth coord., sensor model etc.	"Dewarping" correction coefficients for image benchmarks	Geometric Manipulations	2×10^{-3} Sec	8	30	40	340	170,000
1st application stage of geometric correction	Radiometrically corrected, but geometrically warped image data; rectification control data	Image data "de-warped" to within position error of about 8 pixels	Image pixel resampling in 2 axes	10^{-5} Sec	8	20	30	230	23×10^{6}
GCP correlation	Dewarped image data in vicinity of GCP's. Reference image data	GCP location errors in 2 dimensions	Sequential sample difference analysis (SSDA)	10^{-4}	8		8	6	80,000
2nd stage of geometric correction and image registration	Radiometrically corrected, warped image data, GCP location errors in 2 dimensions	Image data geometrically corrected and registered within fractional pixel errors	Image pixel resampling and re-registration in 2 axes	10^{-5}	8	20	30	230	23×10^{6}
								TOTAL	48.5×10^{6}

*Assuming a data processor with 10 adds equivalent to 1 multiplication.

TABLE 5-4
REGISTRATION DEMONSTRATION
DATA STORAGE REQUIREMENTS

- IMAGE BUFFER STORAGE (NOT NEEDED FOR CID's)
  - SIZED TO CORRECT A 1^{o} ROTATION, 40 LINES OF BUFFER STORAGE NEEDED

    10^5 BITS FOR MSS

    10^6 BITS FOR THEMATIC MAPPER

    RANDOM ACCESS TIME $\sim 10^{-5}$ SECS

  - IMAGE REFRESH STORAGE FOR CREW DISPLAYS

    $\approx 10^7$ BITS

  - DATA NEEDED DURING DEMO. AND LOADED PRE-FLIGHT
    - GCP DATA: 8 PIXELS x 8 PIXELS x 8 BITS = 512 BITS
      512 BITS x 50 GCP's $\approx 2.5 \times 10^4$ BITS
      WITH ACCESS TIME $\approx 10^{-5}$ TO 10^{-4} SEC
    - SENSOR/OPTICS MODEL $\approx 10^4$ BITS
    - PRE-STORED GPS-RELATED DATA $\approx 10^4$ BITS
    - " " POINTING-RELATED DATA 10^4 BITS
    - AIMPOINT PROGRAM COMMANDS $\approx 10^4$ + BITS
    - DATA FOR GEOMETRIC TRANSFORMATIONS $\sim 10^4$ BITS
    - PRE-STORED INTERPOLATION PARAMETERS $\sim 10^4$ BITS

TABLE 5-4 (Cont'd)

DATA STORAGE NEEDS (Cont'd)

- DATA COMPUTED AND USED DURING DEMONSTRATION
  - ANCILLARY DATA = ACCESS 10^{-4} TO 10^{-3} SECS
    - EPHEMERIS DATA $\sim 10^3$ BITS
    - POINTING DATA $\sim 10^3$ BITS
    - AIMPOINT DATA $\sim 10^3$ BITS
  - DATA NEEDED FOR IMAGE CORRECTION (READ-IN $\sim 10^{-3}$ SEC, READ-OUT $\sim 10^{-5}$ SEC)
    - RADIOMETRIC CALIBRATION DATA $\sim 10^3$ BITS (LOOK-UP TABLE)
    - GEOMETRIC CORRECTION COEFFICIENT DATA $\sim 10^3$ TO 10^4 BITS
- ARCHIVAL STORAGE* (NOT ACCESSIBLE IN SPACELAB)
  - PAYLOAD CORRECTED IMAGE DATA:

$$6.66 \times 10^3 \text{ METER/SEC} \times 152 \times (10^3) = 2.5 \times 10^5 \ \frac{\text{IMAGE CELLS/}}{\text{SEC}} \ \text{CHANNEL}$$

ASSUME: $\sim$800 SEC OPERATION

AND 8 BITS/CELL

RESULTS IN $\sim 10^9$ TO $2\ (10^9)$ BITS

---

*THE USE OF ARCHIVAL STORAGE OF PAYLOAD SENSED IMAGRY DATA REPRESENTS AN ALTERNATIVE TO PRIMARY APPROACH USING WIDEBAND DOWN- LINK PROVIDED BY ORBITER/TDRSS

5.6 AN ADVANCED APPROACH TO THE DEMONSTRATION BASED ON APPLICATION OF CID TYPE SOLID STATE ARRAY DETECTORS

5.6.1 Potential Advantages of This Type Sensor

The availability of the Charge Injection Device (CID) type of linear and area array detectors provides potentially significant advantages for the design of the demonstration, most specifically in relieving the computational burden discussed in Section 5. Specific features of these sensors which are of interest are:

- The capability for reading out sensing elements in any desired sequence (i.e. random readout).
- The capability of reading out the algebraic (i.e. sums and differences) of any (permissible)* combination of sensing elements. (This includes transform readout capability).
- Option for either destruct or non-destruct readout.
- High degree of sensing element sensitivity uniformity (potentially less than 1% non-uniformity) reducing or avoiding need for sensor calibration processing.
- High spatial resolution (15 to 25 micrometer bit spacing) permitting sufficient "oversampling" so as to potentially avoid need for pixel interpolation.

Other features of interest include the square shape of sensing elements which can have advantages when interpolating as well as unique capabilities for noise rejection and anti-blooming. The discussion of this section relates to any array type of sensor having these characteristics.

However, at the present time the CID sensor is the only such sensor known. Potential advantages from the standpoint of the demonstration include use of

*Permissible refers to compatibility with the constraints of 2 axis addressing.

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"data processing in the image plane" with attendant reduction in computer hardware and software needs as well as reduction in data storage requirements. A related potential advantage is the reduction in required data processing times so as to be more compatible with the real time needs of the demonstration.

Certain specific potential functions offered by this type of sensor for the image registration demonstration are:

- o Non-orthogonal readout controlled in such a way as to provide image dewarping "on the image plane."
- o Discrete image transform generation and selected sub-array readout for purposes of correlation of candidate and stored reference Ground Control Point (GCP) images.

In addition to these functions specifically related to the registration demonstration other functions which more generally provide potential advantages for electro-optical imaging from a spaceborne platform are also possible. Some of these functions permitted by this type of sensor, not necessarily part of the initial planned demonstration are:

<u>"Analytic" Scan Control and Stabilization</u>

Ability to control scanning direction "analytically." Some of the solid state array sensing operations which have been proposed in the past involve a type of "pushbroom" operation in which the cross-scan axis of the array must be precisely controlled so as to be maintained orthogonal to the intended in-track scan direction. Typically this is proposed to be done by some combination of precisely controlled vehicle attitude and instrument pointing. For imaging at nadir, for example, it would involve precise control of vehicle yaw angle. The CID type of sensor can avoid this need for precise mechanical control by providing a precisely selected and controlled scan direction in the array which is at all times orthogonal to the intended intrack scan direction. This is referred to as "analytic" or electronic control and stabilization. It provides potential advantages by permitting simplification and more relaxed control specification of vehicle attitude control and instrument pointing.

The control signals for this "analytic" control of the CID type of sensor would originate from the same sources used by mechanical control of pointing and stabilization (i.e. from inertial and stellar sensors, ephemeris data, etc.). Alternatively sensed imagery data can, in principle, be used in a real time mode to determine the direction and magnitude of the live image plane. This could be obtained, for example, by image correlation techniques. This data could be used for control of the scan direction.

"Block Summations" of Sensing Elements Outputs

The ability of the CID sensor to take sums of sensing elements permits operation with blocks of sensing elements (e.g., readout of sums of the 4 elements of a 2 x 2 "block"). This in effect permits selection of a change in sensor resolution. For a data collection system which is bandwidth limited, this means that a trade-off can be made between resolution and earth surface area coverage. Furthermore, this trade-off can be made at any time in a sensing operation with wide changes in size and shape of the selected imagery pixels. Hence, an imaging operation could, for example, combine a wide area assessment of earth resources, and also a more detailed examination of selected localized earth surface phenomena.

Hadamard Transform for Data Compression

Previous studies have shown that potential exists for data compression by encoding a scene with discrete types of transform such as the Hadamard transform. This potential is to some extent user-dependent and scene-dependent. It may involve, for example, elimination of the high "sequency" terms of a Hadamard transform or, alternatively, the encoding these high sequency terms with fewer bits. In addition to data compression potential, the Hadamard transform has possible advantages in that transmission bit errors may result in more acceptable types of image degradation for many users when experienced by Hadamard transforms of images rather than directly on the image itself. The concept of a possible "descewing Hadamard Transform" analogous to the descewing image operation is attractive but it does not appear to be presently readily compatible with the algebraic sums and differences which are possible with the x/y addressing technique of the CID.

Present Status of CID

CID array sensors having various sizes and response characteristics are presently available from General Electric. However, most of these arrays are limited to sizes of not more than 512 sensing elements in either axes. Although such sensors can be useful for initial demonstrations the full advantages of this type of sensor will depend upon the future availability of significantly larger arrays.

5.6.2 Demonstration Overview

The approach discussed below is based on the premise that response uncertainties in this type of sensing instrument provide no significant contribution to distortion. Hence there is no need for use of GCPs as "anchor points" in the image for purposes of geometric correction. Rather, GCPs can be used as an autonomous means for improving the already rather good available ephemeris and pointing data and also as means for reducing the mapping errors and thereby achieving the desired registration relative to prior imagery.

Unlike the scanning types of sensors, the solid state array types of sensors provide no significant geometric uncertainties or instabilities of either a static or dynamic nature which would contribute to image distortion. This is due to the rigid fixity of the sensing elements and their optics. This is in contrast, for example, to uncertainties and variations which may occur in the response of a scanning mirror over the operational lifetime of an image scanner.

Thus, the operation of solid state array types of sensors and their optics for the present demonstration, can be judged as not contributing to unknown or varying degrees to distortion. The response characteristics of the sensor can be considered as invariant, but of course, must be well known and well modeled in order to correct distortion. This precise modeling based on analysis and experimental measurement can be expected to be straightforward and to present no problems.

Thus, the primary residual contributors to uncertainty in image distortion which remain after application of GPS ephemeris data and stellar-inertial pointing data are due to:

- residual errors in sensor pointing
- residual errors in ephemeris determination
- earth-related errors (e.g. mapping errors and geoid errors).

It is proposed that these errors can be reduced to acceptable levels by obtaining precision "fixes" relative to pre-selected GCPs. This is tantamount to an autonomous augmentation of earth-referenced ephemeris and pointing determination in the well known manner of "known landmark tracking." It is further proposed that this GCP recognition and precision tracking be performed by the same "payload" solid state sensor as is used for obtaining the primary image data thus not only simplifying the demonstration and its sensing requirements but also eliminating any possible sensor misalignment as a source of geometric distortion and misregistration.

5.6.3 Sensor Mounting

The present demonstration could alternatively be implemented with the sensor either body-mounted or mounted on a shuttle instrument experiment mount (e.g. Small Instrument Pointing System, SIPS). In order to provide more options on earth surface coverage it is assumed that an instrument mounting system and specifically the SIPS is available for this demonstration. The SIPS is intended for installation on the pallet of the Spacelab for at least some of the Spacelab flights which will have a pallet. It is a three axis mount capable of pointing a payload package weighing up to 1500 pounds over a wide range of angles at angular rates as high as 2 degrees/sec. Its angular pointing control resolution relative to the Spacelab is 5.3 minutes of arc which by itself would provide an inadequate measure of pointing. The SIPS, however, incorporates one of several possible alternative self-contained stellar inertial reference systems, each having different predicted attitude reference performance. Based on limited available information, a 3 sigma pointing accuracy of this sensor relative to a stellar reference frame is taken to lie in the range of 1 to 10 arc seconds (0.00028 to 0.0028 degrees). In the absence of better information a 3-axis 3 sigma uncertainty of 0.0025^{o} (= 9 arc secs.) will again be assumed. As in the case of the alternative demonstration of 750 bm Spacelab operating altitude will be selected. Based on anticipated ephemeris determination performance as described in Section 5.3 and a maximum viewing angle of 45° from nadir, then the 3 sigma image misregistration error due to these attitude and ephemeris uncertainties will be in the range of 70 to 90 meters. Were the operating altitude chosen to be 265, then the comparable misregistration error would be between 25 and 35 meters.

In the planned demonstration, the SIPS will be directed by precomputed and stored acquisition commands to direct the sensor so as to transit the selected earth surface areas to be imaged. The operation of the sensor and specifically the layout of the sensing elements on the image plane are discussed in Section 5.6.5.

5.6.4 Sensor Radiometric Calibration

There is presently a question not completely resolved as to whether or not a radiometric calibration procedure is needed for the CID sensing array when used, for example, for multi-spectral analyses of Earth Resources Imagery. Sensing elements of CID arrays presently exhibit variations in gain of 0.1% to 0.5% from sensing site to sensing site and a variation in bias (i.e. offset) of 2% to 3%. General Electric's Corporate Research and Development reports that the bias uncertainty can (and likely will) be reduced significantly below 1% in the relatively near future. At the present time CID sensors which are in acceptable usage as imaging devices do not incorporate any calibration.

General Electric's experience with Landsat imagery has shown that multi-spectral imagery is acceptable for Earth's resources purposes if the total sensor response variation in sensing elements is less than about 1% (i.e. stripping will be unnoticeable). In view of this as well as the expected reduction of CID bias variations, it is considered unlikely that a calibration data processor will be needed. However, this will need to be verified by experiments and simulation.

In the presently unexpected event that calibration should be necessary, it could be accomplished by calibrated levels of illumination of the entire array, together with sequential readout and data processing calibration of each sensing element. It is unlikely that calibration would be required more often than once per orbit. Consequently, there would be considerable time to sequentially update a calibration look-up table prior to each orbital pass over the ground scene of interest. However, for present demonstration development purposes, it is realistic to assume that calibration will not be necessary.

5.6.5 Demonstration Optics and Sensor Characteristics

The demonstration will depend on application of these components:

- o Telescope Optics
- o Solid State CID's array(s) mounted in focal plane of Telescope

Because these components can be the most significant hardware cost items, a distinction will be made between an ultimate operational system and a lower cost initial feasibility demonstration. Consider first the ultimate operational system.

Ultimate Operational System

Because of the wide applicability of multi-spectral imagery for uses such as Earth resources investigations, and because of the wide spectral responses inherent in the CID, a multi-spectral sensing and analysis capability is an assumed design requirement.

The CID has a broad, nearly flat response from about 0.5 to about 0.95 micrometers and has useful response to 1.1 micrometers. Spectral filters could be used with four separate, parallel arrays of CID detectors located in the telescope image planes providing nearly the same four bands of imagery provided by MSS:

Band 1:	0.5 to 0.6 micrometers
Band 2:	0.6 to 0.7 micrometers
Band 3:	0.7 to 0.8 micrometers
Band 4:	0.8 to 1.1 micrometers

The sensor design and operation will be influenced by these factors:

- o No expected requirements for radiometric calibration

- o Operation in a "pushbroom" mode with image "sweeping" obtained primarily by orbit motion.
- o Parallel multi-spectral bands (tentatively selected as 4 in number).
- o "Dewarping" mode of readout resulting in need for finite sensor array width greater than one pixel.
- o Capability of automatic acquiring, detecting and locating of pre-selected GCP's.

A comparison and selection of the precise orbit parameter to provide a selected ground area repeat cycle needed to meet some specific mission requirements is beyond the scope of the present effort. Furthermore, repetitive ground cover cycles are not needed for demonstration purposes. A preliminary analysis indicates that operations at 750 Km with a sensing field of view of 12^o can provide realistic area coverage for some missions. This provides a swath width when sensing near nadir of 158 Km. A basic resolution of 40 meters is recommended so as to provide a resolution which is approximately twice as good as that provided by Landsat.

In order to provide this area coverage at this high resolution, and, in order to simplify image point resampling by use of oversampling by a factor of 4, array lengths having 10^4 sensing elements in each of four spectral bands are selected. Based on a sensing element pitch of 20 micrometers, this results in a total array length of 20 centimeters.

The width requirements for each array depends on the magnitude of the many factors contributing to distortion when using this type of sensor, as well as other factors such as degree of yaw angle constraint. A detailed quantitative derivation of this distortion as well as the trades involved in selecting attitude angle tolerances is beyond the scope of the present study.

A tentative engineering judgment will be made that to meet the above stated requirement, the width of each array should be 1% that of its length. This, for example, would be sufficient when viewing near nadir of compensating for a yaw angle error of 0.6^{o}. This leaves for each spectral band, a 10,000 x 100 array having dimensions of 20 cm by 2 mm.

For reasons of the economics of manufacturing yield, the arrays described above will be expected to be composed of multiple chips so lined up as to form the equivalent of such wide array. Manufacturing procedures may also preclude end-to-end butting of such chips. One approach to overcome this problem is to use overlapping staggered chips. If so designed, the data processing will necessarily have to compensate for the staggered arrangement. Since the exact manner of how individual chips might best be arranged is presently unknown, no further consideration as to what compensation if any will be given at this time. It is expected that in the future, end-to-end butting of sensor chips may be possible; hence, eliminating this possible complication.

Two general methods for spectral separation of imagery have been considered: spectral filters and spectral separating prisms. The former is preferred since it permits greater freedom in the geometric arrangement of the arrays on image plane. It is proposed then, that the primary sensing arrays be arranged in parallel with 2 mm separation between adjacent spectral arrays. This results in a sensing configuration for obtaining wideband multi-spectral image data having dimensions of 20 cm x 1.4 cm. This results in a focal plane arrangement fitting in an active focal plane diameter of 21 cm.

Consider next the matter of optical energy at the focal plane and its impact on design of the telescope optics. Based on a 750 Km operating attitude and a 40 meter ground sample dimension, the orbital velocity of 6.7 Km/sec will result in an image motion at nadir for the body mounted system equivalent to one ground resolution cell per 0.006 seconds. In order to permit the desired degree of resampling without smear and also to permit the pre-readout erase cycle described subsequently, an integration time of 0.3 (10^{-2}) second is selected.

Minimum detectable signal for CID types of arrays as dictated by noise equivalent signal is less than 10^{-3} micro joules/cm^2. A useful linear dynamic range lies within the approximate range of 5×10^{-3} to 1.0 micro joules/cm^2.

Data adapted from an earlier investigation* indicates that the optical energy density at the focal plane for an f/16 telescope when viewing the Earth will range from approximately 0.003 to 0.1 microjoules/cm^2. This presumes a 0.3 (10^{-2}) second integration time and a spectral bandwidth of 0.1 micrometer. It also is based on viewing a range of Earth surface materials ranging from highly reflective sand to low reflective deep water. It also considers a wide range of solar illumination based on an expected range of daily and seasoned sun angles.

Because the range of optical power densities provided by an f/16 telescope is a good match for that required to meet the operational range of the CID, it is selected as a telescope design parameter. As discussed, nearly the same field of view, 12°, as used by MSS is also assumed for the CID demonstration. Based on these parameters and the sensor image plane requirements discussed above, the telescope parameters are selected as follows:

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* Final report NASA contract No. NAS 5-23090, Advanced Earth Resources Information System Modeling Investigation - J. D. Welch, Aug. 1973.

f/16

F.L. = 105 cm

Clear Aperture = 8 cm

Useful Image Diameters = 22 cm

As discussed, the readout of the image data will, in general, not be of the conventional raster scan readout mode. For this reason, provision must be made for possible variations in intervals between readout of the sensing elements so as to avoid the adverse effect of variations in integration times. Several possible alternative approaches for avoiding this problem exist. One is the use of a mechanical shutter to provide equal integration time for all elements. Another would involve keeping track of integration intervals for each sensing element and appropriately compensating in the software.

However, the approach recommended is neither of these. It involves a pre-erase cycle of each sensing element. In this mode, each sensing element is erased by a distruct readout in exactly the same sequence as the sensing readout of data to be recorded. This insures the same integration time for each element being read out. This approach avoids the disadvantages associated with mechanical shutters and the complexities of the memory and software which would be attendant upon the other approaches mentioned above.

A LOWER COST INITIAL FEASIBILITY DEMONSTRATION

A meaningful demonstration can be made with a reduced area coverage than that discussed above for an operational system. Furthermore the demonstration can be limited to a single spectral band. This will permit a significant cost reduction in demonstration hardware. In order to demonstrate the desired registration performance it is recommended that the same resolution be maintained.

It is recommended that the ground swath width be reduced by a factor of 10. This results in a ground track of 16 km when operating at 750 km which is sufficient to demonstrate the image registration operation. The key sensing and optical hardware then becomes:

Single CID array:

1000x10 elements

2 cmx0.2mm.

Optics: f/16

min. field of view: 1.2^{o}

Useful image diameter: 2.5 cm

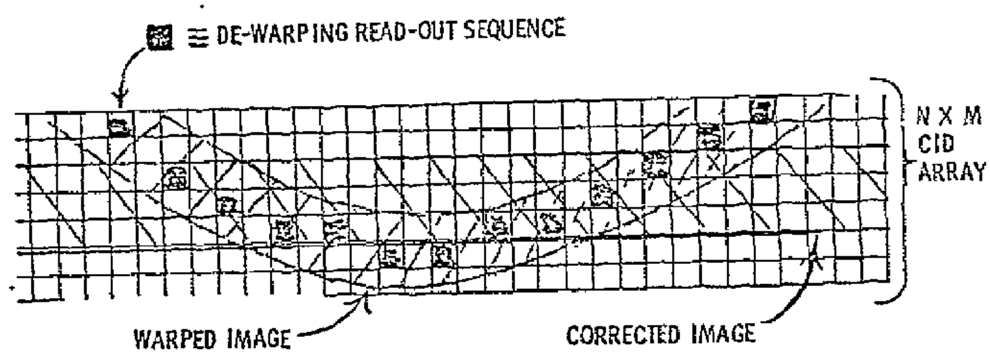
F. L. = 119 cm.

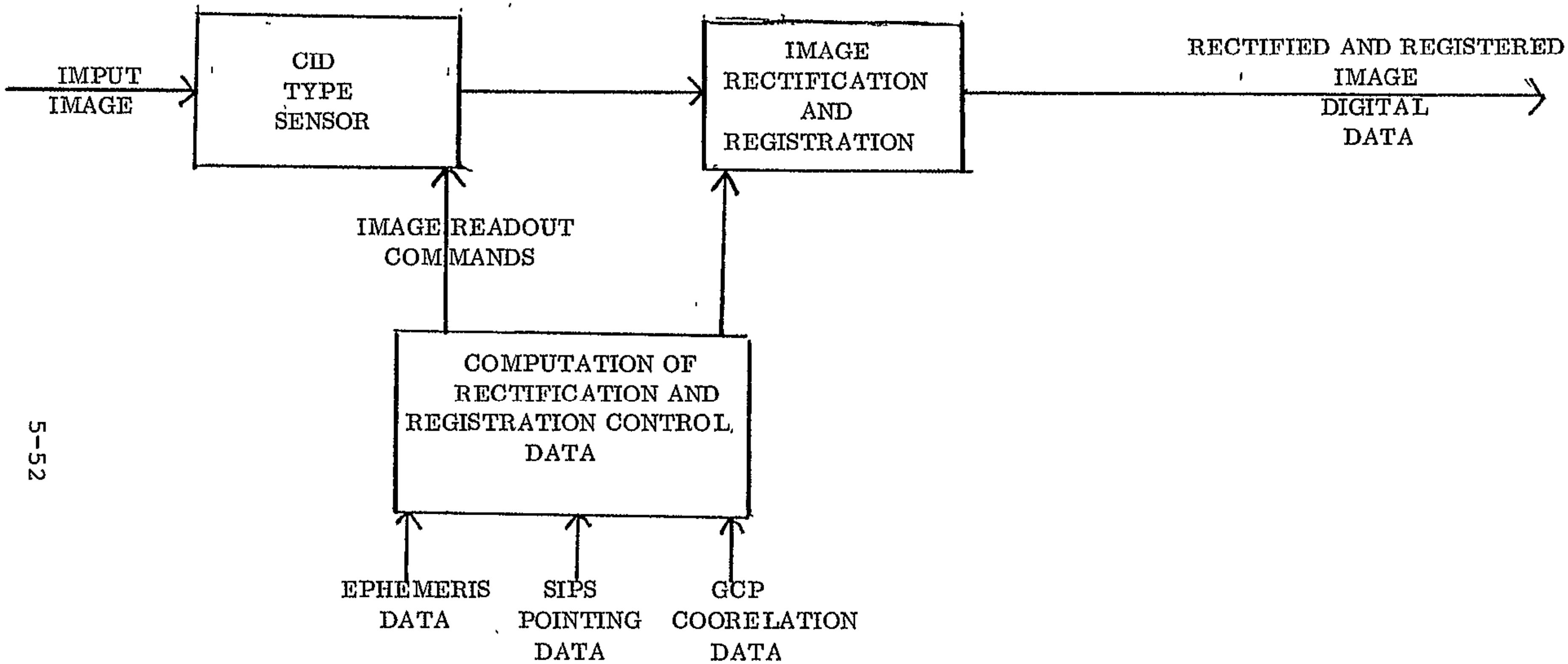
It should be recognized that the 1.2^{o} field of view is a minimum. A larger field of view can be selected if the size of the image plane is also increased. This can lead to a shorter focal length telescope. A survey of available "off the shelf" telescope designs is recommended to insure low cost hardware for such a demonstration.

5.6.6 SCHEMATIC BLOCK DIAGRAMS

Figure 5-7 is a simplified schematic general block diagram of a system approach which differs from a more conventional approach discussed in Section 5.5 in that the "input control data" is used to compute the optimal non-orthogonal sensing element readout sequence rather than manipulating the data which has been obtained in an orthogonal scan and which has been temporarily stored in a buffer. It also differs in the way in which the GCP correlation data is obtained and used. The non-orthogonal readout is computed to be a "dewarping readout" (i.e. the inverse of the warping function which is to be removed in the registration process). "Rectification and registration control data" is computed based on available up-to-date geometric input data which includes ephemeris of the Spacelab and the pointing of the sensing instrument relative to inertial space as well as characteristics of the sensor and its optics.

CONCEPT OF A "DE-WARPING" READOUT





AN APPROACH TO REAL TIME IMAGE RECTIFICATION AND REGISTRATION USING A RANDOM ACCESS TYPE SENSOR

FIG. 5-7

The ephemeris and instrument pointing data is derived not only from the GPS system and the optical inertial reference system of SIPS but also from the application of image-derived GCP correlation data.

The control data which is computed describes the "dewarping correction" which must be performed so that the desired rectification will result. More specifically, this control data will be used to determine the sequence by which the sensor array cells will be readout. In effect, the array provides both the sensing and buffer storage function.

IMAGE ACQUISITION AND POINTING CONTROL MODE

The purpose of this mode is to initially direct the SIPS pointing so as to acquire the Earth surface area of interest in the field of view of the CID sensor and to control the needed SIPS tracking rates so as to maintain the Earth surface areas of interest within the field view during the imaging operation. In general the pointing precision potentially available from GCP data will not be required to meet either the initial acquisition or field of view maintenance requirements. Available SIPS pointing data and ephemeris data from GPS will be adequate for acquisition purposes.

Figure 5-8 is a schematic block diagram of this mode. It is assumed that, for demonstration purposes, there is no control over either the Spacelab ephemeris or Spacelab attitude. Hence, all acquisition and pointing control of the sensor is accomplished by the SIPS. Prior to and during acquisition and imaging the demonstration data processor computes and updates the Earth surface "aimpoint" of the sensor. "Aimpoint" is defined as the intersection of the sensor telescope optical axis with the surface of the Earth. During operation this is a continuous recursive computation based on GPS derived ephemeris data and pointing data of the SIPS relative to inertial space as derived from the SIPS stellar/inertial reference system. The recursive filter also incorporates a model of the rotating Earth.

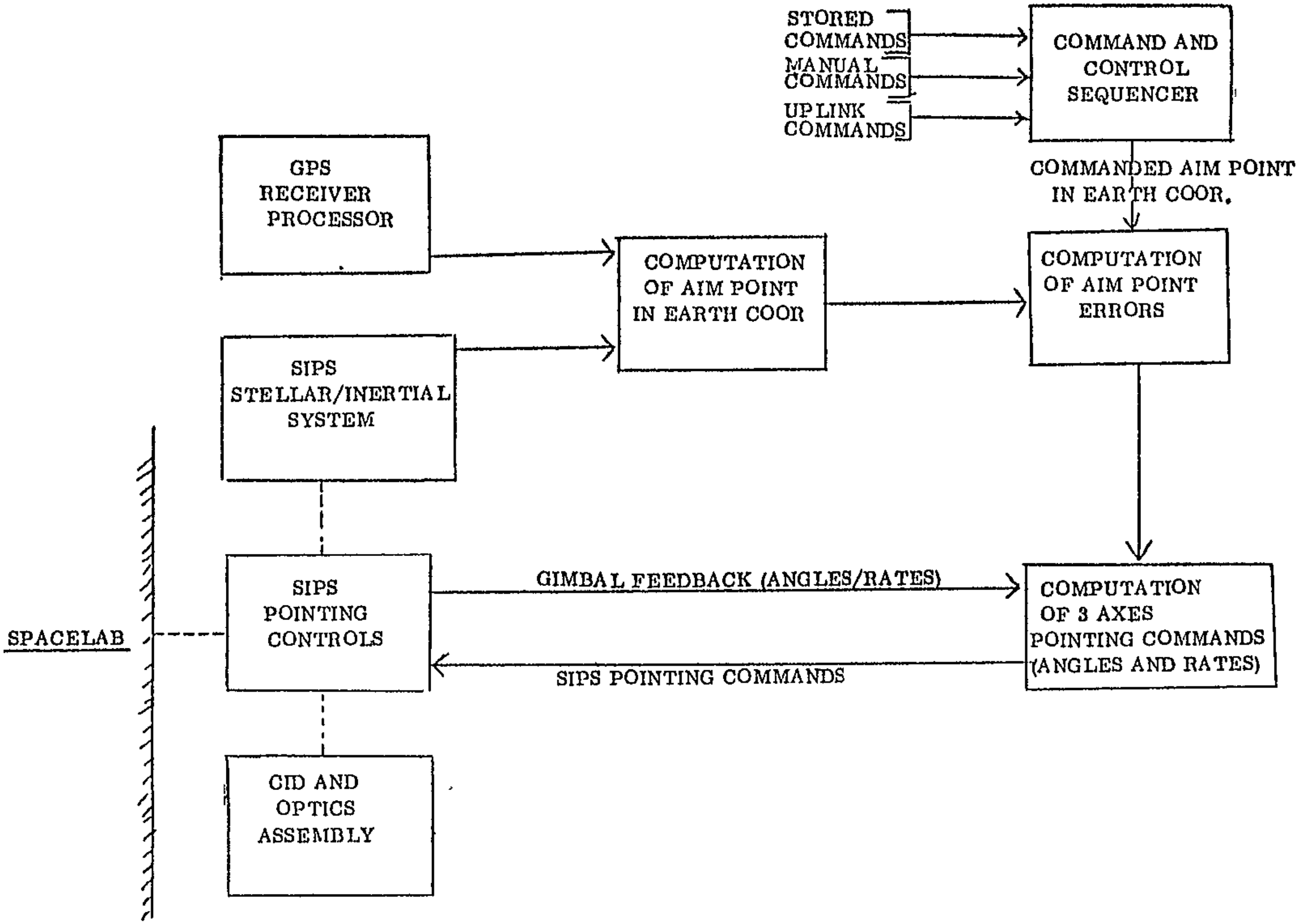


IMAGE ACQUISITION AND POINTING CONTROL MODE

FIGURE 5-8

A file of aimpoints and aimpoint path used for initializing each imagery phase of the demonstration is stored in the data processor memory. This data includes the location of each aimpoint in an Earth reference frame together with the time (day, hour, minute, second) for the acquisition operation of each aimpoint. This stored data is based on pre-flight mission planning and is subjected to up-date via the communications up-link to account for vehicle ephemeris being significantly off-nominal. Override control is also provided to the crew to account for changes in the imaging sequence due to current weather or other contingencies.

As shown in Figure 5-8 the commanded aimpoint in Earth coordinates is compared to the present computed aimpoint in the data processor in order to compute the present aimpoint error. This aimpoint error then provides the basis for computation commands in 3 axes to the SIPS pointing control systems. The algorithm incorporates a model of the SIPS pointing controls so as to insure optimum sequencing of gimbal commands and avoidance of gimbal lock. Pointing angle feedback data is provided so as to null the SIPS pointing errors when acquisition is achieved.

Although, sensed image data is not used in this mode an optional acquisition verification display can be provided to the crew. (This is not shown in Figure 5-8). This involves use of displaying present image data sensed by the CID and displayed by means of a soft display and refresh storage. This display would incorporate a superimposed display showing the error between the commanded and present aimpoints.

Upon achievement of acquisition to within some acceptable acquisition error which might typically be a few hundreds of meters the demonstration is automatically (with manual override option) switched to the image correction and registration mode during which time the image tracking performed by the SIPS continues.

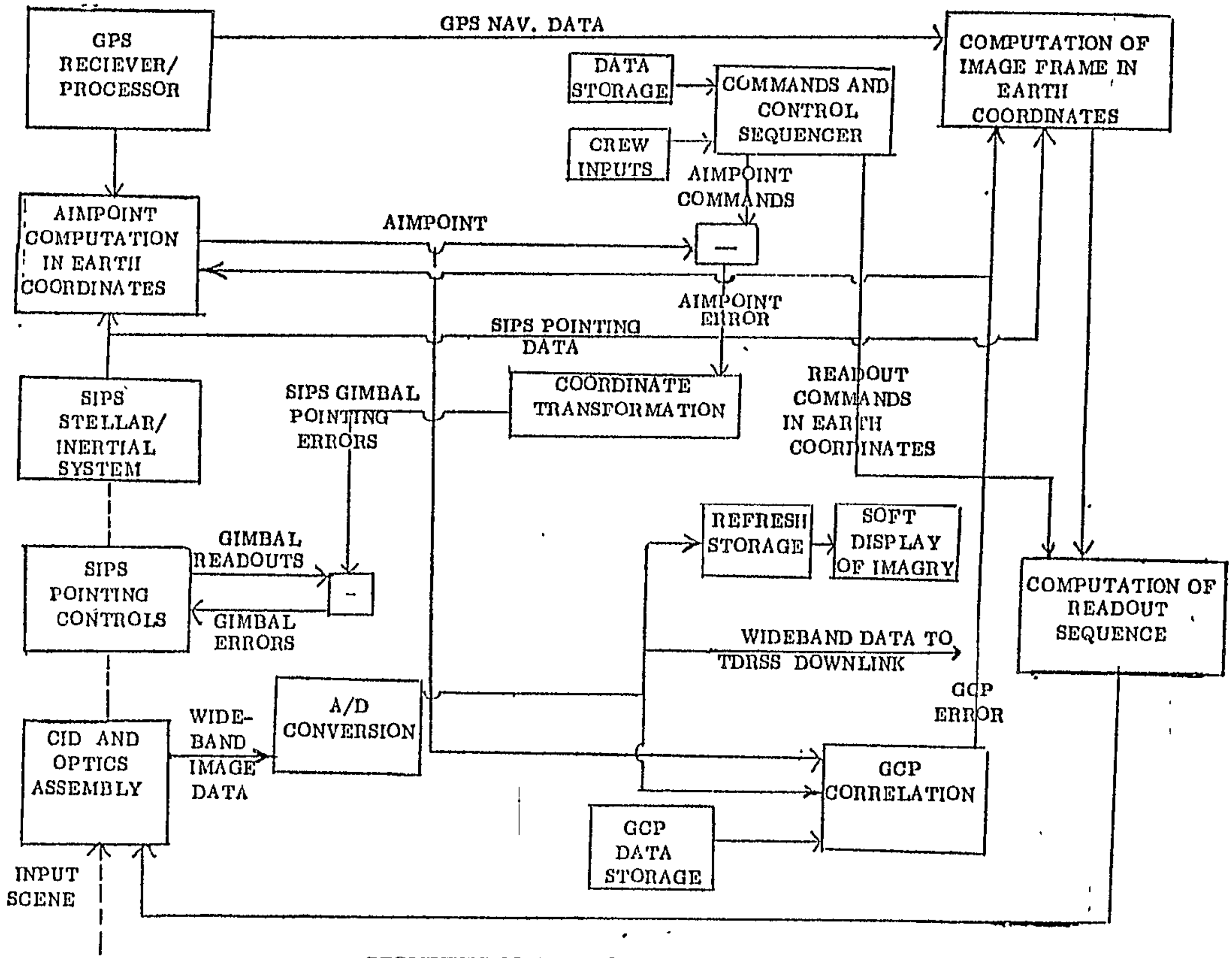
GEOMETRIC CORRECTION AND REGISTRATION

Figure 5-9 is a schematic block diagram of the demonstration operating in its primary mode of Geometric Correction and Registration. As discussed, and unlike the Scanner Type of demonstration, these two functions are combined. As discussed above GCP correlation data is used, in effect, to improve ephemeris and pointing rather than as "anchor points" in the image correction. Figure 5-9 shows the operation of two primary control loops:

- o The SIPS pointing control loop
- o The geometric correction and image registration loop.

As shown the pointing control loop provides a function similar to that described for the acquisition mode. Because, however, it is based on GCP data it functions with greater precision than does the acquisition mode. The manner for deriving GCP position and error data is duscussed in the next section.

The pointing control loop provides continuous control of aimpoint according to the "aimpoint program" stored in the demonstration command and control memory. The "aimpoint program" is developed prior to the flight demonstration but, however, is subject to update by data uplinked from the ground or by input from the ground or by input from the crew. The aimpoint program distates the specific areas to be imaged by the sensor as a function of time. The aimpoint velocity to be either greater than, equal to or lesser than velocity of the nadir point.



GEOMETRIC CORRECTION AND REGISTRATION MODE

FIG. 5-9

The present aimpoint computation includes SIPS stellar-inertial data as well as navigation data from GPS and periodic landmark type of fixes from "errors" in predicted GCP locations. Because the pointing data is derived from a stellar-inertial reference incorporated on SIPS the control data will not only control SIPS to follow the aimpoint program but will also remove effects of any Spacelab attitude disturbance.

Aimpoint error is computed by comparison of presently predicted aimpoint with the aimpoint profile command which is stored as a function of time. The aimpoint errors are transformed to SIPS gimbal pointing errors. These are compared to actual gimbal angles so as to derive error signals needed for the SIPS drive servos.

The geometric correction and image registration control loop has the function of providing the CID sensory element readout in the non-orthogonal scan sequence as needed for correction and also providing the sensed data with the correct registration. As shown in Figure 5-9 the command and control sequencer provides readout commands in Earth coordinates from its memory. The "inverse imagery model" transforms this geometric data to a dewarping readout sequence. This model uses as inputs the following:

- o GPS Navigation Data
- o SIPS Stellar/Inertial pointing data
- o GCP correlation data

The model also incorporates the characteristics of the solid state detector arrays, the optics as well as the characteristics of the rotating Earth. Some of the types of factors involved in this model have been discussed in Appendix E. The details of the distortion producing effects of the solid state sensor and its optics are beyond the scope of the present effort.

The output of this model provides the basis for the readout sequence commands. As in the case of the scanner demonstration, the commanded readout sequence may typically require image readouts which are not exactly centered on a sensing element. Two general approaches (or some combination thereof) are possible to solve this problem:

- o Selection of a high resolution sensor permitting image oversampling
- o Application of one of several possible resampling techniques

An adequate comparison of these options can be best made by means of digital simulation. However some discussion of alternatives will be presented here.

Figure 5-9 shows the possible incorporation of an interpolation model. The figure also shows the application of soft image display and refresh storage for purposes of crew monitoring of the results of the demonstration. Corrected and registered wideband data is shown as being transmitted to Earth via the Orbiter-TDRSS down link.

As discussed previously when performing a "dewarping" correction there exists the problem of constructing an output pixel based on a corrective remapping from a position located between discretely located pixels of the distorted input image. In performing this resampling operation the solid state detector array has the potential for higher resolution (i.e. smaller pixel size on the image plane than the scanning types of sensors). This permits a degree of sensor oversampling. (Here by "oversampling" is meant making use of a sensor having a higher resolution than that needed by the basic system resolution requirements). This permits a more precisely controlled locating of the point being read-out on the distorted input image and hence permits either the avoidance of interpolation or use of a more simplified interpolation scheme. As discussed provision for oversampling by a factor of 4 has been allotted in the CID sensor specification. Further evaluation by simulation is needed to determine what, if any interpolation is needed when using this high level of oversampling. Listed in order of computational complexity and also interpolation precision these interpolation schemes can be considered if they should be needed:

- "Nearest neighbor" Technique with oversampling
- Bi-linear interpolation
- $\frac{\sin x}{x}$ approximation

From the standpoint of mechanization in a real time operation the nearest neighbor approach has advantages in avoiding the need for interpolation. It would be the preferred approach if it could be shown that it resulted in satisfactory output imagery with acceptable costs for the sensor designed to have oversampling capability. Previous experience with MSS imagery obtained from Landsat indicated that nearest neighbor interpolation did not provide the degree of intensity smoothing needed for interpolation did not provide the degree of intensity. However by using oversampling Techniques the response of the nearest neighbor Technique can be expected to be significantly improved! This permits a nearest neighborhood resampling which is more representative of the desired intensity level than would otherwise be possible. The nearest neighbor approach has more potential applicability for the present demonstration when using CID types of sensors than it has when using scanning types of sensors. This is due to the higher inherent spatial resolution which is possible with the solid state detector arrays than with scanner types of sensors. The MSS, for example, has an instantanous field of view of 0.086 milliradians and scan field of view of 11.56 degrees. This is "equivalent to" an array having 2,346 sensing elements in length. Since state of the art solid state arrays have a typical sensing element pitch of 15 to 20 micrometers such an array with 2,346 sensing element would typically have a length of about only 4 cm in length. Because of this relatively short array length, it is realistic to consider increasing the number of detectors (i.e., increase length of array) so as to provide a significant degree of oversampling. Oversampling by a factor of about 4 may be expected to eliminate a requirement for re-sampling and yet would possibly with arrays of only about 16 to 20 cm in length. As outlined in the design concept discussion of Section 5.6.5 a sensing instrument having arrays of about 20 cm in length is not unrealistic from the standpoint of its physical configuration. It is recommended that this approach be evaluated by means of data processing simulation and that it be compared with the simulation results when using the resampling techniques.

In the next degree of interpolation improvement and operational complexity, "Bi-linear resampling", the four input image pixel (i.e. sensing elements) which have been determined by the rectification control data to surround a given "resampling point" are interrogated and linearly interpolated to determine the correct value at that resampling point. This would be incorporated only if it were shown that the oversampling technique failed to provide satisfactory results.

5.6.7 DERIVATION OF ERROR SIGNALS FROM GROUND CONTROL POINT (GCP) AND OTHER DATA

For the demonstration based on CID's the function of GCP data is to reduce the effect of residual navigation, pointing and mapping errors. The application of such data involves these functions:

- o Recognition (correlation) of sensed GCP's by comparison with stored reference GCP's
- o Computation of GCP position errors which relate actual and predicted location of GCP's
- o Incorporation of GCP position error data into the rectification and registration computations.

As discussed in Section 5.4.2 a maximum 3 sigma residual misregistration errors when using GPS navigation data and SIPS stellar inertial data is expected to be in the neighborhood of 100 meters. It is proposed that GCP's be defined over a 8 x 8 pixel format where a pixel, near nadir, is 40 meters. To account for a possible initial error of 100 meters then the problem can be defined by identifying and locating a 8 x 8 pixel GCP image over a 16 x 16 pixel area of the sensed image. This is then the same problem as described in Section 5.5.6 for the alternative demonstration discussed.

Prior to performing the correlation test, of whatever kind, it is necessary to establish a common geometric rectification frame between the 16 x 16 pixel candidate imagery and the 8 x 8 pixel reference GCP. This can be accomplished in either or two alternative ways:

- o Rectifying (i.e. "dewarping") of the 16 x 16 pixel candidate imagery
- o Warping the reference GCP reference imagery to conform to the distortion of the candiate imagery.

Although the former approach is the conventional one, the second approach is favored. This is due to the increased time available to make the geometric modification of the GCP data. This warping operation can be performed prior to the sensing of the candidate imagery based on an extrapolation of present data to predict the viewing geometry which will occur during the sensing operation. This can significantly ease the problem of achieving real time operation since it can permit several milliseconds to accomplish this geometric distortion. A further alternative for the demonstration would be to precompute and store in a look-up table all possible distortions of the GCP's. The best manner of handling of this geometric distortion needs further investigation preferably aided by simulation.

Several approaches to correlation can be conceived. Two are considered here:

- o Make use of SSDA correlation of the type described in Section 5.5.6
- o Use transform capability of CID to directly sense the Hadamard transform for use in correlation.

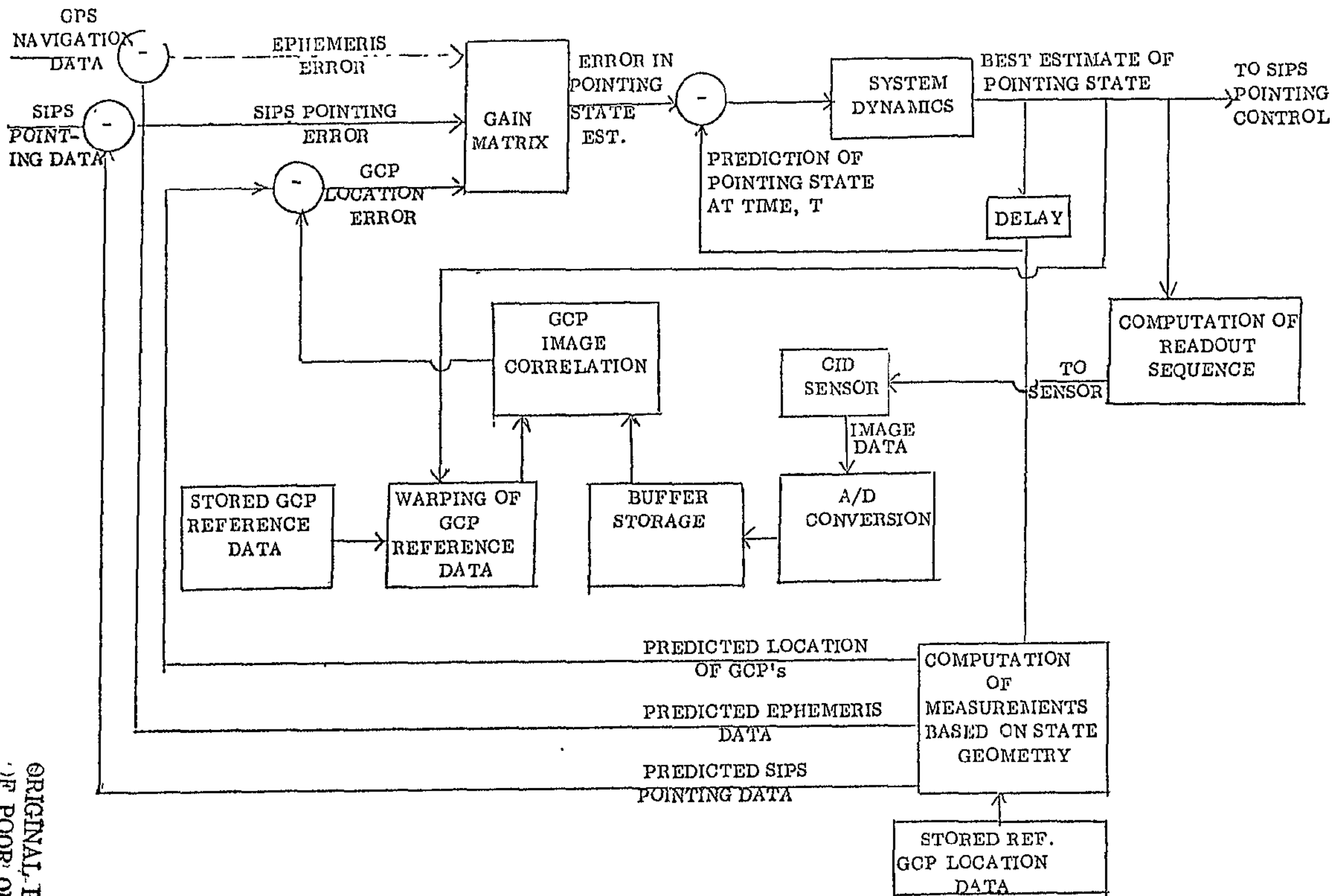
The first of these is the more conventional and is the tentatively favored approach. Assuming that the gray scale can be adequately represented by 16 bits then this approach will require a buffer storage of some 4096 bits.

The second approach has potential advantages of a requiring less buffer storage and providing faster computations since, in effect, much of the computation is done in the sensor image plane. However, it does require a minimum array width of 16 pixels. It also requires some further definition in the optimum use of the Hadamard transform to store the GCP reference data and to provide the needed correlation operation. Also up to the present time CID's having transform readout capabilities have been limited to 4 x 4 element transforms. It is recommended that this approach to GCP correlation be investigated further.

Figure 5-10 is a simplified schematic block diagram showing how GCP data can be combined with SIPS stellar-inertial data and GPS data to provide the best estimate of the present sensor-pointing state. It represents an expansion of the part of Figure 5-9 concerned with pointing geometry. Because of the inclusion of GCP data the sensor pointing state estimate is provided relative to an Earth reference frame. The pointing state estimate includes the latitude and longitude of the aimpoint as well as data defining the obliquity and range from the sensor to the entire image scene. It is precisely this pointing state data which is needed as a basis for computing the dewarping readout sequence for the SID sensor as well as for computing the SIPS pointing controls.

Figure 5-10 represents a simplification of a recursive algorithm of the Kalman type for providing the best estimate of the pointing state. Input data from GPS, SIPS pointing reference and from GCP correlation are the basic inputs. Each of these inputs is compared with predictions of what these measurements will be based on a geometric computation of previous best estimates of the pointing state and also GCP location data. These comparisons result in "errors" in ephemeris, SIPS pointing and GCP location.

These errors are appropriately gain-weighted in a grain matrix to result in a computed error in the estimate of the present pointing state. The weightings of the gain matrix reflects the degree of confidence placed on each of the input measurement errors. Although not shown in the Figure the values of gains in the gain matrix will be continually recalculated to reflect the changing estimates in the confidence of the measurements.



APPLICATION OF GPS NAVIGATION DATA, SIPS POINTING DATA AND GCP DATA TO DETERMINE SENSOR POINTING STATE (A SIMPLIFIED SCHEMATIC)

Figure 5-10

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The computed error in the present pointing status is used to modify the present state which has been predicted based on the prior best estimate of the pointing state and the characteristics of the system dynamics. System dynamics includes both orbit dynamics as well as pointing dynamics. This results in a updated best estimate of the pointing state which in turn, is used to compute CID readout sequence as well as to generate SIPS pointing control signals.

As shown in the figure candiate imagery vignettes in the predicted vicinity of the GCP's is temporarily stored in a buffer storage. Pointing state data is used to warp the stored GCP reference data as previously described. This warped data is then made available to perform correlation by means of the SSDA algorithm with the sensed vignettes of imagery data. The result of this is the measured error in GCP location and is then one of the inputs to the previously discussed gain matrix.

5.6.8 HARDWARE REQUIREMENTS

Table 5-5 provides a summary of hardware needed to pursue the Image Registration demonstration. It also provides a judgement as to whether these requirements should be provided by the Spacelab, the SDTF or whether they should be provided as demonstration-specific equipment.

5.6.9 DATA PROCESSING AND STORAGE NEEDS

Because the CID type of sensor provides both oversampling and non-orthogonal scan in manner described above there exists potential for avoiding the most critical of the real time data processing requirements needed for the scanner type of sensor: namely the requirement for image resampling. In addition the CID sensor is not expected to require radiometric calibration which is the second most critical of the real time data processing requirements when using the scanner type of sensor.

Table 5-5. Spacelab Mounted Precision Image Registration Demonstration Hardware Requirements

Hardware Needed	Spacelab-Provided	Demo.-Specific	SDTF-Provided
• Sensor - CID Sensor (includes spectral filters)		X	
• Telescope (for CID Sensor) f/16 F.L. = 116 cm Clear AP. = 8 cm Image diam. = 22 cm		X	
• Instrument Pointing System (e.g. SIPS)	X		
• Optical-Inertial Reference System (mounted on Instrument Pointing System)		X	
• Global Positioning System (GPS) - Receiver/Antenna - Data Processor	X		X
• Image Display Devices (E-O driven) with inter-active and image superposition capabilities			X
• Alpha-Numeric Displays			X
• Earth-oriented Viewport	X		
• A/D Converter			X
• Manual Override Pointing Control for Instrument Pointing System			X
• CUE Display Device			X
• Onboard Data Processing for Computing - Ephemeris - Attitude - Pointing - Geometric and radiometric coefficient generation - Image correction application - GCP correlation - etc.			X
• Data Storage Capabilities - Microprogram memory - Scratch pad memory - Cache memory - Main memory - Programmer memory			X

Table 5-5 (cont'd)

Hardware Needed	Spacelab-Provided	Demo.-Specific	SDTF-Provided
• Demonstration Command and Sequencer Unit			X
• Communications Link - Up-link - Down-link	X		
• Interactive Controls - Keyboard(s) - Joystick(s) - Various controllers			X
• Volume for Demonstration-Specific Hardware	X		X
• Power distribution and conditioning for demonstrations and other parts of SDTF		X or	X
• Data interfaces with demonstrations and with other Spacelab systems			X

Table 5-6. Estimates of Computational Requirements for the Image Registration Demonstration Based on Use of CID Sensor

FUNCTION	EQUIVALENT ADDS PER SECOND
GPS Ephemeris	104,000
SIPS Pointing Data Generation	100,000
Aimpoint Computation	90,000
Computation of Aimpoint Errors	5,000
Computation of Pointing Commands	40,000
Computation of Readout Sequence (equivalent to Rectification Control Data)	170,000
Warping of GCP Reference Data	20,000
GCP Correlation	80,000
TOTAL EQUIVALENT ADDS PER SECOND	609,000

As a consequence, the primary data processing requirements as modified from the requirements listed in Table 5-3 are listed in Table 5-6.

It should be noted that the largest single computational need is that of computation of the readout sequence. It is the result of this computation which provides the departure of the CID readout from a nominal orthogonal scan readout. It should be noted that, as in the case of the more conventional sensors, a read pulse generator is needed to provide the discrete signal needed to read each sensing element at the read bit rate. It will accept, as control inputs, the results of the readout sequence computation. The exact design of the read pulse generator is not considered further here. Rather it is recommended for future effort.

The estimated data storage requirements are also reduced primarily by eliminating the requirement for buffer storage of the image data prior to correction as needed for operations with the scanner type of sensor. This eliminates a requirement for a storage of 10^5 to 10^6 bits (as estimated to be needed by the MSS and Thematic Mapper respectively.)

Based on the above computation estimates the data processing and data storage requirements for real time data processing when using a CID type sensor appears to be within the present state of the art of space-borne data processors.

Future effort should consider in more detail the trade-off between control of the spacecraft attitude and ephemeris on the one hand and the complexity of the computation algorithms on the other hand. This should include further consideration of how the correction computational needs might be simplified by controling the spacecraft so as to minimize geometric distortions.

6.0 SELECTED DEMONSTRATION FOR FURTHER DEFINITION OF SDTF DESIGN REQUIREMENTS

6.1 INTRODUCTION

Three additional proposed demonstrations are identified here for further definition of the SDTF design requirements. The SDTF capability will then be expanded as may be necessary, to support these deomonstrations. The additional demonstrations which have been selected are:

- A "Heads Up" display demonstration for Spacelab
- A precision laser ranging demonstration for Spacelab
- A Spacelab low light level sensing demonstration

These three candidate demonstrations have been previously identified in Section 4 as being responsive to the demonstration selection criteria listed in Table 4-1. As such they were highly rated during the previously discussed demonstration review process conducted by the panel of consultants.

6.2 A "HEADS UP" DISPLAY (HUD) DEMONSTRATION

This would be a demonstration of advanced soft display concept(s) for presenting real time critical imagery and other data to the crew. The essence of a HUD, as the term is used here, is the superposition of real time soft displays of information so designed to provide the crew with rapid access to critical data in a readily interpertable format. HUD might be used, for example, to provide the crew simultaneously with cue data superimposed over presently sensed Earth Surface imagery. This could be used, for example, as a means to alleviate the difficult problem which astronauts have reported in the past in identifying land areas over which they are orbiting. Although this is believed to be a good demonstration of HUD, the concept of HUD as applied to manned space flight is conceived as being broader than that. Table 6-1 summarizes some potential applications of HUD to manned space flight.

TABLE 6-1

SOME POTENTIAL TECHNIQUES AND ULTIMATE APPLICATIONS OF HUD TO MANNED SPACEFLIGHT

	TECHNIQUES	TYPICAL POTENTIAL ULTIMATE APPLICATIONS
1. CUE IMAGERY	• PROJECTION OF PRE-STORED CUE IMAGERY ON VIEWING SCREEN FOR SUPERPOSITION OVER SCENE DIRECTLY OBSERVED THROUGH VIEW-PORT OR PRECISION WINDOW.	• RAPID IDENTIFICATION OF LAND AREAS BELOW. • MAN-AIDED AUTONOMOUS NAVIGATION AND INSTRUMENT POINTING • RAPID MEANS FOR DETECTION OF EARTH SURFACE CHANGES.
2. COLLATERAL DATA	• PROJECTION OF COLLATERAL DATA IN ALPHA-NUMERIC OR GRAPHIC FORM ON VIEWING SCREEN SUPERIMPOSED OVER SCENE DIRECTLY OBSERVED THROUGH VIEWPORT OR PRECISION WINDOW.	• RAPID ACCESS TO NAVIGATION AND AIM POINT DATA/ERRORS. • SUPERIMPOSED DISPLAY OF EXPECTED LOCAL WEATHER AND VIEW CONDITIONS FOR IMAGE QUALITY ASSESSMENT. • SUPERIMPOSED DISPLAY OF OUTLINE MAPS TO AID LAND IMAGE IDENTIFICATION.
3. UV, IR OR SAR IMAGERY DISPLAY	• PROJECTION OF IMAGERY OBTAINED IN NON-VISIBLE SPECTRA SUPERIMPOSED OVER VISIBLY OBSERVED IMAGERY	• REAL TIME PRESENTATION OF IMAGERY OBTAINED OVER WIDE SPECTRAL BAND TO PERMIT RAPID IDENTIFICATION AND ASSESSMENT OF IMAGERY INCLUDING CHANGE DETECTION.
4. COMPUTER-GENERATED IMAGERY DISPLAY	• SUPERIMPOSED PROJECTION OF SYNTHETIC IMAGERY BASED ON PRE-STORED IMAGE DATA AND SUITABLY "WARPED" BY THE COMPUTER TO CONFORM TO PRESENT VIEWING GEOMETRY.	• RAPID DISPLAY OF GEOMETRICALLY CORRECTED GRAPHIC DATA TO AID IN IDENTIFICATION AND INTERPRETATION OF IMAGERY WHEN VIEWED OVER A WIDE RANGE OF VIEWING CONDITIONS.

These applications generally related to providing the crew with a rapid and effective means for either:

- Presenting "cues" for identification purposes
- Presenting data to aid in image interpretation (a "Geographic" mode of operation).

The objective of a HUD demonstration would be to show real-time capability for registration superposition display of imagery including that possibly obtained in different spectral bands as well as super-position of projected maps and other collateral data in graphic or alpha-numeric form with presently sensed imagery. The technologies which would be involved are listed in Table 6-2.

Table 6-3 summarizes a rationale for development of a HUD demonstration. It outlines objectives and cites specific problem areas anticipated as well as specific implementation capable of overcoming those problem areas.

Table 6-4 provides a summary of hardware needs for the demonstration showing whether these needs should be supplied by Spacelab, the SDTF or directly as being demonstration-provided. This listing shows these possible capabilities in addition to those needed for the Image Registration demonstration which should be incorporated into the SDTF:

- Head constraint for crew when viewing superimposed imagery
- Scan Conversion Electronics
- Cue slide display device
- Photographic Camera

TABLE 6-2

TECHNOLOGIES INVOLVED - HUD DEMONSTRATION

TECHNOLOGIES	SPECIFICS/COMMENTS
• Sensing	• Direct view through window or viewport by crew. • UV, IR and/or SAR sensing.
• Data Handling	• Data Processing and Data Storage Requirements significantly less than that for Image Registration Demonstration except when computer-generated imagery is included.
• Display	• Transparent Projection Screen • CRT displays • Optical Projection Techniques including projection CRT's and "light valves".
• Instrument Pointing	• SIPS type of system for mounting of uv and/or IR sensors.
• Navigation	• GPS capability desirable.

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TABLE 6-3 HEADS-UP DISPLAY OF TYPICAL IMAGERY SENSED UV OR I.R.

A TYPICAL OBJECTIVE	PROBLEM AREAS	SELECTED ALTERNATIVE IMPLEMENTATIONS ON-BOARD

TO PROVIDE CREW TARGET ACQUISITION AIDS SUCH AS HEADS-UP DISPLAY OR TERRAIN SENSED IN UV OR I.R.	• SENSED IMAGERY DATA MAY NOT BE IN FORMAT WHICH IS COMPATIBLE WITH HEADS-UP PROJECT ON DISPLAY. (SCAN FORMATS/RATE ETC.)
	• DIGITAL DISPLAY OF COLLATERAL DATA NEEDED
	• SYNCHRONIZATION OF DISPLAY OF COLLATERAL DATA WITH TERRAIN IMAGERY DISPLAY NEEDED
	• STORAGE OF COLLATERAL DATA NEEDED
		• STATE OF ART IMAGE SCAN CONVERTERS
		• SCAN CONVERSION COMBINED WITH IMAGE CORRECTION/ ENHANCEMENT IN DIGITAL DATA PROCESSOR
		• "HEADS-UP DISPLAY" BY SUCH MEANS AS
		  • PROJECTION CRT
		  • PROJECTION LIQUID CRYSTAL LIGHT VALVE
		• DIGITAL DISPLAY BY:
		  • LE D DISPLAYS
		  • FIELD EFFECT LIQUID CRYSTAL DISPLAYS
		• ADVANCED UV, IR SENSORS
		• DIGITAL STORAGE OF COLLATERAL COLLATERAL DATA

TABLE 6-4

A "HEADS UP DISPLAY" DEMONSTRATION FOR SPACELAB

TABLE OF HARDWARE NEEDS

HARDWARE NEEDED	SPACELAB PROVIDED	DEMO.-SPECIFIC		SDTF PROVIDED
o Viewing Port and/or High Quality Window Access with Earth Viewing Capability	X			
o Viewing Screen at Viewing Port Suitable for "Heads Up" Display		X		
o Head Constraint (To Immobilize Astronauts Head During Demo.				X
o Instrument Pointing System (e.g. SIPS) located on Pallet	X			
o Imaging Sensors Operating in Visible, UV, and/or IR. May be scanners, Solid State Arrays or Image Tube Types.		X	OR	X
o Scan Conversion Hardware to accommodate a wide range of scan formats and rates for use with a variety of sensors and displays.				X
o Projection type display device(s) suitable for Heads Up displays. (May be CRT's, light valves, liquid crystals displays or other.)		X	OR	X
o Means to control spacelab internal lighting to prevent interference from same (e.g. switches, screens, curtains).				X
o Alpha-Numeric Display(s) suitable for display of collateral data (e.g. time, Ephemeris, attitude, pointing, landmark identification, baseline demonstration procedures).				X
o Astronaut controls for control of Instrument Pointing System and/or Spacelab Attitude.				X
o Interactive Control Console (e.g. Joystick(s), Keyboard....) suitable for control of displayed imagery.				X
o Soft Display(s) of Imagery (CRT's, light valves, etc.) Suitable for superimposed imagery display, Alpha-Numeric, display, false color, various types of reticles etc.				X

A "HEADS UP DISPLAY" DEMONSTRATION FOR SPACELAB

(CONTINUED)

HARDWARE NEEDED	SPACELAB PROVIDED	DEMO.-SPECIFIC	SDTF PROVIDED
o "Cue" Slide Display (+ Slides) to aid in landmark recognition			X
o Photographic Camera (e.g. Polaroid Type) for recording superimposed images.			X
o Data Input Keyboard(s)			X
o Stellar-Inertial Reference System Mounted on Instrument Pointing System	X		

6.3 PRECISION LASER RANGING DEMONSTRATION

This would be a demonstration of advanced active ranging techniques making use of a pulsed laser located on Spacelab. It would be primarily a cooperative ranging making use of retro-reflectors located on key Earth sites and/or on-board other spacecraft. The ultimate objectives of the technique which are further described in Table 6.5 would be in the fields of earth geophysics and gravity modeling. It is expected that ranges of up to 1,000 km would be determined with typical uncertainties in the neighborhood of two to five cm.

The objective of the Laser Ranging demonstration would be to show precision ranging to prepared targets positioned on Earth's surface and/or on other spacecraft. Expected precision is in the two to five cm. range. The technologies which would be involved are listed in Table 6-6.

Table 6-7 provides a summary of hardware needs for the demonstration showing whether these needs should be supplied by the Spacelab, the SDTF or directly as being demonstration provided. This listing shows that this demonstration does not impose any further hardware requirements on the STDF beyond what has already been considered. Furthermore, the data handling requirements are generally less severe than those identified for the Image Registration demonstration. Hence no additional computer requirements are anticipated.

TABLE 6-5

SOME POTENTIAL TECHNIQUES AND ULTIMATE APPLICATIONS OF LASER RANGING CAPABILITY

LASER RANGING	TECHNIQUES	TYPICAL POTENTIAL APPLICATIONS
1. o Laser Ranging to Earth Sites	o Active ranging from Spacelab to retroreflectors (e.g. corner reflectors) placed at key locations on Earth.	o Measurement of tectonic plate motion to support geophysical scientific investigators o Measurement of geophysical creep at faults for Earthquake prediction, detection and quantification. o Measurement of flow in glaciers ice fields (e.g. as may be of interest to shipping safety)
2. o Laser Ranging to other Spacecraft	o Active ranging from Spacelab to retro-reflectors placed on other spacecraft.	o Precise measurement of spacecraft-to-spacecraft ranges can provide basis for improvement in definition of Earth gravity model.

TABLE 6-6

TECHNOLOGIES INVOLVED - LASER RANGING DEMONSTRATION

TECHNOLOGIES	SPECIFICS/COMMENTS
o Sensing	o Active sensing with pulsed laser on-board Spacelab
	o Solid state optical sensor for sensing of returned pulse.
	o Cooperatively located target (retro-reflectors)
o Data Handling	o Processing of returned signal so as to improve signal-to-noise ratio for improved range measurement has only modest computational requirements.
	o Compution of instrument (i.e. laser and sensor) pointing commands based on GPS ephemeris data, stellar inertial reference date and retro-reflector location data has less severe data processing requirements than does Image Registration demonstration.
o Display	o Range measurement display is numeric form.
o Instrument Pointing	o Pointing of laser and receiver must be directed with errors typically of about 3 to 10 arc secs. This can be accomplished with SIPS and high performance steallar inertial inference.
o Navigation	o GPS quality navigation needed for both computation of instrument pointing commands and also for demonstration validation.

Table 6-7. Demonstration Needs

Demonstration Needs	Spacelab-Provided	Demonstration-Provided	SDTF-Provided
• Mounting space for laser and receiver on instrument pointing system	X		
• Mounting space within pressurized module for experiment-specific electronic equipment (est. vol. 15 cm x 15 cm x 15 cm)			X
• Data Storage Capability			
- Pre-flight and updated stored data on experiment procedures, target locations, etc. (to be specified as to number of words, bits per word, serial or random access, max. access time, max BER, etc.)			X
- Data collected during experiment including measured range (or transit time) data, attitude, ephemeris and/or time data taken during ranging, target identification, measured SNR, etc. (to be specified as above)			X
• Data Processing to compute range from transit time, to compensate for atmosphere, to compute precision attitude from star and inertial sensors, to compute precision ephemeric from GPS and/or other inputs, to compute laser pointing commands based on ephemeris, attitude, pointing and target location data.			X
• Precision laser pointing mount, drive and interface with computer.	X or	X or	X
• Digital display of: present state of ephemeris, attitude, laser pointing direction, target identification and location, present computed pointing error, measured transit time and/or range, etc.			X
• Graphic display of ephemeris, attitude, target situation tracking error, etc.			X
• Up-link communications: update on experiment sequencing, targets, global weather conditions.	X		
• Down-link communications: telemetry of status data on key equipment, measured range data, progress reports of experiments.	X		

Table 6-7 (cont'd)

Demonstration Needs	Spacelab-Provided	Demonstration-Provided	SDTF-Provided
• Targets on Earth surface and in space (e.g. corner reflectors)		X	
• Manual control for laser mount (for override of automatic function)			X
• Cooling plate for laser	X		
• Laser, pulsed type		X	
• Laser receiver		X	
• GPS receiver and data processor	X	or	X

6.4 A LOW LIGHT LEVEL SENSING DEMONSTRATION

This would be a demonstration of using advanced electronic image intensification techniques to extend capability for Earth viewing during twilight and nighttime. A further objective is to use these techniques to improve astronomical capabilities in space by permitting viewing of more faint astronomical objects than would be viewable without image intensification.

Several alternative types of image intensifiers are available for this demonstration. Some types (i.e., "Generation I Types") have demonstratable optical gains as high as 200,000: 1. Other types ("Generation II Wafer Types) have somewhat more modest gains but are so very small and have such lightweight that they can be incorporated into head mounted viewing instruments (i.e., "goggles",. This latter type also has a high degree of positional linearity.

These devises are used in Earth-based operations for viewing at extremely low light level nighttime conditions.

The proposed demonstration would make use of these techniques in space to permit operations such as surviellance of shipping etc. during the night. These intensifiers have also been extensively used for faint star observations at Earth-based observatories. The proposed demonstration would extend this type of operation to Spacelab.

Table 6-8 summarizes some potential applications of image intensified viewing from space. These relate to either Earth viewing or astronomical viewing.

The objective of the Low Light Level Sensing demonstration would be to show extended capability for Earth viewing and/or sensing during twilight and nighttime as well as to show extended capability for detecting and observing faint astronomical objects. The technologies which would be involved are listed in Table 6-9.

Table 6-8. Some Potential Techniques and Ultimate Applications of Low Light Level Sensing from Space

LOW LIGHT LEVEL SENSING	TECHNIQUES	TYPICAL ULTIMATE APPLICATIONS
• Viewing Earth at night.	• Use of electronic image intensifier(s) by crew to observe dimly illuminated Earth surface. Consider both head-mounted wafer type intensifiers as well as spacelab-mounted larger "Generation II" intensifiers.	• Night time surveillance of marine activities including fishing and shipping as well as ice flow and iceberg movements. • Night time surveillance of natural disasters including floods. • Search and rescue operations.
• Faint Object Astronomy from Spacelab	• Use of image intensifiers and telescope to provide crew with capability to observe faint astronomical objects from Spacelab.	• Observation of faint objects extended to space platform which avoids atmospheric caused degradation of viewing.

Table 6-9. Technologies Involved - Low Light Level Sensing Demonstration

TECHNOLOGIES	SPECIFICS/COMMENTS
• Sensing	• Application of "Generation I" and "Generation II" wafer intensifiers with suitable optics for viewing by crew or detecting by other cameras or sensors.
• Displays	• Primary display would be that provided by phosphor screen of intensifier itself.
• Man-Machine Interface	• Some form of head constraint needed to immobilize head during viewing.
• Data Handling	• Minimal requirements relate primarily to storage and presentation to crew of target locational data.

Table 6-10 provides a summary of hardware needs for the demonstration showing whether these needs should be supplied by the Spacelab, the SDTF or directly as being demonstration-provided. Primary additional capabilities which should be added to the SDTF as a result of considering this demonstration are:

- o A Head Constraint for crew viewing.
- o Audio Tape Recorder.

The data processing requirements are significantly less than those of other demonstrations considered above and therefore do not impact the SDTF data handling requirements.

Table 6-10. Demonstrated Needs

	Spacelab-Provided	Demonstration-Provided		SDTF-Provided
• Image Intensifiers (several types)		X		
• Telescope Optics		X		
• Night Vision Goggles		X		
• Power supplies or power conditioning for intensifiers		X	or	X
• Video Displays				X
• Tape Recorder (for note taking)	X		or	X
• Head Restraint (to facilitate viewing with "goggles")		X	or	X
• Photographic Camera. (e.g., Polaroid type) for recording displayed images				X
• Viewing Port and/or High Quality Window directed to Earth and stars (as required)	X			

7.0 DESIGN OF THE SPACELAB DATA TECHNILOGY FACILITY

7.1 APPROACH TO THE DESIGN

The initial design approach discussed in this section is based primarily on requirements identified in Section 5 for the Real Time Image Registration demonstration and is further refined by the requirements of the three additional demonstrations identified in Section 6. Although these demonstrations provide the chief design requirements it is also judged that the facility should be capable of supporting a wide range of other demonstrations.

Demonstrations of interest include those requiring support of a payload specialist as well as those not having such a requirement. Likewise the SDTF should be capable of supporting both demonstrations which are primarily housed in the pressurized module as well as those which are mounted on the pallet.

In order to most effectively support such a wide range of demonstration types it is advantagous to design the facility to have significant modularity and operational flexibility. For example, if on a given spacelab flight, only demonstrations not requiring interaction with a payload specialist were to be flown then the man-machine interface modules including displays and keyboards might be deleted from the facility to be flown on that flight. This could provide additional volume for locating hardware specifically dedicated to a demonstration or experiment.

As described below the facility will consist primarily of computational and data storage capabilities, man-machine interfaces in the form of displays and controls, as well as various electrical and mechanical interfaces between the facility and the demonstration specific hardware which may be located either within the pressurized module or on the pallet.

An assumption is made that an instrument pointing system (e.g. IPS or SIPS) is available on the pallet as needed for specific demonstrations.

7.2 FACILITY REQUIREMENTS BASED ON DEMONSTRATION NEEDS

The hardware needs forthe Image Registration demonstration have been identified in Section 5. . The corresponding data handling needs for that demonstration are identified in Table 5.6. As discussed these needs provide the primary basis for design specifying the requirements of the SDTF.

These design requirements are further supplemented by the needs of the three other demonstrations discussed and tabulated in Section 6.

7.3 COMPARISON AND SELECTION OF ALTERNATIVE COMPONENTS AND SUB-SYSTEMS

SDTF design alternatives for meeting these requirements identified for the demonstrations are compared in this section and specific recommendations will be made to meet each of these design requirements. As will be shown, it will be convenient to incorporate the primary components of the SDTF in a standardized single width Spacelab rack.

SOFT DISPLAY REQUIREMENTS

To meet demonstration requirements the facility must incorporate capability for soft display of both imagry data and alpha-numeric data. To provide the needed display capability two identical soft displays capable of displaying both image and alpha-numeric data are recommended. The existence of two such displays can provide the flexibility of many possible simultaneous display options as needed by the demonstrations. Some of these needs are:

- o Display of presently sensed imagry and previously sensed imagery recalled from data storage.
- o Display of imagery of the same scene sensed with different sensors or in different spectral bands.
- o Display of sensed imagery data simultaneously with extensive collateral data in alpha-numeric form.
- o Simultaneous display of raw imagery data and corresponding corrected re-registered imagery.

As discussed below these displays would also be capable of displaying inputs obtained from interactive operations by the payload specialists.

In order to provide the optimum flexibility and capacity for interactive display of imagery a tri-color display is recommended. Current and previous work with interactive displays of this type have shown that a 19 inch diagonal screen format is a convenient display size for the operator. This is also the maximum size display which can be accommodated in a standard single width Spacelab rack.

A projection of the state of the act for the next 20 years indicates that the above display requirements can be best met with standard 19 inch diagonal tri-color (green, yellow, red) cathode ray tube (CRT) displays. Each can have the same capability to display either alpha-numeric data, image data or some super-imposed combination of these. A minimum of 128 different symbols, for example, can be made available for display.

The video displays should be located in the facility at a convenient eye level for use by the crew. The preferred location of the SDTF rack is in proximity to the overhead viewport and the precision optical window. This would permit the payload specialist to view with near simultaneity the soft displays and a direct scene as presented to him by this viewport and window.

CONTROL AND DATA INPUT UNIT

The SDTF Control and Data Input Unit is the primary means by which the payload specialist directly addresses the SDTF and indirectly addresses the demonstrations which are making use of it. It also provides interactive control shown to be needed by the demonstration of sensed data and its display for purposes of interpretation and analysis.

Both digital and analog control types of data inputs are needed by the Image Registration demonstration as well as by the other demonstrations which have been considered. Standard types of keyboards are expected to continue to provide the most convenient means for inputing of digital data into the facility. Various versions of two axis joysticks and control knobs are available for providing needed real time analog control data. This type of control input is needed, for example, for coarse pointing and acquisition of the instrument pointing system and also, for example, for interactive positioning of computed display reticles on the soft image displays.

A standard keyboard with 45 alpha-numeric symbol and control keys is recommended. Two control joysticks on control knobs of a type to be more fully specified at a later stage of the design also recommended. Control switches and knobs are also provided on this unit for direct control of the operating parameters of the CRT displays (e.g. controls for image brightness, contrast) as well as for other descrete commands needed for the facility. It is recommended that this Control and Data Input Unit be located below the CRT video displays for convenient use by the crew.

ADDITIONAL METER AND SWITCH PANEL

It is recommended that an addition meter and switching panel be located in the facility preferably in an overhead location above the two video displays. This panel would be available to provide further display and control functions which can be identified for specific functions. Because the overhead location is somewhat less accessable than the location recommended for the control and Data Input Unit it is expected that this additional panel would be used to satisfy the non-primary and/or less frequently addressed control and display needs of the demonstrations. It is expected that this panel would incorporate analog and digital meters as well as switches and controls in a configuration to be more fully specified during a later stage of the design.

DATA PROCESSOR

The facility should be designed to incorporated the data processing load as required to perform the image registration demonstration using the CID sensor. The primary data processing requirements for that demonstration has been tabulated in Section 5.

As discussed previously these data handling requirements are generally more extensive than most of those identified for the three demonstrations identified in Section 6 and hence will serve as the basis for design specification of the SDTF data processing. However, as also previously noted, a more advanced version of the Heads Up demonstration which makes use of computer-generated imagery will also be expected to require data processing as extensive as that required for the Image Registration demonstration.

Table 5.6 has indicated a need to perform an equivalent of 609,000 ADD's per second. This assumes a computer designed with one MULTIPLY being equivalent to 10 ADDS. A 25% increase in capacity is recommended to account for increased word length of some computations and possible uncertainties in the present design specification. This results in a data processor needed to perform 750,000 equivalent ADD's per second.

The SDTF data processor should also incorporate data storage requirements as listed previously in Section 5 and as modified for the Image registration demonstration based on application of the CID Type of sensor. Including allowances for uncertainties and contingencies. this results in a need for a storage in core of an estimated 3×10^7 bits. This includes refresh storage for the displays and storage of pre-computed data needed during the demonstration as well as data computed and used during the demonstration. It does not include archival storage of payload sensed data.

Based on the above and specific needs of the demonstration the SDTF data processing and data storage needs are summarized in Table 7-1.

A SDTF data processor based on these requirements will permit significantly greater computational capability than will be available with the three computers to be provided by the Spacelab Command and Data Handling System (CMDS). Indeed, it will provide the capability of present day "large scale" general purpose central processing units (G.P. CPU). As such the inclusion of such a computational capability in the SDTF will require a significant development program. Nonetheless it is this magnitude of computational capability which may be expected to be developed using large scale integration (LSI) techniques for operation in the mid 1980's and beyond.

The alternative of a specialized hardwired data processor dedicated to the specific image registration needs represents an alternative to the large capacity spaceborne GPU. However, because of its capability to meet the needs of a wider range of demonstration the general purpose spaceborne computer is presently favored. This, however, is a design area which needs further investigation.

MEMORY OF DEMONSTRATION DERIVED DATA

This memory may be provided as an optional alternative to the primary approach which depends on down link transmission of demonstration-derived data via the Orbiter-TDRSS wideband data link. Such on-board storage can provide for data storage during any portion of the orbit when the Orbiter-TDRSS data link is not operative and, during which time, it may be attractive to operate the demonstration. This includes periods of time when the TDRS is obscurred during many Earth orbiting missions. This can be up to 50% of some orbits depending primarily on orbit inclination. Based on the data projected to be collected during the Image Registration demonstration a possible need for a payload devised data storage having a 5×10^8 bit capacity and with read-in rates in excess of 2 megabit/sec is projected. Because, however of the expected availability of the Orbiter-TDRSS downlink the

Table 7-1. Summary of SDTP Data Processing Needs

• Equivalent Add/Second:	750,000
• Bits per word:	16
• Precision:	Double Precision
• Equivalent Adds per multiply:	10
• Data Storage:	3×10^7 Bits

inclusion of this archival data storage unit is presently regarded as being optional.

Based upon the projected state of art of space-borne archival storage of digital data it is expected that this function could be best provided by a magnetic tape recorder.

INPUT/OUTPUT DATA UNIT

The function of the Input/Output Data Unit is to provide the coupling link to and from the facility computer. Specifically it provides the interface and switching function between the facility computer and the RAU, the data storage units, the data displays and the keyboard and other control units.

DATA MULTIPLEXER AND DATA TRANSMISSION SUB-SYSTEM

This multiplexer formats the serial data flow from the experiment(s) and demonstration(s) in preparation either for its real time transmission to ground via the Orbiter/TDRSS wideband Ku band processor and data link or, alternatively for its storage in a wide band data storage (tape recorder) which can be optionally incorporated as one of the modules of the facility. When used with a wide band data storage it will be also capable of accepting playback data for multiplexing prior to its down link transmission. The multiplexer should be designed to handle data rates up to 10 megabits/sec.

Figure 7-1 shows a "typical spacelab-to-ground flow of demonstration-derived data". It shows the wideband data derived from the image registration demonstration being processed by the SDTF High Data Rate Multiplexer prior to its being transmitted via the Spacelab CDM and the KU band Signal Processor and the TDRS down link to the ground. Here the wideband data is available for interpretation and evaluation.

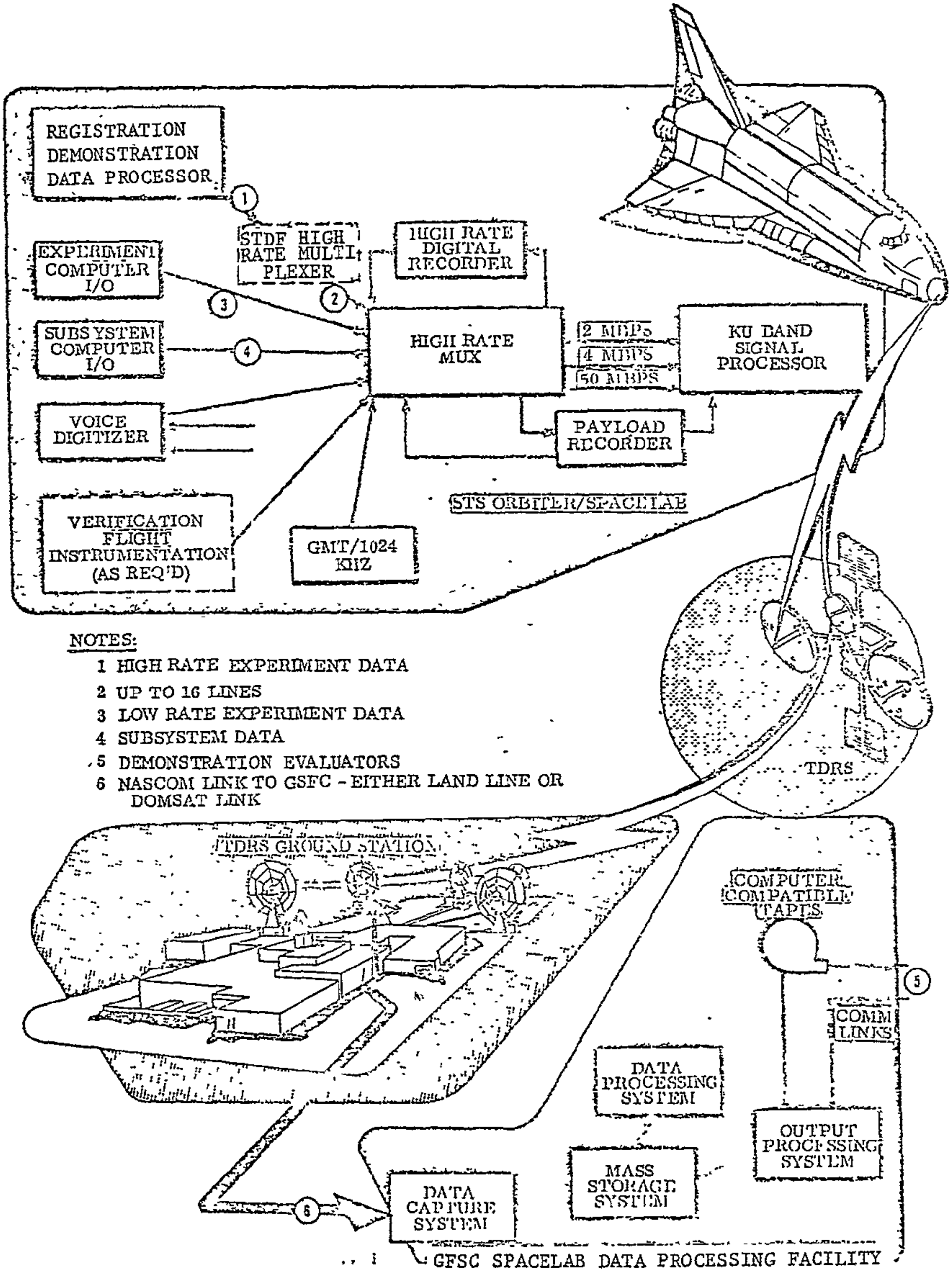

Figure 7-1 A Typical Spacelab-to-Ground Flow of Demonstration-Derived Data

REMOTE ACQUISITION UNIT (RAU)

The bi-directional communication and command interface function between the Spacelab Command and Data Management System (CMDS) and also the between STDF and the demonstrations served by it is performed by Remote Acquisition Unit (RAU). This is a standard piece of GFE hardware which is available for all Spacelab equipment racks. Inputs and outputs of the RAU include analog signals, discrete command signals, low bit rate digital data and clock up-data signals. The RAU functions include sampling and analog to digital conversion of experiment derived analog data and may also include error correction encoding of that data. A single RAU is incorporated in the facility at the bottom of the rack just above the rack's electrical power switching panel to provide this function.

Figure 7-2 which has been extracted from the ESA Spacelab Payload Accommodation Handbook shows the components and dimensions of the "experiment-type" of RAU. This is the larger of two types of RAU's. Unlike the smaller or "sub-system" type of RAU this RAU accommodates PCM input and output data and has a user time clock for precision reference timing data as well as the power supply module, core module and interface module.

This Rau incorporates 128 flexible differential inputs for analog or discrete signals as well as 4 serial PCM data input channels with associated clocks. Its output capability includes 16 on/off command channels, 4 serial PCM command channels, 4 user clock channels and 4 user clock update channels. The RAU is address perioically at intervals which can be selected as 10 ms, 100 ms or 1 sec.

ELECTRICAL POWER SWITCHING PANEL (EPSP)

The EPSP is a standardized power control unit incorporated within the STDF. It provides control and distribution, as well as fused current protection for all powered components in the SDTF rack. Its functions are manually controlled by means of switches on the front panel.

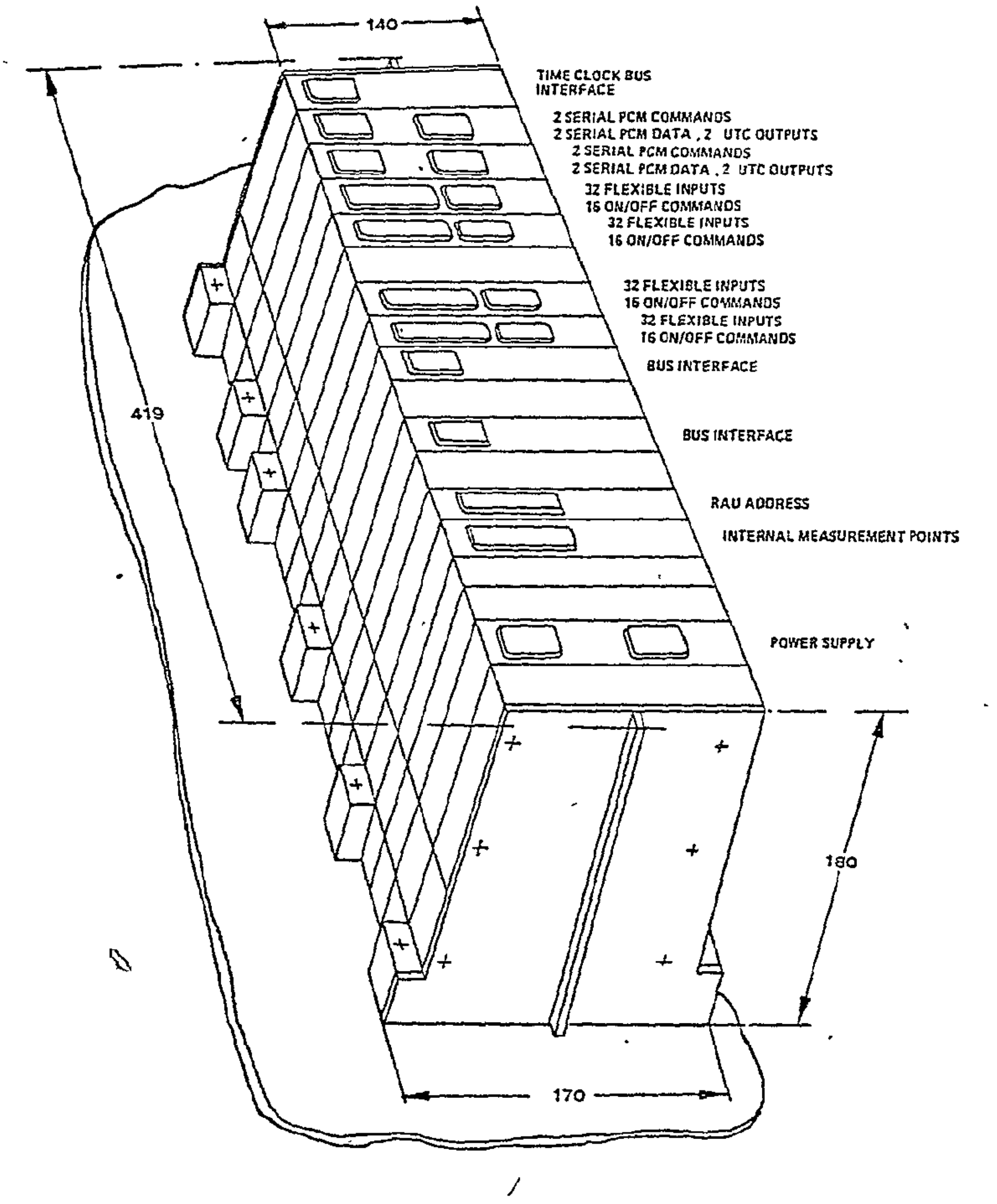

FIG. 7-2 PHYSICAL RAU DIMENSIONS

- Rack internal connections (externally switchable) are:
  - (4) DC outputs 28 ± 4 volts (35 amp protection per output)
  - (1) DC output 28 ± 4v (not fused in EPSP but protected at 75 amp in Spacelab Electric Power Distribution Box)
  - (2) AC outputs, 3 phase 115/200 volt 400 Hz (protected at 3 amp per phase)
- Power available at EPSP front outlet:
  - (1) DC output, 28 ± 4 volts (7 amp protection)

POWER CONDITIONING UNIT

A facility power conditioning unit is recommended to supply non-standard electric power requirements which any of the data technology related experiments may have. Non-standard power, as used here, refers to any power requirements other than the 28 volt DC power and the 115 3 phase 400 Hz power made available by the Spacelab Electric Power Distribution System (EPDS). A specific application example might be to supply the high voltage excitation needed for operation of some of the Image Intensifiers used in a Low Light Level sensing demonstration.

7.4 SERVICES PROVIDED BY THE SPACELAB TO THE SDTF

The Spacelab must provide services for the SDTF:

ELECTRIC ENERGY

Electrical energy is derived from the Orbiter hydrogen/oxygen fuel cells and stored in energy kits. Electrical power will be available at 28 ±4 volts DC and 115 ±5% volts 3 phase power at 400 ±1% hz. Power is supplied by the Spacelab power bus via the experiment power distribution box nearest to the facility. Within the rack the power is distributed by the Experiment Power Switching panel located at the bottom of the rack.

For early Spacelab flights a maximum power of 1.9 kw will be available for all experiment and demonstration purposes (i.e. this power available does not include that which is required by the Spacelab Sub-Systems). For later flights this is expected to increase from 1.9 kw to 4 kw and eventually to 7 kw.

The power levels required by the SDTF will vary with the nature of the demonstrations and the combination of demonstrations which may be flown and operated at any flight. In order to more completely define the STDF power requirements the power requirements will be analyzed for each demonstration in order to determine the total payload system electrical power demand. Basic data required from all STDF equipment and demonstration-specific hardware will include as a minimum:

- Power/time profile.
- Standby, average, and maximum power for each component.
- Required voltages and frequencies
- Regulation
- Thermal control power
- Power distribution
- Safety and protection needs
- Any EMI problems and control requirements

Based on the needs of the registration demonstration and specific SDTF component needs the power requirements are itemized and estimated in Table 7-2.

THERMAL CONTROL

The Spacelab must provide heat rejection to the STDF which is in proportion to the electrical power utilized in it. Heat rejection can be provided to the STDF by a combination of avionics air cooling and by a system of heat exchangers. The primary cooling made inside the rack will be by air cooling provided by the "avionics cooling loop" or the "cabin cooling loop". These loops provide a maximum of4.5 and 2.7 KW heat rejection capability, respectively, for in pressurized module purposes. The SDTF needs must be met by some as yet undetermined fraction of this.

The air avionics flow loop within the rack is shown as part of the assembly design in Figure 7.5.

Liquid cooling is available in the Spacelab for both in cabin and on pallet purposes. The prime liquid loop is freon. This loop cannot be used directly for cooling rather it must be used by interfacing with a liquid-to-liquid heat exchanger which, if needed, is supplied by the user. The secondary loop liquid can be either freon or water. The exchanger transfer capacity is 4 kw. Cold plates each of which has a 1 kw capacity are driven by the secondary loop and can be used, if needed, to cool equipment either on the pallet or in the module.

Based on the needs of the SDTF and the hardware specifically dedicated to the requistration demonstration the cooling requirements are quantitatively the same as the electrical power requirements summarized above.

Based on these needs the available heat transfer capability provided by the avionics air cooling system these loops are judged to be adequate. No liquid cooling is judged to be required for the SDTF as designed for the image registration demonstration.

Table 7-2. Estimated Electrical Power Requirements

	400 Hz 115/200 V AC			28 V DC		
	Normal (watts)	Peak (watts)	Standby (watts)	Normal (watts)	Peak (watts)	Standby (watts)
• <u>BASELINE STDF COMPONENTS</u>						
(1) CRT Display (#1)	150	150	-			
(2) CRT Display (#2)	150	150	-			
(3) Control and Data Input Unit				10	20	-
(4) Digital Data Processing Unit	200	300	20			
(5) Digital Data Storage (except Archival)	20	20	10			
(6) RAU	10	10	-			
(7) Input/Output Unit				10	10	-
(8) Data Multiplexer				10	20	-
(9) Wideband Data Archival Storage	50	100	10			
(10) Additional Meter and Switch Panel				10	10	-
(11) Recessed Work Area	-	-	-	-	-	-
(12) Power Conditioning Unit	20	100	-	20	50	-
(13) EPSP	-	-	-	-	-	-
(14) Scan Conversion Electronics	10	20	-	-	-	-
(15) Audio Tape Recorder	10	20	-	-	-	-
(16) Volume Available for Demonstration - Specific Equipment						
(17) Ditto						
• IMAGE-REGISTRATION DEMONSTRATION - SPECIFIC EQUIPMENT						
• SENSOR	20	20	-	-	-	-
TOTAL POWER REQUIREMENTS	640	910	40	60	110	0

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INSTRUMENT POINTING

It is anticipated that the spacelab will provide the SDTF with a pointing mount (IPS or SIPS) for mounting of sensing instruments. It is anticipated that this mount should be controllable from either the SDTF or from the Control and Data Management System (CDMS) sub-system of the Spacelab.

The IPS is believed to be presently baseline equipment for Spacelab. It incorporates a Gimbal System for pointing of payloads mounted on it. It also incorporates a Payload Clamp Assembly consisting of three clamping mechanisms to support payloads.

7.5 SUMMARY OF SDTF COMPONENTS

A summary of components and sub-systems is presented in Table 7-3. This is based on a comparison of alternative hardware which has been presented in Section 7.3. The Table also presents estimates of the weight, dimensions and volume of the hardware items based on projected state the art of this hardware. It also includes estimates of volumes within the single rack which should be available for demonstration-specific usages. This latter volume when added to the volume occupied by the facility components equals the total volume by the single rack.

The estimated combined weight of all of the facility hardware to be mounted is 131 kg. This compares to a rated single rack carrying capacity of 290 kg.

Table 7-4 summarizes additional SDTF equipment resulting from the requirements of the three additional demonstrations discussed in Section 6. This equipment may be stored in one of the available storage compartments when not in use.

Table 7-3

SUMMARY OF FACILITY "RACK" COMPONENTS

MODULARIZED COMPONENT	WEIGHT (kg)	SIZE (CM) (H x W x D)	VOLUME (cm^3)
1. CRT Display (#1)	15	40 x 45 x 45	81 (10^3)
2. CRT Display (#2)	15	40 x 45 x 45	81 (10^3)
3. Control and Data Input Unit	2	20 x 45 x 5	5 (10^3)
4. Digital Data Processing Unit	25	30 x 45 x 42	70 (10^3)
5. Digital Data Storage (except Archival Storage)	15	15 x 45 x 60	40 (10^3)
6. Remote Acquisition Unit (RAUO	7	17 x 41 x 18	10 (10^3)
7. Input/Output Data Unit	16	30 x 45 x 40	55 (10^3)
8. Data Multiplexer	3	30 x 20 x 15	9 (10^3)
9. Wideband Archival Data Storage	20	25 x 45 x 45	50 (10^3)
10. Additional Meter and Switch Panel	3	30 x 45 x 5	9 (10^3)
11. Recessed Working Area (convertible to desk drawer and experiment volume)	0	20 x 45 x 33	30 (10^3)
12. Power Conditioning Unit	7	25 x 45 x 15	17 (10^3)
13. Electrical Power Switch Panel (EPSP)	2	40 x 12 x 12	4 (10^3)
14. Scan Conversion Electronics	1	6 z 12 x 15	1 (10^3)
15. Audio Tape Recorder	2	20 x 10 x 10	2 (10^3)
16. Volume Available for Demonstration-Specific Equipment	0	40 x 45 x 32	60 (10^3)
17. Ditto	0	20 x 45 x 55	50 (10^3)

Table 7-4. Additional SDTF Components

COMPONENT	FUNCTION	COMMENT
• Audio Tape Recorder	• For crew convenience in demonstration-related note taking.	• Small module wheel can be incorporated in SDTF rack or stored in storage compartment.
• Photographic Camera(s)	• To provide rapid storage and assessment of displays.	• Likely a "Polaroid" type stored when not in use in overhead storage volume.
• Photo Slide Display	• For display of pre-stored cue purposes.	• Likely consists of small commercially available unit stored when not in use in overhead storage volume.
• Head Constraint	• To immobilize head of drew member to avoid unwanted parallax and image motion when viewing HUD type of display or during low light level viewing.	• A component to be further defined. Likely stored when not in use.

7.6 INITIAL DESIGN OF THE SDTF

CONFIGURATION AND LOCATION OF FACILITY

- The primary configuration requirement of the SDTF can be met by a single standardized spacelab rack. The preferred location within the pressurized module is near the overhead viewport and high quality window. This would permit the payload specialist to have near simultaneous direct view to the outside and also view and access to the interactive displays and controls of the SDTF. It is anticipated that the primary part of the SDTF will be an integrated rack configuration having standardized design for all flights, missions, and demonstrations where it will be needed but also having modularity of design so that specific modules not needed on any mission can be deleted.

This primary part of the facility will be supplemented, as appropriate, with facility dedicated interfaces between the primary facility rack and demonstration-specific equipment located on the instrument pointing system or elsewhere on the pallet or, alternatively, in the pressurized module.

- The facility will consist of components of these Types:
    - Man-machine interface devices (i.e. displays, controls and control panels) which clearly must be located in the pressurized module.
    - Electronic-related devices (e.g. computer, data storage).
    - Interface and other devices (e.g. mounts, enclosures) which must be located in vicinity of demonstration-related hardware.
    - Space and interfaces for demonstration specific hardware.

As discussed, it is advantagous to design the facility to be functionally modularized so that it can be most effectively adapted to a wide range of demonstration types. However it is also advantagous to design the facility so that all of its modules (excepting those components which must, of necessity, be located adjacent to remotely located demonstration-specific equipment) can be co-located in the same rack rather than have them distributed in several racks on other locations in the Spacelab.

It will be shown that all mountable components of the facility (again excepting components which must be co-located with remotely located demonstration-specific hardware) can be accommodated in a single standard Spacelab rack. A single standard Spacelab rack is rated for carrying up to 290 kg of equipment. It has a width of 56.3 cm. It is recommended that the equipment modules be so located in that rack such that those modules which may not be needed on a given mission can be readily deleted. This will provide more space for demonstration-specific hardware or for other purposes for these missions. The primary candidates for deletion are those modules having a crew interface function (i.e. displays, controls etc.).

In order to enable the experiment specialist to most effectively operate with the Image Registration demonstration and other demonstrations which involve external viewing it is recommended that the facility rack be so located within the Spacelab such that the payload specialist can have near simultaneous viewing access to the overhead viewport and high quality window and also the interactive displays and controls of the facility.

OVERALL DESIGN

The overall design of the SDTF rack is developed by fitting the various selected components and sub-system as discussed previously in the most appropriate locations in the rack. The two soft displays must be located at convenient eye level for the crew. The control and data input unit can be most advantagously located below these two displays so as to allow the crew to operate with it while observing the soft displays. The less frequently used additional meter and switching panel can be conveniently located above the topmost of the two CRT displays.

The RAU must be located near the floor in a location and orientation as specified in the Spacelab Payload Accommodations Handbook so as to provide optimum interface with the Spacelab electrical bus. The exact location within the rack of most of the remainder of the electronic equipment is not critical so long as the c.g. limits within the rack are maintained as specified in the Spacelab User's Manual. Space which is made available for demonstration equipment should generally be located for easy access by the crew.

Based upon these design constraints and considerations a sketch of the initial design is presented in Figure 7-3. The module numbers correspond to those used in Table 7-3.

The rack incorporates a standard set of horizontal struts at the rear of the rack for mounting of experiment cabling. The same struts support the air cooling ducts and a fire suppression line.

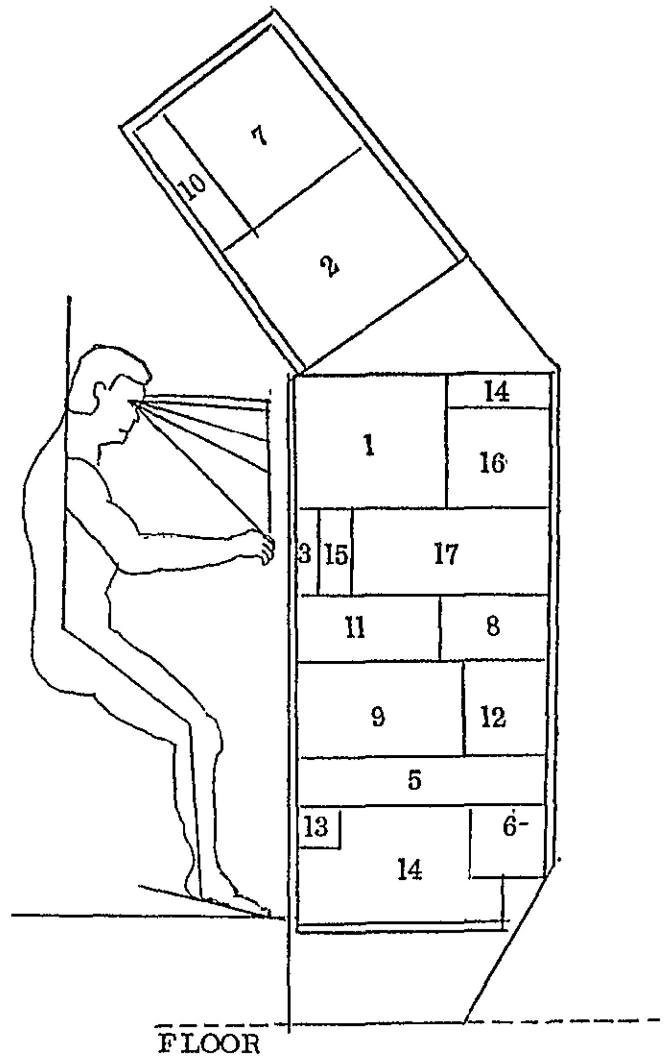
Mounting of the components shown is accomplished by a combination of front panel to frame attachments and shelving, runners and rails especially located for mounting purposes.

Figure 7-4 shows how the SDTF rack may typically fit into the pressurized module of the Spacelab. It shows the SDTF rack located in Rack 6 on the port side as being convienent to the overhead viewports. It also shows in overhead racks and under the floor which is available for storage of demonstration equipment not presently being used.

Figure 7-5 shows some of the key installation functions and interface of the SDTF rack. It shows the cabling interfaces between the Spacelab and the Remote Acquisition Unit and the Electric Power Switching Panel. Also shown is how the avionics air conditioning air flow circulates in the rack. Finally the structural attachment of the rack to the floor and also to the overhead structure are shown

MODULARIZED COMPONENT

1. CRT Display (#1)
2. CRT Display (#2)
3. Control and Data Input Unit
4. Digital Data Processing Unit
5. Digital Data Storage (except Archival Storage)
6. Remote Acquisition Unit (RAU)
7. Input/Output Data Unit
8. Data Multiplexer
9. Wideband Archival Data Storage
10. Additional Meter and Switch Panel
11. Recessed Working Area (convertible to desk drawer and experiment volume)
12. Power Conditioning Unit
13. Electrical Power Switch Panel (EPSP)
14. Scan Conversion Electronics
15. Audio Tape Recorder
16. Volume Available for Demonstration-Specific Equipment
17. Ditto



SPACELAB TECHNOLOGY FACILITY "SINGLE RACK" PRELIMINARY DESIGN

FIGURE 7-3

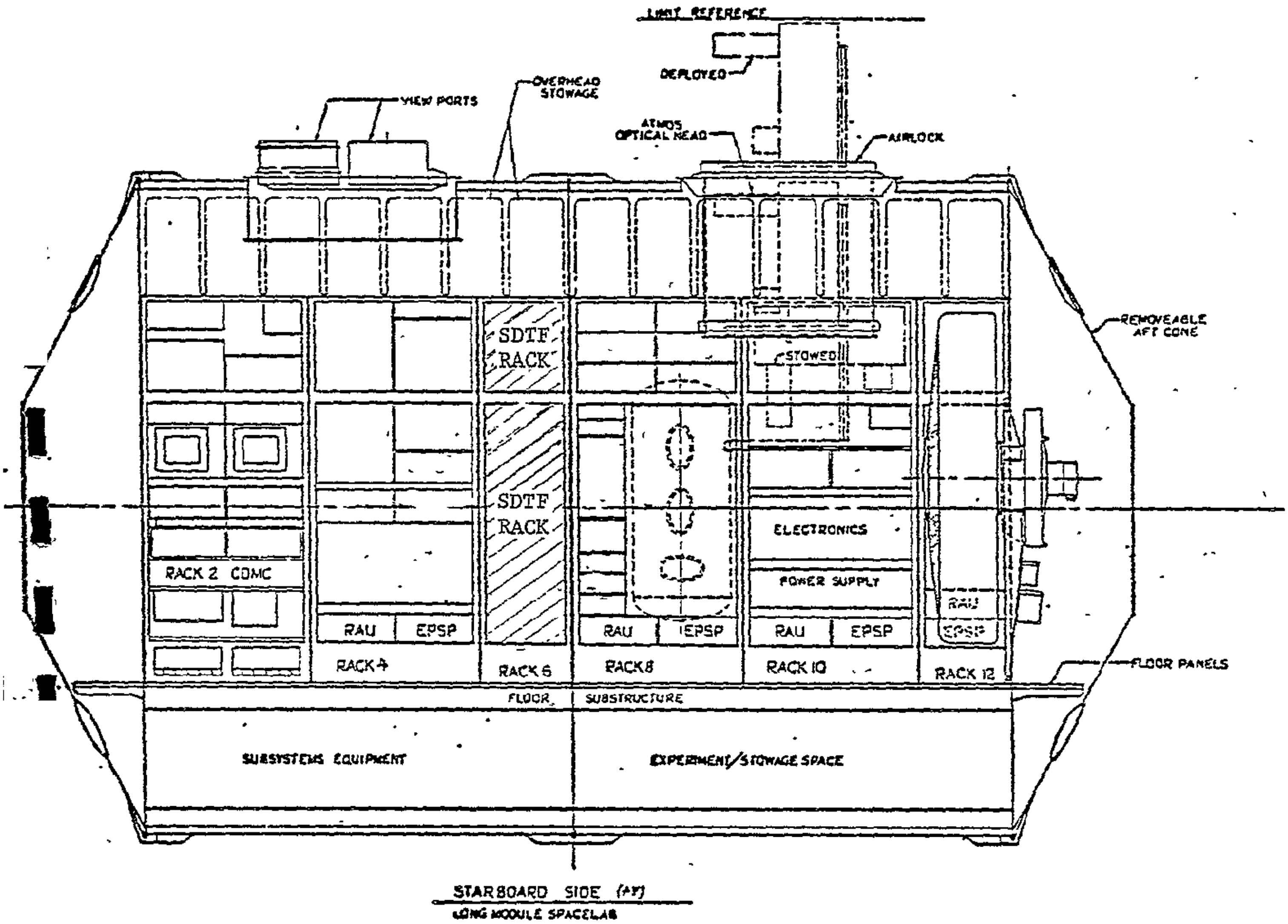


Figure 7-4. Preliminary Configuration of SDTF Rack. Shown Located in Rack 6 on Port Side of Pressurized Module
(Experiments in other Modules not Presently Specified)

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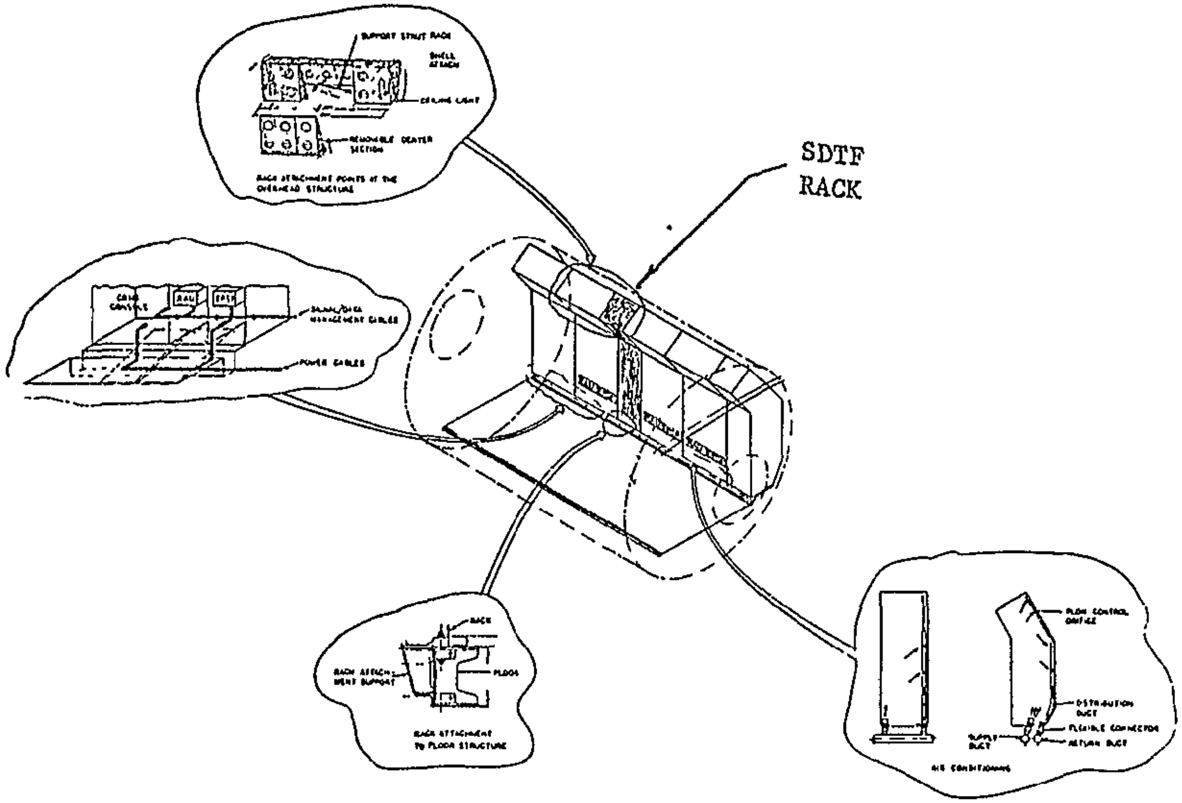

Figure 7-5. Assembly and Installation Design of SDTF Rack

SDTF CENTER OF GRAVITY CONSTRAINTS

The design of the rack must conform to existing center of gravity constraints which are imposed on the racks. As shown in Figure 7-6 taken from the Spacelab Accommodations Handbook there is a generous latitude allowed for c.g. location even for a maximum single rack mass of 290 kg.

As stated before the expected SDTF rack equipment weight will be about one half of this and the latitude in c.g. location can be expected to be even larger. Consequently c.g. location control is not regarded as a difficult problem.

DIRECT VIEWING ACCESS

Most demonstrations, such as the Image Registration Demonstration, which involve earth viewing and real time interaction of the crew will either require, or could profit from, access by the crew of a direct view of earth either through a viewport and/or the high quality window. For this reason it is recommended that the facility be located and designed to operate with direct view access through the overhead viewport and the high quality window. This view capability should be made available to both the crew and also, as required, to sensors which can be mounted at the viewport or at the high quality window. In addition to the direct view by the crew member which would be possible by tilting his head upward toward the ceiling it is also suggested that a direct view be also provided through a specially designed periscope (not shown in the figure). The periscope could be designed so that its output image could be viewed at the same eye level and orientation as used for observing the CRT video displays. The periscope should be designed with two manually controllable angular degrees of freedom. This would permit, for example, angular view coverage within a 45° cone centered about an axis to nadir when the Spacelab is oriented (inverted) toward Earth. The recommended conical field of view of the periscope is 10°. The present orientation in two axes of the periscope could be one of the read-out options which can be called for on the CRT display. The periscope should be designed so that it could be removed from the viewport when the viewport is used for direct viewing or for other purposes.

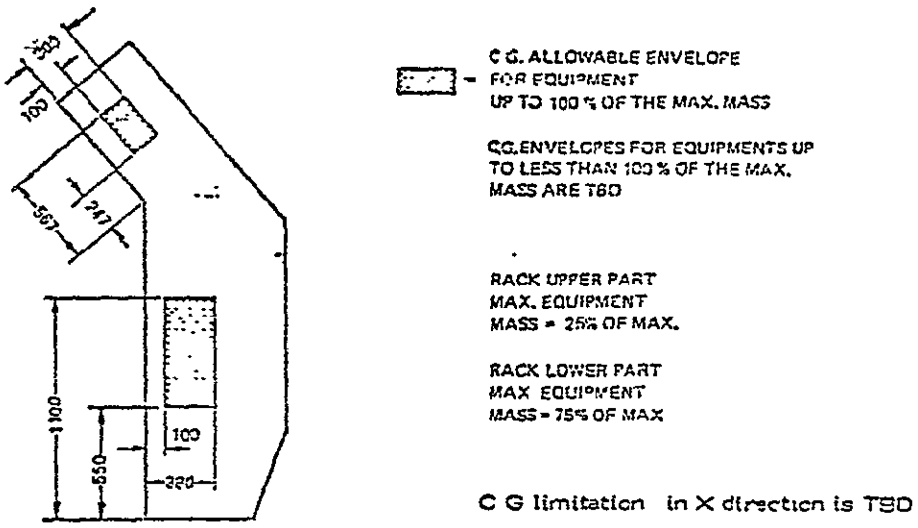

Figure 7-6 C.G. Mass Distribution Limitations

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Although it is expected that most sensor-related demonstrations would make use of the instrument pointing system located in the pallet, the facility should also provide the option of mounting a sensor behind the precision viewing window. This option has the advantage, for example, of permitting the payload specialist to directly interact with, replace or otherwise modify, the sensor. It is also recommended that provision would be provided for pointing this sensor by slaving it to point in the same direction or the periscope.

VOLUME AVAILABLE IN FACILITY FOR DEMONSTRATION - SPECIFIC EQUIPMENT

In order to provide for the support of a number of different types to demonstrations, other than the Image Registration demonstration, it is recommended, as shown in the figure, that certain volume within the facility rack be made available for data processing related demonstrations which can be performed in a relatively small volume. These available volumes can include both space which is always available for demonstration equipment as well as space which is made available when other modularized equipment may not be needed when no-data-technology related demonstration on a given flight requires real time interaction with the crew). Appropriate control, communication, mechanical environmental and power interfaces should be provided to these volumes as is appropriate for the specific demonstrations being considered.

ILLUMINATION CONTROL

The anticipated normal spacelab ambient illumination of 200 to 600 lumens per square meter can be expected to interfere with low light level viewing operations. Because of this potential interference in direct viewing through theviewport, the high quality window or in viewing of CRT displays the facility should incorporate ambient spacelab illumination control. This should include provision directly at the facility for dimming and/or extinguishing Spacelab interior lights. If necessary it may also include provision for screens or curtains which can be deployed about an area enclosing the precision viewing window, the overhead viewport and the CRT soft displays.

APPENDIX A

SELECTED DATA TECHNOLOGY RELATED RTOP's

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY RTOP's

SUBJECT	TITLE	NO./CENTER	COMMENTS
(1) LARGE ERECTABLE MIRROR	LARGE ERECTABLE SPACE STRUCTURE	506-17-11/LaRC	30 m MIRROR FOR POWER TRANSMISSION BOOMS, PLATFORMS, ANTENNAS ETC.
(2) LARGE ERECTABLE ANTENNAS	ADV. CONCEPTS FOR SPACECRAFT ANTENNA STRUCTURES	506-17-15/JPL (1975)	IMPROVE DEEP SPACE COMM.
(3) CCD VIDEO CAMERA	ADV. IMAGING SYST. TECH.	506-18-11/JPL	IMPROVED SENSITIVITY CAMERA BEING DEVELOPED UNDER CONTRACT FOR PLANETARY FLY BY MISSIONS USING 400x400 ELEMENT CCD ARRAY
(4) ENVIRONMENT SENSING	HIGH RESOLUTION SENSORS	506-18-12/LaRC	VARIOUS TECHNIQUES INCLUDING LIDAR, IR DIODE LASERS, UV SENSORS, ULTRASONIC SENSORS
(5) E-O SENSORS FOR SPACE TELESCOPE	ASTRONOMICAL HIGH RES. SENSOR	506-18-13/GSFC	RELATES ALSO TO "REAL-TIME IMAGE PROCESSING". CCD SENSORS FOR ASTRONOMY
(6) ACTIVE LASER TECHNIQUE	HIGH RESOLUTION SENSOR DEVELOPMENT	506-18-15/WAL.	EMPHASIS ON LASER TECHNIQUES APPLIED TO OCEANOGRAPHY
(7) WIDE RANGE OF NEW ELECTRONIC COMPONENTS	ELECTRONIC DEVICES AND COMPONENTS	506-18-21/LaRC	DEVELOP NEW COMPONENTS: IR DETECTORS, SPECTROMETERS, VARIOUS MEMORIES, DISPLAYS ETC.
(8) FIBER OPTICS	FIBER OPTICS FOR DATA TRANSMISSION AND PROCESSING	506-18-23/JPL	EMPHASIS ON CCTV FOR SHUTTLE
(9) LSI ARRAYS	DESIGN, PROCESSING TEST OF LSI ARRAYS	506-18-31/MSFC	OBJECTIVE: TO IMPROVE PERFORMANCE AND REDUCE COSTS OF LSI CIRCUITS
(10) CMOS	PREDICTABLE LONG-LIFE COMPONENT TECHNOLOGY	506-18-33/JPL	RELIABILITY/MODES OF FAILURE OF CMOS (RELATES TO OTHER RTOP's ON ELECTRONIC RELIABILITY

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OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY RTOP's (CONT'D)

	SUBJECT	TITLE	NO./CENTER	COMMENTS
(11)	LASER GYROS AND RELATED INERTIAL SYSTEM	INERTIAL COMPONENTS	506-19-11/MSFC	HIGH ACCURACY LASER GYRO AND HIGH RELIABILITY SYSTEM
(12)	CONTROL COMPONENTS	ADV. COMPONENT FOR PRECISION CONTROL SYS.	506-19-12/GSFC	EMPHASIS ON MECHANICAL ACTUATION SYSTEM FOR SYSTEM TO ACHIEVE 0.01 ARC SEC. POINTING PRECISION
(13)	CONTROLS	ADV. SPACECRAFT AND EXP. CONTROL SYST.	506-19-13/LaRC	WIDE RANGE OF HARDWARE AND SOFTWARE DEVELOPMENT
(14)	ATTITUDE CONTROLS	EXTENDED LIFE ATTITUDE CONTROL SYST. FOR UNMANNED PLANNETARY VEHICLES	506-19-14/JPL	RELATES TO INTER PLANETARY MISSIONS, WIDE RANGE OF COMPONENTS INCLUDING SOLID STATE. STAR SENSOR (STELLAR)
(15)	STELLAR INERTIAL SYSTEM FOR MANNED APPLICATION	VIDEO INERTIAL POINTING SYSTEM FOR SHUTTLE ASTRONOMY PAY-LOAD	506-19-15/AMES	USES JPL "STELLAR" CCD STAR TRACKER, CRT DISPLAY, MICROPROCESSOR
(16)	AUTONOMOUS NAVIGATION (ULTIMATE GOAL)	GUIDANCE AND NAV. FOR UNMAN-NED PLANETARY VEHICLES	506-19-21/JPL	MAKES USE OF ADVANCED HARDWARE (e.g. TERMINAL TRACKERS) AND SOFTWARE
(17)	VIDEO TERMINAL GUIDANCE, LANDMARK TRACKING	VIDEO GUIDANCE, LANDING AND IMAGING SYSTEM FOR SPACE MISSIONS	506-19-22/LaRC (1975)	MAKES USE OF MARTIN'S VIDEO TRACKER
(18)	SOFTWARE DEVELOPMENT LEADING TO ROBOTIC SYSTEMS	ARTIFICIAL INTELLIGENCE	506-19-31/Hq (1975)	EMPHASIS ON DATA MANAGEMENT
(19)	ROBOTIC MODELS	ARTIFICIAL INTELLIGENCE FOR INTEGRATED ROBOT SYSTEMS	506-19-32/JPL	INCLUDES CONSTRUCTION OF SELF-MOBILE MACHINE, MANIPULATORS ETC.
(20)	DATA MANAGEMENT	ADVANCED DIGITAL DATA SYSTEMS FOR DEEP SPACE	506-20-11/JPL	GOAL: INTEGRATED DATA SYSTEM FOR DEEP SPACE SPACECRAFT

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY RTOP's (CONT'D)

	SUBJECT	TITLE	NO./CENTER	COMMENTS
(21)	PARALLEL DATA PROCESSING	AUTOMATED DATA HANDLING TECHNIQUES AND COMPONENTS	506-20-14/GSFC	TSE AND MPPC
(22)	COMMUNICATIONS	MICROWAVE COMPONENTS AND TECHNIQUES	506-20-22/JPL	INCLUDES ELECTRONICALLY STEARABLE ANTENNA, CODING TECHNIQUES, LARGE UNFULLABLE ANTENNAS ETC.
(23)	COMMUNICATIONS	MICROWAVE AMPLIFIER TECHNOLOGY	506-20-23/LEWIS	IMPROVED MICROWAVE POWER AMPLIFICATION
(24)	COMMUNICATIONS	MICROWAVE NEAR EARTH DATA TRANSFER AND TRACKING	506-20-24/GSFC	DEVELOP DATA TRANSFER TECHNIQUES UP TO 240 Mb/S
(25)	COMMUNICATIONS	OPTICAL DATA TRANSFER RESEARCH	506-20-32/Hq	BASIC LASER COMM. SYSTEM RESEARCH FOR DATA RATE OVER 300 Mb/Sec. SHUTTLE EXPERIMENT PLANNED
(26)	PRECISION RANGING	GEOPHYSICAL MEASUREMENT TECHNOLOGY	506-20-33/GSFC	PRECISION LASER RANGING (2 cm, 0.003 cm/sec), SPACE-TO-SPACE AND SPACE-TO-GROUND
(27)	DATA MEMORY	SOLID STATE DATA RECORDER	520-71-01/LaRC	DEVELOP 10^8 BIT BUBBLE MEMORY
(28)	SPACELAB	SYSTEM DESIGN OF SPACELAB COMPATIBLE ADVANCED TECHNOLOGY LAB.	750-01-01/LaRC	DEVELOP SPACELAB AND EXPERIMENTS

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OFFICE OF APPLICATIONS RTOP's

	SUBJECT	TITLE	NO./CENTER	COMMENTS
(29)	SENSORS	SENSOR SUB-SYSTEM ANALYSIS AND DESIGN	175-31-41/GSFC (1975)	EARTH OBSERVATION SYSTEM BASED ON SCANNING RADIOMETER
(30)	DATA PROCES-SING/ MANAGEMENT	SPACECRAFT DATA PROCESSING	175-31-42/GSFC (1975)	MULTI-DISCIPLINARY EFFORT TO OPTIMIZE EARTH OBSERVATION DATA MANAGEMENT
(31)	EARTH OBSERVATION	EARTH OBSERVA-TION SENSOR SUB-SYSTEM	177-22-42/GSFC (1975)	NEW SCANNING AND OTHER SENSOR SYSTEMS
(32)	SENSOR SYSTEMS	VISIBLE AND IR SENSOR SYSTEM TECH. DEVELOP.	177-22-81/JSC (1975)	SOLID STATE SENSORS FOR VISIBLE, I.R. AND V. FOR EARTH RESOURCES AIRPLANE PROGRAM
(33)	COMMUNICATIONS	DEVELOPMENT AND EVALUATION OF ONBOARD DATA COMPRESSION TECHNIQUES	177-25-41/GSFC (1975)	DATE COMPRESSION BY REDUNDANCY ELIMINATION

OFFICE OF MANNED SPACECRAFT

	SUBJECT	TITLE	NO/CENTER	COMMENTS
(34)	CONTROLS	CONTROL COMPONENTS FOR EARTH ORBITAL SYSTEMS	909-81-08/GSFC (1975)	DRIVE MOTORS, GIMBALS, CMG'S ETC.
(35)	COMMUNICATIONS	COMMUNICATIONS	909-44-07/JSC (1975)	IMPROVED LSI AND OTHER TECHNIQUES FOR SPACELAB
(36)	COMMUNICATIONS	COMM/NAV/TRACKING OF ALL-DIGITAL TV PROCESSING AND TRANSMISSION SYSTEMS	909-44-29/JSC (1975)	ALL DIGITAL TV SYSTEM

Appendix B SUMMARY OF PROPOSED DEMONSTRATION CONCEPTS

The tabulation of this appendix provides summaries of 40 of the proposed demonstration concepts. The 4 other concepts which have been utilized for STDF design purposes are summarized in Section 4. In making this tabulation, effort was made to list these concepts in an order which is judged to reflect the demonstration criteria outlined in Table 4-1.

TITLE OF DEMONSTRATION (Related Technologies)	OBJECTIVES OF DEMONSTRATION	APPLICABILITY OF TECHNOLOGY/MISSION TO SPACE SYS.	REASON FOR SPACE DEMONSTRATION
5. Cloud Cover sensing/mapping and/or recognition of cloud types. (DATA PROCESSING SENSING, MAN MACHINE INTERFACE, COMMUNICATIONS, DISPLAY).	o To demonstrate capability of sensing and locating cloud cover and/or evaluating % of cloud cover in a given FOV by active and/or passive means. o To make cloud cover data available in spacelab and/or transmitted to ground in timely manner.	o Determination of relative cloud cover can serve as basis for rejecting scenes or images of no interest and is thus a form of data compression. Can also be used for weather and climatology investigations.	o Clouds and associated atmospheric conditions cannot be adequately simulated. o Distinguishing of clouds from snow fields presents the most difficulty and it would be difficult and probably nonconvincing to demonstrate by analysis or simulation.

6. Recognition and mapping of flooded areas. (Sensors, Data Processing, Communication, Man-Machine Interface, Displays)	o To demonstrate avility to distinguish water from non-water areas in earth surface observation under a range on various viewing, lighting and atmospheric conditions. o To demonstrate combination of man and advanced electro/optical sensors and data processors in sensing and classifying flooded areas. o To demonstrate capability to distinguish flooded areas from natural water bodies whose location and other characteristics are stored and displayed on-board as collateral data. o To demonstrate ability of man and/or machine to timely communicate via down link with low bandwidth the observed essential flood descriptors	o Identification, location and change detection of flood areas can have major socio-economic impact	o Atmospheric conditions have significant impact on sensed images of water and non-water areas. These are difficult to adequately simulate o Any Earth-based simulation would not be expected to provide a demonstration as convincing as that performed in space.

7. Real time Image Data Correction (DATA PROCESSING)	o To demonstrate on-board near real-time correction such as: - Rectification - Restitution - Radiometric correction by advanced data processing means	o On-board image data correction would greatly relax Earth-based data processing requirements and would expidite transmission of information to end users. o Would eliminate need for time tagging of collateral data, etc.	o Space demonstration would most nearly provide operational characteristics of this complex operation including interaction of effects of attitude, pointing and ephemeris determination and also degradation of viewing condition by the atmosphere etc. o Simulated Ground-Based demonstration would be less convincing

<u>COMMENT</u>: Most of the concpets which are part of this proposed demonstration have been incorporated in "On-Board Image Registration" demonstration.

8. Man-Machine Interactive Multi-spectral Image Analyzer in space. (Data Processing, Display, Comm, Sensing)	o To demonstrate a space-borne on-line "real-time IMAGE 10". Type of image processor. o To demonstrate a means for obtaining recognition signitures o To demonstrate a classification technique which makes use of simultanous space-based and earth based sensed data. o To demonstrate operation of solid state multi-spectral sensors (visible and I.R.)	o This demonstration can provide a basis for improving means for obtaining ground truth data o It can provide a very rapid means for obtaining classification of Earth observed materials and/or monitoring critical Earth Events (e.g. forest fire monitoring). o It can provide basis for refining classification algorithms.	o Space demonstration needed to próvide realistic viewing through atmosphere and also to provide realistic attitude and path dynamics of vehicles.

9. Landmark and/or starfield recognition and tracking with coherent optical matched filter system (Data Processing, man machine interaction, display, spacecraft control, navigation)	o Demonstrate technique with wide range of landmark types, viewing, illumination conditions and (clouds) o Demonstrate different types of matched filters. o Demonstrate alternative real time optical interface devices such as liquid crystal and pockets cell devices o Demonstrate operation for recognition and tracking of star fields. o Evaluate man's GPS as a control means for evaluating performance of landmark Tracking	o May serve as primary input to autonomous space navigation system o May be used for precision pointing of payload sensors. o May be used for stellar attitude referencing.	o Operation depends critically on viewing conditions including effects of viewing angles, atmospheric effects, clouds, and illumination conditions not all of which can be adequately simulated on ground. NOTE: Initial experiments may be limited to demonstration of optical interface devices.

10. Precision nav. by GPS Processor (Global Positioning System) and/or other inputs (e.g. TDRS, existing DME and/or OMEGA) (DATA PROCESSING COMM)	o Determine converging times and nav. precision using GPS receiver and two or more alternative nav. algorithms o Determine man's role (if any) in nav. by GPS (e.g. can man use GPS + "hand calculator" to navigate?) o Compare operation of "fine mode vs. coarse mode" of GPS. o Determine performance as function of orbit parameters (e.g. perigee, apogee) o Compare performance with other approaches (e.g. TDRS)	o GPS has potential for providing accurate nav. data in real time for operations in space needing such data at low cost. Positional determination in orbit should be in area of 5 to 15 meters or less for fine mode and possibly even for "coarse" mode (after sufficient integration time). No other on-board system is expected to provide comparable performance.	o Performance will be effected by non-availability of GPS NAFSATS obscurred by earth. Performance can be best demonstrated in space operation. o Small uncertainties in several effects (e.g. uncertainties in gravity model, uncertainties in refraction of GPS radiation transiting the edge of the ionos-phere) may have some effect on achieving ultimate potential precision. These can be evaluated only by direct experimentation.

11. Recognition by Crew of Landmarks and/or Star Fields (Man-machine functions, displays, Data Storage)	o Demonstrate application of various cue and other displays as adjunct to recognition of landmarks under various atmospheric, lighting and viewing conditions and/or star fields from various orientations	o Ability of man to recognize landmarks and/or star fields under a wide range of conditions including adverse conditions can have utility in man's participation in a number of experiments and operations.	o Viewing from space and the rapid dynamics associated with space operation are difficult to simulate on Earth

12. Ice Mapping (Sensing, Data Processing, Communication Man-Machine Interface	o Demonstrate capability to recognize and characterize floating ice formations o Demonstrate capability to map flow rates and directions over an interval of time o Demonstrate capability to provide speedy and cryptic data on ice conditions via down-link o Demonstrate man/machine combination to accomplish above	o Wide area ice conditions are best observed from space o Knowledge of ice conditions can have significant impact on safety and efficiency of shipping, off-shore mineral extraction, fishing, etc.	o No convincing approach to ground-based simulation is known

13. Precision spacecraft orientation (SPACECRAFT CONTROL, ATTITUDE SENSING)	o Demonstrate precision orientation of spacecraft to acquire targets by man-assisted and/or automated means (either) through ephemeris/ attitude determination loop and/or through image sensing loop.	o Many types of Earth Observation require precision pointing at specific targets. One example is change detection of natural or man-caused phenomena.	o Because of many complex interactions of the spacecraft system the only acceptable demonstration would be one in realistic space conditions. o Sensing and tracking Earth-Based targets can be difficult to simulate due to uncertainties in atmosphere etc.

14. High Resolution Radar Altimeter for Terrain Profile Type Navigation and other Purposes (Sensing, Data Processing)	o Evaluate precision of radar altimeter from Spacelab o Demonstrate "terrain profile type" of navigation based on well-developed TERCOM concepts o Demonstrate GPS as a control standard to evaluate above terrain profile navigation o Demonstrate radar altimeter over ocean as a means for more precisely determining gravity fields of Earth	o Possible use as instrument for autonomous navigation o Use as instrument for investigation Earth's gravity field.	o No adequate or convincing demonstration of the high precision potential of this instrument is known other than by space flight. NOTE: GE has developed light weight, low power orbital radar altimeter with precision of 1 ft (as advanced outgrowth of S-193 Program)

15. Solid-state image detector performance demonstration and/or comparison	o Demonstrate and/or compare imaging operation of linear and/or area detector arrays of these and possibly other types: - CCD - CID (charge Injection Diode) Compare relative to SNR, sensitivity, resolution, integration time, spectral response etc. o Evaluate operation for both Earth viewing and star tracking and/or star field mapping o Demonstrate a wide range of data processing "in the image plane" including data compression, change detection, noise reduction, pattern recognition etc.	o Several types of solid state sensors have advantages over beam addressable type tubes for image sensing such as greater reliability, lower power, smaller size etc. and have significant potential for many imaging types of operations. - CCD's have advantage of TDI (time delay integration) which can separate integration time from resolution constraints for linear arrays. - CID's have advantages of random scan capability and also transform (e.g. Hadamard) type of readout as well as a unique noise rejection capability.	o Imaging performance highly dependent on viewing, atmospheric and lighting conditions all of which are difficult to simulate on Earth. Also demonstration in space will insure operation with a wide range of land, water and cloud types.

16. Man-Machine Technique Demonstration (Man-machine Interface)	o Demonstrate relative capability of man to operate various man-machine interface devices in space	o Such devices which may have utility in space are: o keyboards o light pens o "joysticks" o selecting and changing tapes on tape recorders o other	o Certain man-machine operations may be difficult in Zero g environment and under conditions of dis-orientation and highly dynamic stresses

17. Millimeter Wave Communication Experiment (MWCE)	o Demonstrate wideband data links in the millimeter wavelength bands. o To demonstrate effects of precipitation	o Provides a means for very high data rate transmission	NOTE: This is an approved exp. Program. How can SDTF support it?

18. Variable Stability and Controllability Spacecraft (ACS, Data Processing Sensing)	o To demonstrate spaceborne simulation of a wide range of spacecraft dynamics, stability and control ability in the well-known manner of "variable stability aircraft". (Technique makes use of various feedback techniques to "artificially vary attitude response characteristics of spacecraft)	o Can provide a useful tool for design and check-out of future spacecraft attitude control and other related subsystems o Can provide a "standard" reference against which ground-based attitude simulators can be calibrated	o A space located demonstration can be more convincing than a ground-based demonstration. o Some doubt always exists on the validity of Earth-based simulation.

19. Non-Conventional Light-weight Optical Elements (Sensing, man-machine interfaces)	o Demonstrate formation and use of various non-solid lenses and mirrors formed, for example, by liquids and pellicles in the manner of "soap bubbles" or by others advanced techniques.	o Such advanced light-weight optical elements could revolutionize Earth viewing and astronomy from space by providing high quality optics having very light weight, low cost and low launch costs.	o Since these techniques are very gravity-sensity, no convincing demonstration can be expected on the ground

20. Star and/or Star Field Recognition and Referencing (Sensing, Data Processing)	o To demonstrate capability to identify (TBD) stars based on detected brightness alone o To demonstrate capability to identify (TBD) stars on basis of brightness and spectral characteristics o To demonstrate capability to identify (TBD) stars and/or star fields based on detected brightness, spectral characteristics and relative spatial orientation	o This technique can provide a "universal" attitude referencing capability even from an initial totally disoriented condition	o Precision brightness, spectral characteristics, and relative location of stars together with realistic attitude dynamics are difficult to simulate on Earth

21. Real Time Modeling of Atmosphere (Sensing, Data Processing, Communications, Man/Machine Interface)	o Evaluate optical properties of atmosphere (i.e., transmissivity, backscatter, refraction, etc.) as function of wavelength, altitude, time and location in Earth coordinate frame o Evaluate various multi-spectral sensing techniques and "standard" ground reference targets for this investigation. o Demonstrate man/Machine interface in performing this evaluation	o Changing optical characteristics of atmosphere have significant impact in evaluating many types of Earth observations data obtained from satellites especially multi-spectral remote sensing	o No known ground based simulation would provide a meaningful demonstration.

22. Micro "g" Acceleration Sensing (Sensing, Data Storage)	o Demonstrate capability for precision sensing of acceleration in the sub-micro "g" regime (e.g., 10^{-8} to 10^{-10} g)	o Ability to sense very low gravity levels can be useful in modeling non-gravity forces in space (e.g., solar radiation pressure, low pressure atmospheric drag, low force level thrusters) o Ability to sense low gravity levels at high frequency has been shown to be of special significance for certain space processing functions and also for investigations such as Cloud Physics studies.	o Earth based measurements are dominated by forces countering gravity forces. No adequate Earth-based demonstration is available.

23. Advanced attitude sensing (Sensing, Data Processing)	o Demonstrate operation and performance in space environment of advanced components such as: - Laser Gyros - Tuned Rotor Gyros - Cryogenic Gyros - Solid state star trackers	o Advanced attitude sensors have potential improved performance as needed for long life deep space missions, long duration Earth observation missions etc. Improvements are needed in long life reliability, reduced drift, higher resolution, etc.	o Performance of most inertial sensors are gravity sensitive hence a zero g environment is needed for their evaluation in space. o Star sensing is critically concerned with such factors as shielding from extremous (e.g. solar) illumination which can be best simulated in space.

24. Soil-Moisture Determination (Sensing, Data Processing)	o Demonstrate sensing capability by SAR and/or other means to determine moisture content of soils	o Soil moisture measurement over wide areas has great significance in determining crop forecasts, fire hazards, etc., and yet remains a technical problem which has not been satisfactorily solved.	o No known ground based demonstration would predict capability of determination from space

25. Electro Magnetic Propagation Investigation in 20 to 200 giga hz regime	o Demonstrate atmospheric propagation in these frequency regimes from Spacelab to Earth	o These very high frequency bands have ptoential for space-to-space and space-to-earth comm. links if antennas can be pointed with sufficient accuracy and if there is not excessive ambient radiation noise.	o Because of expected high atmospheric attenuation to known Earth-based demonstration would be expected to be convincing.
(Communication, Data Storage, Sensing)	o Demonstrate precision pointing needed for highly directional antennas needed		NOTE: cf. NASA GSFC RTOP 650-60-11
	o Determine natural interfering radiation from Earth, Sun, etc., in these frequency bands	o Atmospheric effects can be expected to severely limit space-to-Earth links at very high frequencies	
	o Sensing water vapor at 183 ghz	o Operation at 183 ghz shows some promise as a means of measuring water vapor in atmosphere	

26. Advanced Techniques for Display of Orbital State (Display, Data Processing)	o To demonstrate advanced techniques such as "hodography-inside out display" for showing crew part, present and future expected orbital situation o To display both nominal and actual orbital situation and departure from nominal	o It is expected that the Spacelab flight crew may need improved visual display of actual orbital state as well as departure from nominal planned state. One approach is "hodographic or inside-out display" in which outer space is displayed in the display center and the Earth around the display perphery. All orbits are displayed as circles with ellipticity displayed as an off-centering on the display.	o Since this is a flight operation function its attractiveness can likely be shown to be convincing only in a space demonstration.

27. Atmospheric Sensing (Sensing, Data Storage, Communications)	o Make use of advanced sensing devices and improved data processing techniques to demonstrate improved detection and locating of minor constituents in the atmosphere. o Correlate results in near real time with simultaneous sensing on Earth surface or in aircraft.	o Improved atmospheric sensing is needed so as to better predict the development of adverse conditions in the atmosphere (e.g. ozone depletion) by various man-made and other activities such as increased use of flourocarbons, artificial nitrogen-based fertilizers, supersonic aircraft, etc.	o Only space observation can provide the needed global perspective and observation from above.

28. Advanced Attitude Torquers (Sensing, data processing)	o Demonstrate operation and performance of advanced attitude torquers such as magnetically sus- pended spheres	o Suspended sphere has advantage of providing 3 axis torquing with single device and reliability associated with having no mechanical bearings	o Operation and performance is g. sensitive. (Device may be totally inoperable in a 1 g environment). Since this is difficult to simulate a space flight demonstration is desired.

29. Transmission of Synthetic aperture Radar (SAR) Type of data	o Compare effectiveness (e.g. in terms of SNR) of reconstructed image of wide band data link vs. massive data compression combined with lower bandwidth downlink NOTE: For this experiment the SAR type data itself may be simulated	o SAR data may be: - Stored on-board. - Processed on-board. - Transmitted in realtime via downlink. Real time transmission may require up to 10^3 M bits/sec data link unless major data compression is employed. o SAR is useful in a wide range of Earth Observation Investigations in penetration clouds, in soil moisture studies in oceanographic wave measurements etc.	o Bit error rate of wide band down link and its effect on Imagery is a function of atmospheric conditions (e.g. rain in case of microwaves, clouds in case of laser comm. link). These effects sometimes cannot be adequately simulated

30. Spare Evaluation of High Voltage Power supplies	o Evaluate operations and failure modes of high voltage power supplies operating in space.	o Capability to provide higher fast switching and fast sweeping controlled voltages as needed by certain advanced somponents (e.g. sensors, data storage devices) in space. Application of Electron Beam Memory Devices for example, depends on availability of such high sweep rate, high voltage power supplies	o Space demonstration insures high vacuum conditions.

31. Impact of Space Operation on Operation of advanced data storage device(s) such as bubble memories (i.e. Magnetic domain walls) (Data Storage)	o To demonstrate operation, failure modes and rates, fidelity of memory when subject to space environment.	o Bubble memories provide mass memory storage capability to store large volumes on sensed data expected for Earth Observation Missions. Advantages over tape recorders now used are faster access time (~ 2 microseconds), high capacity (10^9 bits), high transfer rate (1.5M bits/sec) and high reliability associated with "no Moving Parts".	o Performance of magnetic bubble memories is dependent on ambient magnetic field. Earth's magnetic and local magnetic field in spacecraft field cannot be adequately modeled on Earth. o Also magnetic field needed for bubble memory operation may interfere with other spacecraft functions. This needs evaluation in space.

32. Demonstrate operation of liquid crystal displays in space environment	o Evaluate/demonstrate effect of zero g on operation on liquid crystals in scattering and/or various field effect modes.	o L. C. displays are attractive for alpha-numeric displays with high contrast and requiring very low power as compared with some alternative display techniques.	o Effect of zero g on L. C. Displays is unknown and cannot be readily simulated.

33. Selectable pass-band optical filters (sensing)	o Demonstrate performance of selectable pass-band optical filters in various crew and sensor viewing experiments from space.	o Such filters may have use in space: - a means for image enhancement. 9e.g. haze suppression) - for near real-time classification by multi-spectral sensing - as a safety device for solar observations	o Atmospheric influence in Earth viewing difficult to simulate o Simulation of real time Earth observation may not be a convincing demonstration.

C.3

34. Miniprocessor/ Minicomputer Applications in Space (Data Processing, Man-machine Interface, Displays)	o Evaluate capability of man using "minis" to perform a wide range of functions, such as: - Man aided ephemeris and/or attitude determination	o Miniprocessors and mini-computers can be expected to have a major role in spacecraft operation	o Space-located demonstrations may be more convincing than ground-based demonstrations

35. Survace acoustic wave device (SAW) demonstration (DATA PROCESSING)	o To evaluate performance in this accoustic wave device in a zero g environment	o Analog signal processing in space (e.g. computing convolutions and correlations as may be of interest in data processing for applications such as data processing as needed for synthetic aperature radar.)	o Zero g environment may be needed to evaluate operation of this device in space

36. Fiber optics link	o Demonstrate CCTV based on fiber optic links having: - Low power requirements - Hgih reliability - Low vulnerability to EMI - Low costs	o Near term application: CCTV within Spacelab/ Shuttle. o Advanced application: internal digital data transfer o Long term application: Connecting links for compact integrated optical data system in spacecraft.	o Demonstrate operation of fiber optics in spacecraft data links. o Evaluate effect of space radiation-induced photon noise generation in various types of glass and plastic fiber optics. <u>NOTE</u>: ref. RTOP 506-18-23 Ground Simulation may be adequate

37. Adaptive Multibeam Phased Array (AMPA)	Demonstrate Independently steerable high Gain Beams	Can have applicability for radio transmission to selective areas of Earth.	<u>NOTE</u>: This is approved program. How can SDTF support it?

38. Electro-magnetic Environment Experiment (EEE) (Comm, Data Processing Displays etc.)	o To Demonstrate capability to monitor EM radiation power levels over a broad spectral band	o Such an experiment can provide data on possible EM interference which may exist in various parts of the electro-magnetic spectrum and hence provide a guide for design of future communications links.	NOTE: This is approved exp. program. Question is how can SDTF support it?

39. Evaluation of Error Detection and Correction Codes (Communication Data Processing)	o Demonstrate and compare various alternative coding techniques for detecting and correcting errors in wide-band data for Spacelab to ground down-link including: Burst Error Correcting codes, block codes, BCH codes, etc.	o Increased need for sending more sensed data from space to Earth increases interest in maximizing the capability of wideband data links without excessive errors. Application of various codes can enhance capability of wideband data links.	o Many of the error-inducing effects are inherent in the space to Earth link (e.g. atmospheric effects, rainfall, antenna limitations) o Ground-based simulation would not provide as convincing a simulation

40. Demonstration of Multiple Access Communication Links	o Demonstrate and compare alternative multiple access space communications links including: - Frequency Diversion (FDMA) - Spread Spectrum (SSMA) (e.g., PN coding) - Pulse Address (PAMA) - Time Division (TDMA)	o High efficiency, low error rate, non-interferring data links will be needed for several planned applications of multiple access communication links making use of satellites. It is, therefore, important to determine further the relative merits of possible alternative techniques	o Satellite down-links, especially with shaped beam antennas are difficult to simulate o Atmospheric effects (e.g., rain) can have significant impact on relative merits of otherwise near equal techniques

41. Evaluation of High Density Large Scale Integration (LSI) in space (Data Processing, Data Storage)	o To demonstrate both short term and long term degradations (if any) of LSI chips in a space Environment	o Increasingly higher packing density of solid state components may result in both short term performance degradation (likely a reversable noise producing effect) as well as irreversible long term degradation due to material migration etc. in the zero g environment.	o Main concern here is any possible effect of zero g which cannot be adequately simulated on Earth.

42. Electrostatic Cooling " (Electro-convectional augmented heat transfer of gases) (sensing, Data Processing)	o To demonstrate capability of this technique for functioning at zero g and (possibly) at low pressure ambient conditions	o Electro-static cooling may have some advantages of low power, high efficiency cooling for a wide range of space applications including cooling for space processing and for various electronic components	o Operation This convective heat flow technique sometimes is effected by the gravity field. Demonstration in a zero g field would therefore be of interest

43. Demonstrate Radio-wave Attitude Sensing (Sensing)	o Demonstrate multi-axis radiowave attitude sensing with high precision	o May have performance advantages over present IR sensors (e.g., horizon sensors)	o The demonstration is expected to be difficult to model on Earth. Hence a space demonstration may be advantagous.

44. On-Board Switching of Multi-Channel Comm Links

<u>NOTE</u>:
Comsat Corp.
Planning experiments of this type

APPENDIX C

THE MSS SENSOR AND POSSIBLE MODIFICATIONS FOR A REGISTRATION DEMONSTRATION

The MSS collects solar-reflected earth surface image data in 4 spectral bands:

Band 1	0.5 to 0.6 micrometers
Band 2	0.6 to 0.7 micrometers
Band 3	0.7 to 0.8 micrometers
Band 4	0.8 to 1.1 micrometers

Six scan lines in each of the 4 spectral bands are obtained simultanously (a total of 24 channels). Scanning is accomplished by an oscillating flat mirror between the scene and the double-reflector, telescope type of optical chain. It scans in swaths normal to satellite ground track with angular swaths of 11.45° field of view. For the case of the Landsat operating at an attitude of 914 km this produces a swath width on the Earth surfaces of 185 km.

Consider how operating altitude can influence scanner design modification.

Most early Spacelabs mission (e.g. OFT) orbits will have an altitude of about 265 km. In order to avoid radiation hazards to the crew maximum Spacelab operating altitude will be limited to about 750 km. In order to provide maximum ground coverage and also to avoid significant redesigns of the MSS an operating altitude of the Spacelab of 750 km will be assumed. This would result in an instantanous MSS field of view corresponding to an Earth surface area at nadir of 65 meters by 65 meters. This represents a moderate improvement in resolution as compared to the Landsat MSS operation which has an instantanous field of view corresponding at nadir to an Earth surface area of 79 meters by 79 meters. Further investigation is needed to determine what, if any, modifications to the MSS optical front end may be needed to operate at this lower altitude.

The optical signals of each of the 24 channels are detected by 24 separate detectors. These signals are then sampled, digitized and formatted into a digital bit stream by a multiplexer. The sampling interval is 9.95 microseconds corresponding to scan cross track motion of 46 meters. The along track scan is accomplished by orbital motion. For Landsat the along track motion of the sub-satellite point is 6.47 km/sec. By oscillating the mirror at 13.62 Hz the sub-satellite point will have moved 474 meters along track during the 73.42 millisecond active scan and retrace time. Thus the in-track scan field of view if 1/6 of 474 meters or 79 meters, the same as in cross-track. In the case of Spacelab operating in a circular orbit at 750 km altitude the sub-satellite point moves at 6.66 km/sec. By using the same mirror oscillatory rate the instantanous in-track field of view at nadir corresponds to 81.4 meters. Hence, if the MSS is unmodified, the instantanous field of view is 65 meters cross track and 81.4 meters in-track. By modifying the MSS to increase the oscillatory rate of the mirror from 13.62 Hz to 17.06 the instantanous field view can be made to have a nadir field of view equivalent to 65 meters by 65 meters. If a demonstration of this type were planned then a recommendation would be made that this change in oscillatory rate be made so as to have equal scale factors in the cross-track and in the along track directions.

At a 750 km altitude of the Spacelab the MSS will cover a 152 km wide swath width on the ground as compared with the 185 km swath width for Landsat. Thus going to a somewhat lower altitude and increasing the mirror sweep rate by about 25% will result in an area coverage reduction by about 22% and a lower ground sample distance also by about 22%.

The data from the MSS is encoded by an A/D converter in a 6 bit digital code. Encoding can be selected as either in a linear or "compressed" mode.

Calibration data is taken during the retrace interval of the MSS. An internal light and a variable neutral density filter on the shutter wheel introduces an effective calibration wedge. The calibration data is also encoded by the A/D converter so as to be available for updating the calibration look-up table of the calibration operation of the data processor.

The spacing of the fiber optics of the 24 bands is designed so as to provide band-to-band registration of pixels. This is designed as a goal so as to facilitate multi-spectral analyses of imagry without requiring interpolation between pixels of any band. However, there are resideral errors in this registration due to factors such as alignment errors in the fiber optics and variation in scanning of the mirror. Peak mis-registration errors are predicted at the Spacelab demonstration altitude as:

Across track.	$\pm$ 23 meters
Along track:	$\pm$ 3 meters

It is evident that this can be a non-negligible source of registration error in the accross scan direction for such a demonstration unless some of these error sources are further reduced.

APPENDIX D

THEMATIC MAPPER AND POSSIBLE MODIFICATIONS TO MEET DEMONSTRATION NEEDS

The thematic mapper is a more advanced scanner than the MSS. It has extended IR capability in addition to visible spectrum capability with higher resolution than the MSS. The development status of the thematic mapper, however, is less mature than the MSS.

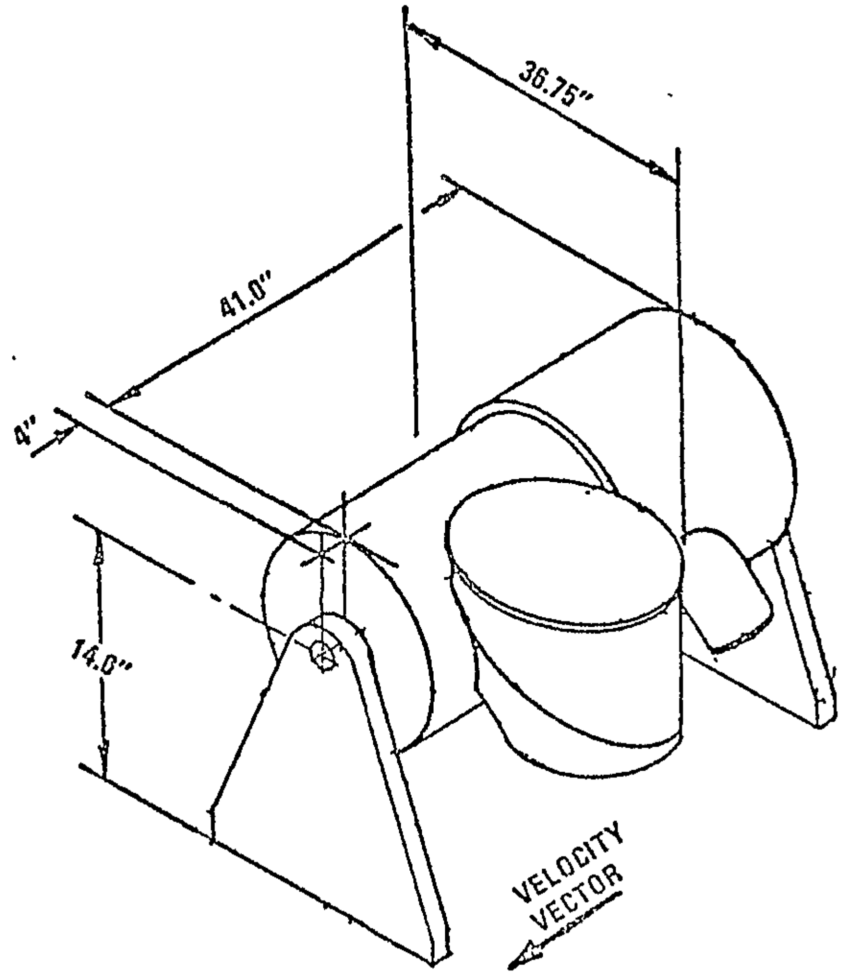
An early design is shown pictorially in Figure D-1 and operates on principles similar to that of the MSS. This design is discussed here. The object plane scanning is obtained by directing the ground scene with an oscillating scanner mirror through a telescope and relay optics to a series of detectors located at the focal plane. Spectral definition is obtained by a series of bandpass filters with spectral separation into the seven spectral bands obtained by spatial separation. Bands 1-6 have 16 elements per array and Band 7 has 4 elements. Data is taken on each half cycle of the scanning mirror oscillation by use of an image motion compensation dual mirror arrangement located in the optical system. The non-linear scan is monitored by an optical scan monitor defining start of scan, end of scan, and an insertable mid-scan indication in the data.

The optical system consists of a scan mirror assembly, the telescope assembly, and aft optics assembly. The scan mirror causes the IFOV to sweep across the swath. It needs to scan only half of the angle of the full field of view because of the angle doubling effect that occurs at reflection. The mechanism has nearly symmetrical scan pattern; i.e., the west to east forward scan and east to west reverse scan. The departure of the scan from the ideal sawtooth must be known and repeatable in order to correct for geometric accuracy. The fact that the actual shape is different in the forward and reverse directions adds complexity to the data processing.

Figure D-1.

THEMATIC MAPPER

- o WEIGHT (KG) :180
- o POWER (WATTS) :260 INCLUDING TAPE RECORDER
- o SWATH WIDTH :7.62°
- o IFOV :30 μRAD
- o DATA RATE :89.4 Mb/s
- o CHANNELS :4 VISIBLE
  2 IR
  1 THERMAL



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A scan monitor assembly is used to produce signals at start, center, and end of scan. This system consists of a gallium arsenide laser diode emitter, an optical projection system, a series of reflectors, and a pair of detectors. The accuracy in measuring the scan position is 0.5 sec. which corresponds to one-tenth of an IFOV.

The telescope assembly includes primary mirror, the secondary mirror, a folding mirror for directing the beam into the aft optics assembly, and the telescope structure, which provides stable, accurate support of the optical elements and the Image Motion Compensator (IMC). The IMC mechanism must produce an offset of the optical beam in the direction of the spacecraft travel by an amount related to the IFOV, the telescope focal length, and the number of detectors per array. The net effect is to compensate for the tilt in the uncompensated ground scan pattern due to spacecraft motion.

Several requirements are placed on the mechanism chosen to provide IMC, such as minimal change in optical path length and constant angle of incidence on the detector plane. The design concept for the IMC uses two rotating flat mirrors in the convergent beam of energy located near the image plane to minimize the magnitude of the scanning motion. These mirrors are driven by a function generator and serve control to compensate for the spacecraft v/h motion during each scan, and resetting at the end of each scan in preparation for the next.

Each of the spectral bands is physically separated from each other in image (and therefore object) space. Thus, they are not simultaneous, and coincidence is achieved by the scanning motion and subsequent matching of samples.

For radiation calibration, a lamp source is available and is reflected onto the detectors by moving a small mirror into the field of view. Issuing a radiation calibration command causes the lamp to be powered by a constant current supply. A continuously variable neutral density filter is included to provide a number of power input levels to the detectors.

The present baseline Thematic Mapper design is compared in Table D-1 with a possible minor modification of the scanning mirror operation to adjust the instrument to the selected Spacelab orbit rather than than the present baseline design. The modifications take advantage of the lower orbit altitude to improve resolution without electronic or data processing penalties, but as in the case of the MSS discussed in Appendix C, there is a sacrifice of swath width. The increase in scan mirror frequency may not present any mechanical problems.

TABLE D-1

COMPARISON OF THEMATIC MAPPER FOR A POSSIBLE REGISTRATION DEMONSTRATION

Parameter	EOS-A Baseline System	Registration Demonstration Modified System
Altitude, km	775	750
S/C Velocity, km/sec	6.64	6.67
Ground Resolution, m	27.1	26.2
Angular IFOV, urad	35	35
Scan Angle, deg.	13.6	13.6
Scan Rate, Hz	7.67	7.9
Ground Swath, km	185	179
Scan Efficiency	80%	80%
Signal Bandwidth, kHz	65.8	65.8
Data Rate, Mbps	89.4	89.4
Clear Aperture, cm^2	990 (40 cm dia)	990
Focal Length, cm	206	206
F-Number	5.2	5.2
S/N - Band 1	22.8	22.8
2	25.6	25.6
3	25.2	25.2
4	27.4	27.4
5	7.0	7.0
6	3.5	3.5
7	.36°K	.36°K

APPENDIX E

DETAILS OF RADIOMETRIC CALIBRATION

This Appendix considers the application of previously developed techniques for meeting the calibration needs of scanning types of sensors. In the case of MSS sensed data will have the form, after A/D conversion, of a sequence of 7 bit values corresponding to 128 intensity quantitization levels in each of 4 channels. It is expected that the thematic mapper will be quantitized in 8 bit value corresponding to 256 intensity levels in each of 7 channels.

In order to compile and update a calibration look-up table in the case of the MSS each detector is exposed to a six step calibration wedge at the end of every second scan. The six calibration values, c_i are used to compute radiometric correction gain, G, and offset, ϕ, coefficients for each channel from the equations:

$$G = \sum_{6} C_i \, c_i$$

$$\phi = \sum_{6} D_i \, c_i$$

where C and D are linear regression coefficients derived from prelaunch calibrations of each detector.

It is desired to continually update these correction coefficients by utilizing the continuously detecting of calibration data. To accomplish this these coefficients are smoothed by a running weighted average technique of this type:

$$\overline{G_i} = \overline{G_{i-1}} + W\,(G_i - G_{i-1})$$

where:

$\overline{G_i}$ = ith smoothed gain coefficient

W = weighting factor defined by:

$$W = \left(\frac{1}{i+1}\right) \qquad o < i < 32$$

$$W = \left(\frac{1}{32}\right) \qquad 32 \leq i$$

The offset coefficient ϕ is smoothed similarily.

Gain and offset coefficients are continuously updated for each detector element in separate look-up tables (24 in the case of the MSS and 20 in the case of the thematic mapper) and stored so as to be available for image data calibration.

The smoothed gain and offset data is then used to compute corrected signal voltages from uncalibrated input data in this manner:

$$V_c = \frac{k (V_u - \bar{\emptyset})}{\bar{G}}$$

where

V_c = corrected output signal

V_u = uncalibrated input signal

k = scale factor

The signals from the sensing elements are substituted in the above equation and the corrected signal levels computed. The range of possible raw signal values from each sensing element channel is computed from the above equation so as to obtain (and update) the entry of the calibration look-up table. Computing this table constitutes the first phase of the radiometric correction. The second phase consists of applying the look-up table to incoming data.

APPENDIX F

GEOMETRIC CORRECTION - DETAILS OF OPERATION

In principle, the correction control function could be computed off-line or, alternatively, on-line. However, prior computation off-line can be valid only if the ephemeris, attitude and instrument pointing are precisely pre-planned and executed and well known in advance of the real time demonstration. For the present demonstration on Spacelab, it is assumed that this may not be the case and that real time computation of data correction control function is needed. The approach described here has been adapted from techniques developed for off-line geometric correction.

Several general approaches can be conceived for implementing the actual real time image correction with a specified geometric control function. It is important to take a broad look at a range of alternatives to determine which is most compatible with the needs of real-time on-line processing rather than simply adapting techniques which are either in user or in planning for off-line geometric processing. One way of classifying alternative approaches is based on the amount of buffer storage required in the data processing. Reduction in the amount of buffer storage is most compatible with real-time pipeline processing. One conceptual approach requiring no buffer storage would be to use the correction function to explicitly relocate in two dimensions each and every input sampled pixel so as to remove the distortion. As a further option the relocation could be performed in the X and Y axes either simultaneously or, alternatively, in sequence. This approach could be implemented with the same parallel multiple channels associated with each sensing element which were suggested for an operational system to perform the radiometric calibration. Unlike the radiometric calibration problem, however, it is not likely that a table look-up approach is applicable due to the non-linearity inherent in the several simultaneous sources of geometric errors. An assumption of superposition validity as needed to implement a practical look-up table cannot be justified. However, this approach has certain computational advantages for pipeline processing in not requiring any buffer storage of image data nor any inter-pixel interpolation. These advantages are outweighted, however, by totally unacceptable disadvantages inherent in the characteristics of the corrected output imagery: non-uniform placement of output pixels and non-orthogonal format of the pixels placement in the output imagery. This latter characteristic would necessitate some positional tagging of each and every output pixel. Furthermore, the resulting data stream would not be readily compatible with any type of "inertia-limited" readout device such as a scanning mirror type of laser beam recorder. However, it could be compatible with inertia-less recorders such as certain types of 2-axis electron beam recorders.

An alternative to the above would be to compute the intensity level of each and every pixel defined in an orthogonal output array of pixels in the vicinity of the GCPs of the geometrically corrected image. Because this remapping will generally involve fractional pixel spacings, some form of two dimensional interpolation of pixels on the input image is required. Such interpolation might be that of "nearest neighbor," linear interpolation or an approximation to $\frac{\sin x}{x}$. Because of the need for interpolation, buffer storage of the image data to be used in the interpolation is required. This approach avoids the previously described problems of tagging and using irregularly spaced output data. However, it has disadvantages of requiring a very high volume of data processing.

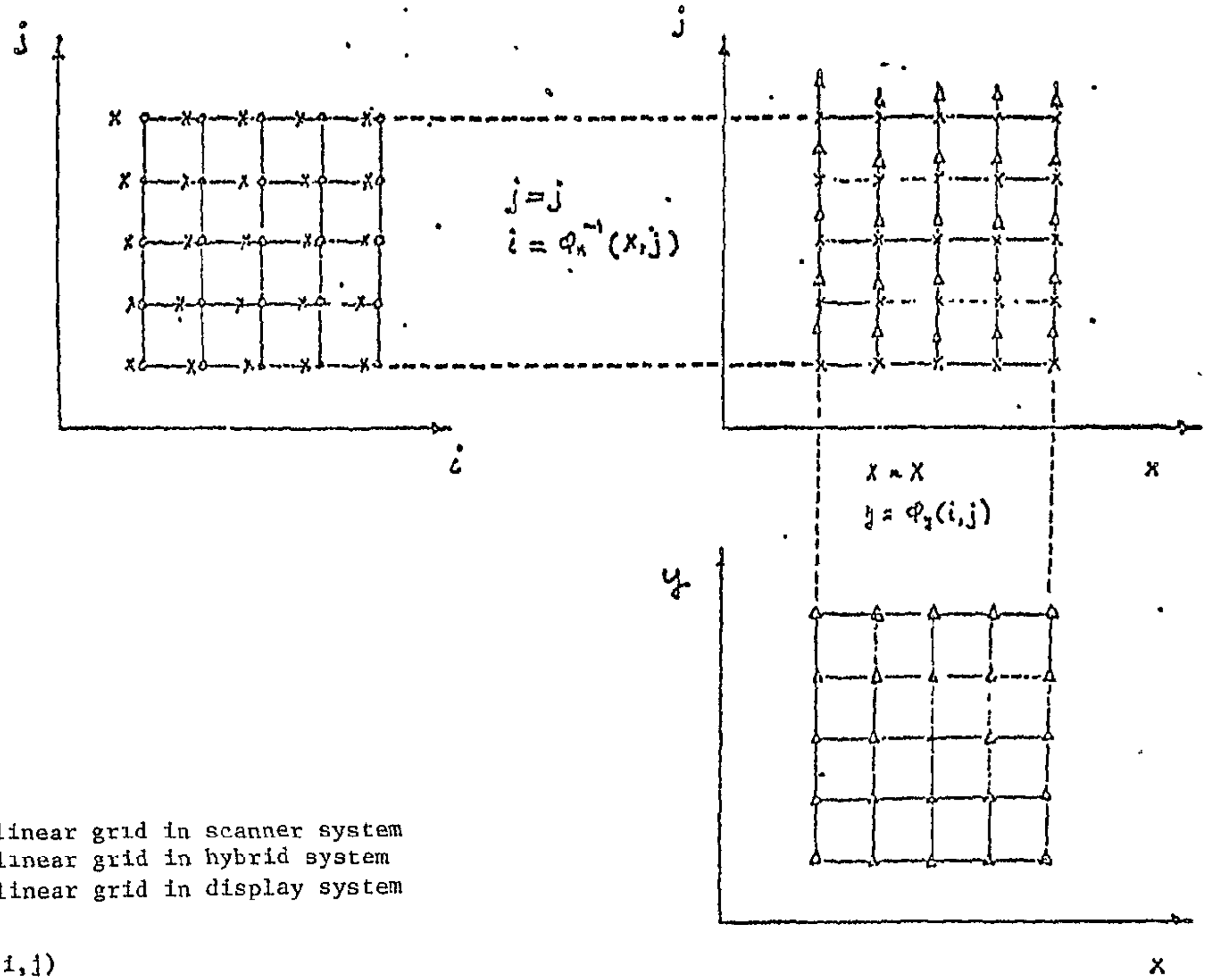
A further alternative is to use some for of "benchmark" technique. "Benchmarks" are defined as a matrix of positional reference points so located that intermediate image points can be located relative to them by linear interpolation. Use of benchmarks, therefore, reduces the data processing load by avoiding explicit computation of the location of each and every pixel. The coarseness with which the benchmarks can be defined is dependent on the extent to which the linear interpolation of positional error is valid.

Alternatives exist in the manner in which benchmarks can be defined. If defined in input imagery space, then a problem exists similar to that described above where output image pixels are non-uniformly distributed and thus must have individual position tags. Hence this definition is not favored.

Alternatively, benchmarks could be defined in output image space. Such definition implies simultaneous two axes resampling to define these benchmarks. This has been shown to require significantly more data storage than performing corrections in the two axes in sequence: first along the scan axis (X) and then orthogonal to the scan axis (Y) (cf. Figure F-1).

As a result, the most favored approach is to define the benchmarks in a hybrid space. The along scan correction is defined in input image space and the cross scan correction is defined in output image space.

Previous experience with off-line correction systems has shown that a four point approximation of sin x / x when performed in sequence in each of 2 axes is an effective resampling technique for obtaining benchmarks. Such benchmarks when spearated in each of the 2 axes by about 200 pixels have been shown to produce acceptable output imagery.



o Rectilinear grid in scanner system
X Rectilinear grid in hybrid system
Δ Rectilinear grid in display system

$x = \phi x(i,j)$
$y = \phi y(i,j)$

Figure F-1. Two Step Process for Formation of Benchmarks

The two step process for locating benchmarks is illustrated in Figure F-1. Three rectalinear coordinate frames are defined:

- Sensor frame in i, j, coordinates
- Intermediate hybrid frame in x, j, coordinates
- Output image frame in x, y, coordinates

Let $\emptyset$ (i,j,) represent the transformation from the sanner frame to the output frame and let it be a function of the geometric corrections needed. As discussed, this is partitioned into two components, $\emptyset_x$ (i,j) and $\emptyset_y$ (i,j). The initial step in obtaining the along scan positions, i, needed in the scanner frame resampling so as to form the benchmark x coordinates of the hybrid frame with no change in the cross scan coordinates is:

$$i = \emptyset_x^{-1} \; (x,j)$$

$$j = j$$

The second step starts from this input and determines the cross scan position value, j, in the x,j hybrid frame for resampling so as to form the benchmark y coordinate of the output frame with no further change in the along scan coordinates:

$$x = x$$

$$j = \emptyset_y^{-1} \; (x,y)$$

In each step a single axis interpolation is made to provide the radiometric interpolation needed to transform the resampled points to the next rectilinear frame (i.e. hybrid in the case of along scan and output frame in the case of the cross scan). Previous effort has demonstrated that a cubic convolution (i.e. 4 point $\frac{\sin x}{x}$ approximation) provides satisfactory interpolation. This is a single axis interpolation of intensity values and has the form:

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$$g(z) = \begin{cases} (|z|-1)(|z|^2-|z|-1) & |z| \leq 1 \\ (|z|-1)(|z|-2)^2 & 1 < |z| \leq 2 \\ 0 & 2 < |z| \end{cases}$$

Geometric corrections of image points between benchmarks are determined by linear interpolation from corrections at the benchmark. This is done first in the x axis then in the y axis (i.e., bi-linear interpolation).

Geometric Correction Application

As discussed, the geometric correction function consists of a matrix of correction values, in two axes at benchmarks which constitutes a regularly spaced array in the corrected output image.

Resampling is a form of interpolation and consists of constructing a data point from adjacent points. As discussed above, this resampling is partitioned in 2 axes so it first performed in the X direction, then in the Y direction using similar techniques. This partition simplifies the correction procedure. Based on this performance comparison as well as the need to provide real time data processing, a four point approximation of the $\frac{\sin x}{x}$ interpolation is selected for the demonstration.

Thus, if the correction value, C, is non-integer, it is necessary to include four points in a computation of the pixel value to be placed in the corrected image. This is depicted in Figure F-2 for correction in the x direction. Output pixel P is to be generated. If the geometric correction at P is C, then the input line pixel at position A = P + C is to be placed in the output line at P. But since there is in general no pixel at A, the pixels i, j, k, l must be resampled, using the above weighting factors to generate the value at A. The distance from A to these neighboring pixels is given by x, while the

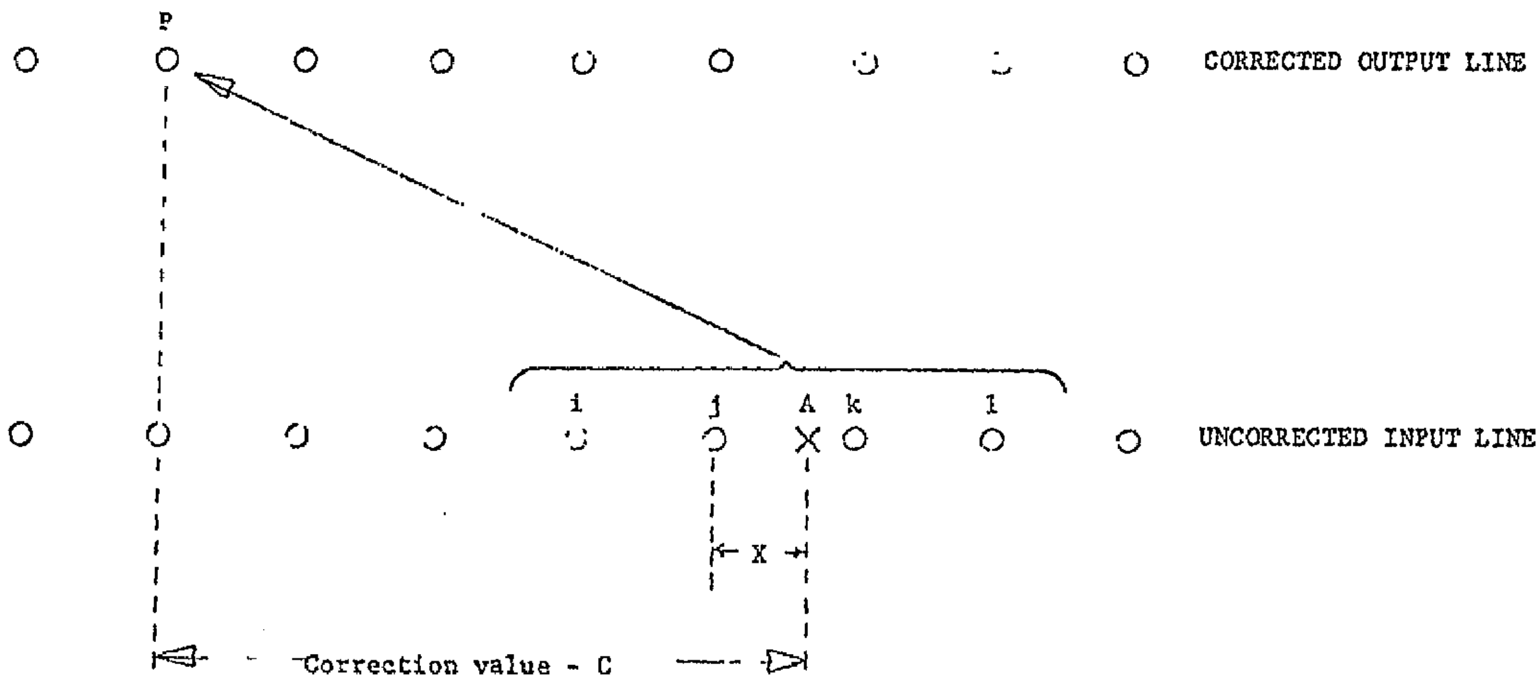

FIGURE F-2. X CORRECTION RESAMPLING SCHEME distance between adjacent input pixels, i.e., i-j, is normalized to one. The process is shown for correction in the x direction along the scan line; however, the identical process is used in the orthogonal direction. In that case, resampling is not performed between consecutive pixels, but between corresponding pixels in consecutive lines.

In practice, the interval between pixels can be divided into 16 parts, and the fractional distance x can be computed to the hearest 1/16. This allows the weights W_i to be precomputed and entered into the software as a 16 x 4 data table. If the resulting performance were acceptable, then, as an alternative, this table need not be computed to reflect (sin x) /x weights. Instead, it could represent nearest neighbor, bilinear, or any other resampling scheme using up to four points.

As noted earlier, the correction values C are given only for a limited number of points called benchmarks in the output image, typically in the case of MSS forming an 11 x 9 matrix. The correction value for each pixel in the output is determined by a bilinear interpolation of corrections at surrounding matrix points.

APPENDIX G

TYPICAL GENERATION OF GEOMETRIC CORRECTION PLANNING

A brief description of the characteristics of Typical geometric correction function is outlined in this section as to provide some further insight into their operation. The corrections discussed here are, in part, based on the MSS and must be considered only as being typical. More specific details of correction needed for a particular demonstration will depend on more detailed data on the sensor, the optics and other demonstration parameters.

Consider a rectangular M x N grid overlay of benchmarks on a scanner-generated image and a similar M x N grid overlay on the ground scene area. What is ultimately desired is the distortion in the image correspoiding to a given grid point on the ground. In the absense of any distortions, grid point (i.j.) in the image corresponds to grid point (i.j.) on the ground. If, however, a component of distortion is present, (e.g. due to spacecraft yaw), the grid point (i.j.) in the image no longer represents point (i.j.) on the ground. Instead, it represents a different point $(X^1, Y^1) = (X_{ij} + \Delta X, Y_{ij} + \Delta Y)$ where (X_{ij}, Y_{ij}) are the X and Y values at (i,j). This new point would not necessarily be a grid point (i.e. a benchmark) of the ground reference grid since ΔX and ΔY are typically not integrally related to the benchmark grid spacing. Grid point (i,j) in the image now represents the non-grid point (X^1, Y^1) on the ground. If another source of error is considered, (e.g., earth rotation), new values of ΔX and ΔY resulting from this second error source can be computed, so that now, grid point (i,j) in the image represents point $(X^{11}, Y^{11}) = X^1 + \Delta X, Y^1 + \Delta Y)$ on the ground. This process is repeated until all error sources being considered have been applied. Some error sources and the equations for computing ΔX and ΔY from selected error sources will be discussed below. The final result is an array of points (X_{ij}^f, Y_{ij}^f) on the ground corresponding to the benchmarks (i,j) in the image. The differences $(X_{ij}^f - X_{ij}, Y_{ij}^f - Y_{ij})$

represents the distortions present at point (i,j) in the image corresponding to point (X_{ij}^f, Y_{ij}^f) on the ground. Since values of these distortions can be determined at all benchmarks (X_{ij}^f, Y_{ij}^f), it is possible, using an interpolation technique to compute the distortions at the original ground reference grid points (X_{ij}, Y_{ij}).

The distortion at a ground reference grid point indicates the point in the sensed input image corresponding to a ground reference grid point. That is, the distortion tells where in the distorted input image the intensity data is to be found for a given ground reference point. The array of distortion values at ground reference grid points constitutes the correction function. This then allows a corrected image to be constructed within the framework of the ground reference grid. Since values for the distortions are computed explicitly only for an N x N array of benchmarks, distortions for individual pixels at points other than reference grid points are determined by interpolation of geometric distortions at surrounding grid points. Obviously, the greater the number of grid points utilized, the shorter the interpolation distance and hence the greater the interpolation accuracy. On the other hand, increasing the number of grid points exacts a penalty in computer computation time, so a tradeoff must be reached. In the baseline demonstration benchmarks can be pre-selected so as to surround the anticipated GCP locations.

Analysis has shown that for typical MSS distortions, an 11 x 9 reference grid results in interpolation errors of less than ¼ pixel.

The level of correction requires that known sources of scene distortion be modeled so that their effects may be removed. The following is an analysis of selected error sources. As previously discussed the evaluation of the error sources requires external inputs such as ephemeris, attitude and instrument pointing as well as specific characteristics of the sensor.

GEOMETRIC ERRORS DUE TO SPACECRAFT ATTITUDE VARIATIONS

The S/C attitude axes are defined as follows: Roll axis is identical to the velocity vector. Pitch axis is parallel to the ground, perpendicular to the velocity vector. Yaw axis is the vertical axis is the vertical axis of the spacecraft, perpendicular to the ground in the absence of roll or pitch offsets.

Geometric distortion, for a flat Earth approximation, due to small 3 axes attitude errors taken one at a time are presented from elementary geometric considerations. Image geometric distortion errors resulting from roll attitude variations are as follows:

$$\Delta X_R = H\ (\tan\ (B + \phi) - \tan B)$$

$$\Delta Y_R = 0$$

where

ΔX_R = roll induced error in X-dimension (across track direction)

ΔY_R = roll induced error in Y-dimension (along track direction)

H = S/C altitude

B = angle between S/C nadir and instantaneous field-of-view

ϕ = roll angle

Similarly, the errors resulting from pitch variations are as follows:

$$\Delta X_P = 0$$

$$\Delta Y_P = H \tan \alpha \approx H \alpha$$

where

α = pitch angle

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Yaw angle errors are as follows:

$$\Delta X_Y = X\ (1 - \cos \gamma) \approx 0.$$

$$\Delta Y_y = X \sin\gamma \approx X\ x$$

where

X = distance on the ground from nadir to point being viewed

γ = yaw angle

GEOMETRIC DISTORTION DUE TO EARTH CURVATURE

Earth curvature introduces errors because the curved Earth's surface is projected into a plane in the image. Referring to Figure G-1 , for a given point X on the ground, the earth central angle is given by

$$\theta = \frac{X}{R}$$

Side S can be found from the law of cosines

$$S^2 = R^2 + (R + H)^2 - 2R\ (R + H)\ \cos\ \theta$$

The instantaneous scan angle B is given by

$$B = \sin^{-1} \frac{(R \sin \theta)}{S}$$

and the projected length A is

$$A = H \tan B.$$

The error is therefore

$$\Delta X = X - A = X - H \tan B$$

GEOMETRIC DISTORTION DUE TO EARTH ROTATION

Scanned images become skewed as a result of the rotation of the earth during the finite frame time. Referring to Figure G-2 , the linear velocity of the earth at image format center is

$$V = \frac{2\pi \text{ radians/day}}{86{,}400 \text{ seconds/day}} \times R \times \cos L$$

where

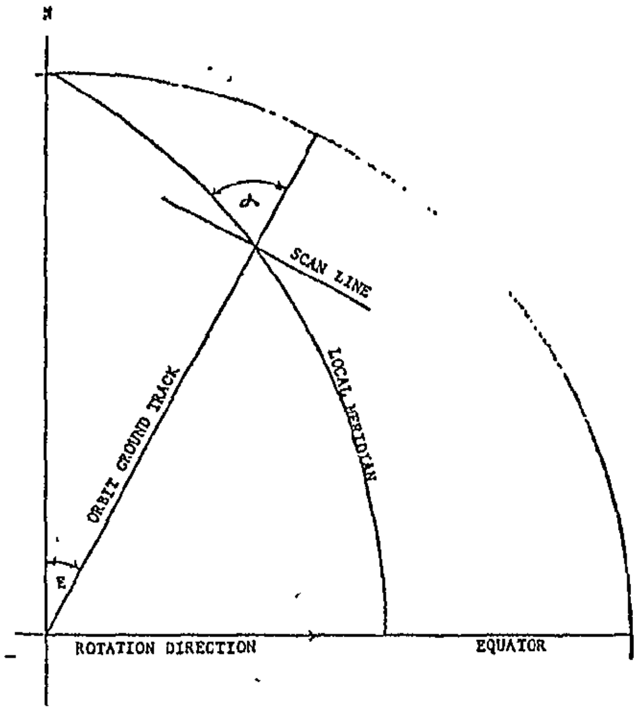

FIGURE G-2 EARTH ROTATION ERRORS

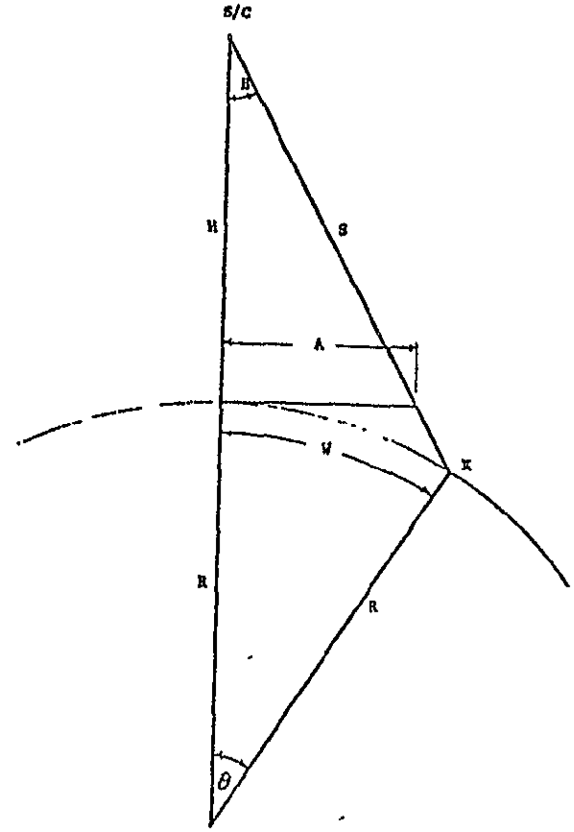

FIGURE G-1 SCENE WIDTH AND EARTH CURVATURE EFFECTS

R = earth radius

L - latitude of format center.

The inclination of the orbit to the local meridian at format center is

$$\alpha = \sin^{-1} \left(\frac{\sin E}{\cos L}\right)$$

where

E = orbit inclination at equator

The distortion components are therefore

$$\Delta X = V (\cos \alpha) \Delta t$$

$$\Delta Y = V (\sin \alpha) \Delta t$$

where

Δt = time from format center.

However, expanding the expression for ΔY

$$\Delta Y = \frac{2\pi}{86,400} R \cos L \frac{\sin E}{\cos L} \Delta t$$

Since the latitude terms cancel, it can be seen that the ΔY term can be treated as a velocity pertubation.

GEOMETRIC DISTORTION DUE TO S/C ALTITUDE

Variations in altitude change the width of the scene and hence the across track (width) scale factor (meters/pixel). As shown in Figure 4.2.6-2, the width can be derived as follows. The side S is derived from the law of cosines.

$$R^2 = S^2 + (R + H)^2 - 2 (R+H) S \cos B$$

where R = earth radius

H = S/C altitude

B = MSS mirror scan half angle (5.775 deg. for MSS)

The earth central angle θ, is given by the law of sines

$$\theta = \sin^{-1} (S \sin B/R)$$

and the full scene width is

$$W = 2R\theta$$

Combining the above relationships provides the needed scale factor change with altitude.

GEOMETRIC DISTORTION DUE TO CHANGES IN VELOCITY

Variations in the nominal velocity affect the length of the sence and hence along the track scale factors. The scene length is given by

$$L = (V_{nom} + \Delta V) \quad t_s$$

where

V_{nom} = nominal ground track velocity

TBD meters/second

ΔV = normalized velocity variation

t_s = time to acquire one scene

Combining the above provides the needed scale factor change with velocity.

GEOMETRIC DISTORTION DUE TO NON-LINEAR SCAN

It has been determined that for the MSS possible corresponding non-linearities for other sensors need further evaluations the mirror scan deviates from the ideal linear case.

All of the error sources described above can be incorporated in a computer program which calculates the correction values, in pixels, for a ground reference grid and are available to perform actual image corrections. Modifications of these distortions for other sensors will be needed as their development becomes more mature.

GENERAL ELECTRIC

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