N82 28737

8.8 A CASE FOR INHERENT GEOMETRIC AND GEODETIC ACCURACY IN REMOTELY SENSED VNIR AND SWIR IMAGING PRODUCTS*

by

Johnie M. Driver**

INTRODUCTION

The multispectral images produced by Landsats 1, 2, and 3 have provided valuable data to a diverse spectrum of users worldwide and there is presently a growing demand for more and better data of this kind. Technologies are under development to satisfy this growing demand -- better detectors, new imaging modes, improved platforms, and innovative utilization techniques. There is a compelling legitimate concern, however, that new data types be mergeable with existing data types. To satisfy this concern, there is a tendency to force new data types to fit existing usage modes with an unnecessary efficiency impairment that can be grossly debilitating with an increasingly large volume of data. This paper argues for image acquisition concepts and processing methods which take proper advantage of new imaging modes and accompanying technologies. The goal is to provide delivery timeliness and throughput efficiencies commensurate with the volume of data acquired.

The inherent inaccuracies in the previous Landsat scanning imaging method rendered extensive image rectification a necessity. By contrast, the inherent linearity in solid state line array imagers shows promise for allowing acquisition of images with inherent geometrical accuracy, leaving platform dynamics as the principal source of error. But new platform developments can potentially provide acceptable stability and pointing accuracy. Hence there is a real prospect for acquiring images with inherent geometrical accuracy at least for certain regions. Platform pointing adequacy, when coupled with adequate orbit state determination, can provide geodetic accuracy as well. Further research is required to determine conditions under which inherently accurate global imagery can be acquired both geometrically and geodetically, and how such imagery can be processed to provide the high volume throughput demanded and the required data mergeability as well.

---

*This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract NAS7-100, sponsored by the National Aeronautics and Space Administration.

**Member of the Technical Staff, Mission Design Section, JPL

IMAGING OBJECTIVE

The long-range imaging objective is to provide information adequate to satisfy the perceived operational mission needs. Principal needs relate to quality, timeliness, continuity, coverage, usage diversity, and economy. These needs are discussed at some length in References 1 and 2 and are summarized in Table 1. This paper focuses on "Data Processing Efficiency" as described under the second bullet of Table 1. The imaging system assumed is one which satisfies the remaining requirements except for Thermal IR and Microwave Imagery. The specific imaging objective as relates to this analysis is to acquire images anywhere on the globe which are inherently accurate both geometrically and geodetically. Acquisition of such images will enable efficiencies in processing with consequent relief from timeliness and throughput problems that have plagued Landsats 1, 2, and 3.

SCIENTIFIC IMPORTANCE

Geometrically accurate images are essential to automatic information extraction as well as extraction of bootstrap information, i.e., mission parameters determination from image data. Qualitative (i.e., photointerpretative) use of images, although forgiving, is enhanced by geometric accuracy as is also the capability for quantitative information extraction in a manual mode. Images which are not geometrically correct when acquired (inherently accurate) must be corrected by various time-consuming rectification processes (image line rotation, translation, stretching, warping, etc.). Obtaining images which are inherently accurate offers the following important scientific advantages:

a) Provides timely quick-look information for reconnaissance and episodic events analysis.
b) Provides the potential for onboard information extraction.
c) Avoids the partial loss of spatial and spectral information which resampling typically incurs.
d) Allows timely analysis of a large volume of high-resolution multispectral data which could be totally intractable using conventional processing techniques.

Geodetic accuracy is essential for such processes as multi-temporal comparisons, ground control point improvement, digital mosaicking, automatic inter-image matching, automatic map updating, and map construction to NMA standards. If the acquired images are not inherently accurate geodetically, laborious ground control point fitting must be employed which can be costly and slow indeed when done automatically by correlation techniques, particularly without benefit of a good *a priori* estimated location. With adequate knowledge of platform orbit state and instrument pointing direction, data can be acquired with inherent geodetic accuracy, making possible the scientifically important uses indicated above which would otherwise be too costly to consider on any massive scale.

TECHNICAL FEASIBILITY

The technical feasibility of acquiring inherently accurate images is examined here in terms of a particular mission and imaging system concept and specific functional capabilities. The analysis considers error characteristics (types, sources, and magnitudes) and conceptual compensation modes. The strawman concepts assumed for this analysis are summarized below but are described in greater detail in References 1 and 2.

Mission Concept

A land remote sensing mission is assumed using a free flyer spacecraft launched from WTR into a near-circular sun-synchronous orbit. The spacecraft is assumed to fly at 882-km altitude, orbiting the Earth every 103 min in a contiguous swathing coverage pattern, completing a repeat coverage cycle in 52 days after 729 orbital periods. Surface spacing between adjacent ground tracks occur one day apart, separated by 55 km at the equator and decreasing separation along latitude lines as the cosine of latitude. The 99-deg inclination required for sun-synchronism allows orthographic imaging of all regions of the Earth below 81 deg latitude.

A pushbroom imaging concept (Ref. 2) is used (Fig. 1) to image the land masses of the Earth in the visible and near infrared (VNIR) and short wave infrared (SWIR) spectral ranges. Each image line is formed by 4000 contiguous detector elements arrayed nominally perpendicular to the spacecraft ground track. Image exposure time is adjusted according to spacecraft altitude to form for each pixel a square Ground Instantaneous Field of View (GIFOV). Area array detectors are used to allow a dispersive imaging approach, enabling selective acquisition of multispectral images from any portion of the covered spectral range with high spectral resolution and inherent spectral registration.

Simultaneous utilization of three types of imaging devices is assumed to provide orthographic, stereographic and arbitrary site oblique imaging. Orthographic imagery is provided by the nadir-oriented imaging device. This device will provide a complete and repetitive set of timely and synoptic land area images on a near global scale. This multispectral imaging device will emphasize uninterrupted coverage with high geometric and geodetic accuracy suitable for cartographic use.

For stereographic imagery, the nadir-oriented device is supplemented by two additional instruments, offset fore and aft, to allow continuous monospectral imaging of the terrain from three different vantage points in space. Extremely high inherent geometric and geodetic accuracy for these stereographic imagers is desirable but not crucial. This is due to the comparatively limited data volume these instruments produce and the characteristically retrospective and selective data usage mode expected.

The third imaging device is multispectral and pointable and is used intermittently to provide timely coverage of rapidly changing phenomena at arbitrary imaging sites anywhere on the globe (Ref. 2). With a capability of pointing 55 deg either side of nadir (Fig. 2), the instrument will be capable of next-day coverage of any point on Earth and next-orbit coverage at high latitudes. Geometric and geodetic accuracy for this instrument, while desirable, is not crucial -- in contrast with the orthographic imager -- since the chief information use depends on its inherent spectral registration instead.

Specific capabilities for these three imaging devices are summarized in Table 2. Table 3 summarizes the expected coverage characteristics.

Error Characteristics

Typical image aberrations include scale variations, displacement, distortion, skew, and rotation. These aberrations are common to all imaging modes, but their relative importance differs from one mode to another. Intraframe, interframe, swath-to-swath, and geodetic registration are affected by these aberrations to varying degrees. The following material discusses the error types, principal causes, and gross magnitudes for each imaging mode and examines inherent accuracy feasibility.

Orthographic Imagery. Table 4 lists the characteristic image aberrations expected for the orthographic imager if no special measures are taken to obtain inherent accuracy. The table shows areas where research is needed to find acceptable error compensation options.

The list in Table 4 is dominated by intraframe errors, the primary determiners of geometric accuracy. Image scale changes of 2.4% typically occur due to altitude variations, driven by the combined effects of gravity harmonics and Earth flattening, hindering one-to-one correspondence of image pixels with predetermined geographic locations. These same altitude changes coupled with velocity variations hinder equilateral pixel dimensions on the ground unless compensated.

Continual platform movement around the pitch axis to maintain a nadir orientation gives rise to keystone distortion in the image, causing a shape like the central portion of an orange slice. This distortion, although worse for wider swath widths, appears entirely negligible for a 60-km swath.

Frame skew occurs when the spacecraft maintains a fixed inertial heading while imaging the rotating Earth. The resultant image is composed of an array of parallelogram-shaped pixels, skewing the frame. This aberration may not pose any serious information extraction problem. The skew can be removed by continuous yawing of the spacecraft as a function of latitude. However, this yaw rotates the image lines and gives rise to nonparallelism which can result in large relative pixel displacements at the image frame edge.

Earth curvature causes image lines to overlap toward the frame edges, particularly for wide swaths. The less than 1% overlap expected due to Earth curvature should not significantly impact image radiometry and is probably negligible. Random distortions can occur within an image frame because of drift, vibration or jitter in the imaging platform or instrument. If drift rates are kept to 10^{-5} deg/s, no serious image impairment should result. However, drift rates as large as 10^{-4} deg/s give cause for concern and would doubtless rule out obtaining inherent geometrical accuracy at the 15-m pixel level except for small swaths.

Significant interframe, swath-to-swath and geodetic errors stem principally from navigation errors, altitude variations, and attitude control inaccuracies. Errors of these types hinder mosaicking, multitemporal comparisons, and map registration. With accurate models and suitable ancillary data, these errors and those above can be compensated if necessary by post-processing. The goal, however, is to obtain inherent accuracy. Hence compensation options are needed onboard the spacecraft so that the received images for the most part are ready for use.

Stereographic Imagery. The principal stereographic image aberrations relate to obtaining interframe registration between a given pair of images from the triplet obtained. The error types, causes and expected magnitudes are shown in Table 5. The scale of one image differs from the other because of differential variations in imaging distance, impairing pixel-to-pixel coincidence between frames. Orbit dynamics, Earth geometric flattening, and attitude control errors, principally around the pitch axis, are the major contributors to stereographic image scale errors. Image displacements hinder inherent frame-to-frame correspondences. Earth rotation is the principal contributor giving rise to a 27-km loss in stereoframe overlap if not compensated (Fig. 3). If compensated by yawing the imaging platform, assuming the focal planes of all three cameras are rigidly fixed relative to the platform, image line rotation occurs (Fig. 4). This line rotation results in non-parallel image lines (4.3 mrad middle-to-offset, 8.6 mrad between offset cameras) as well as a 1.7-km departure from geographical coincidence. In addition, attitude control errors can cause significant interframe displacement errors unless limited by a tighter stability rate requirement. A more detailed analysis of stereographic image aberrations is given in Ref. 3.

Oblique Imagery. All of the generic geometrical imaging error types (intraframe, interframe, swath-to-swath, and geodetic) are found to a significant degree in the oblique imaging mode, particularly for large off-nadir viewing angles and large swath widths. Figure 5 indicates how the image scale changes as a function of off-nadir viewing angle, assuming a fixed imager field of view. The imaging distance variation relates directly to pixel spread alongtrack. The swath width variation shows the combined effects of increasing imaging distance and Earth curvature.

Figure 6 shows the character of the intraimage distortion caused by off-nadir viewing at large angles. It is noted that for sufficiently small swath portions (10-30 km), this keystoning effect can be kept to pixel level across the frame even at large off-nadir angles.

Compensation Options

A stable imaging platform is of fundamental importance to acquiring images with inherent geometrical accuracy. Attitude stability in the vicinity of 10^{-5} deg/s is needed for 15-m GIFOV in a 60-km frame size. A larger frame size at the same resolution implies a pointing stability which is proportionately more precise. Given inherent geometrical accuracy within the image, pointing accuracy, or at least accurate pointing knowledge, becomes the next sine qua non for geodetic accuracy. When coupled with 10- to 15-m orbit position knowledge, a 0.001-deg pointing accuracy will enable geodetic registration to within one 15-m pixel most of the time.

Beyond the basic platform requirements, many mission parameters impact the attainable accuracy as discussed in the previous section. Figure 7 suggests compensation options for some of the potential image aberrations encountered. The principal cause of orthographic image aberration is the image scale and pixel shape errors caused by orbit altitude variations. Methods and options for orbit altitude control should be investigated thoroughly to assess the potential for error minimization. Successful orbit control, whether through orientation and shaping, restricted region operation, or active propulsion, will benefit all imaging modes. Typical orbit characteristics and expected deviations are explored in Ref. 4-6.

In principle, certain instrument design features can be used to compensate for potential image aberrations. If a practical method is found for dynamic focal length variation, image scale problems could be essentially overcome for all imaging modes. Altitude variations could be tolerated for orthographic imagery, geometrical flattening and orbit dynamics could be compensated for stereographic imagery, and the effects of imaging distance variations for arbitrary site imaging could be ameliorated. If focal plane rotation is feasible, image line rotation in stereographic and orthographic imagery need no longer be a problem. The capability for dynamic variation of image line exposure time could be a very valuable instrument design feature. This feature would allow maintenance of square pixels with consequently greater image regularity and scalability even if the overall image scale changed with altitude. Without variable exposure time, instrument electronics redesign would be required to obtain square pixels and variable resolution at different nominal operating altitudes.

Given sufficiently accurate ancillary data, compensation for various image aberrations could be performed onboard the spacecraft. Processes such as geometrical correction, dynamic scaling, resampling to a map grid and registration to star references are conceivable and could enable inherent geometric and geodetic accuracy in images transmitted to the ground.

If inherent accuracy is not achieved through the various processes discussed above, precise orbit and attitude knowledge can still be transmitted to the ground where various high-powered but costly and slow methods can be used to compensate for remaining image aberrations.

TECHNOLOGY READINESS

The continual progress being made in pertinent technology developments heightens the promise and value of obtaining inherent geometrical and geodetic imaging accuracy. The principal technology is the solid-state imager developments which make possible the acquisition of high resolution images with high signal-to-noise content and with inherent spatial linearity in a many-element line array. The extensions being made to allow area arrays make possible inherent spectral registration. Obtaining adequate geometrical accuracy onboard offers the hope for optional onboard information extraction with consequent transmission of only the extracted information to the ground.

Pointing platform technology is indicated by the fraction of an arc second stability and accuracy (Ref. 7) promised for the Annular Suspension and Pointing System (ASPS). While these devices are slanted primarily toward inertial pointing needs, extension to a nadir-oriented device with up to an order-of-magnitude degradation would satisfy the principal inherent accuracy needs envisioned here. The Multimission Modular Spacecraft (MMS), which is inherently geared to Earth observation needs (Ref. 8), also shows promise for providing the 10^{-5} deg/s stability needed for inherent geometric accuracy.

Orbit position knowledge to 10 m is targeted for the Global Positioning System (GPS). This accuracy is commensurate with pixel level geodetic accuracy at 15-m GIFOV. Long-term orbit propagation to commensurate accuracies is potentially attainable using precision propagators such as GSFC's GEODYN Program (Ref. 9). The repeating nature of typical Earth observation orbits should allow construction and refinement of specialized geopotential models suitable for orbit prediction to very high accuracies, particularly with refinement of atmospheric drag parameters and continual updates of the modeled atmosphere.

Active orbit control using OMS propulsion on Shuttle missions is probably a viable option for short-term image compensation. Active orbit control using onboard propulsion is not obviously practical for free flyers. The potential for using such an orbit control mode should be determined.

Continual improvements in computing speed, memory, and size minimization increases the options for onboard computation. Imaginative utilization of this capability can also be a strong factor in the acquisition of inherently accurate images.

Overall, the technology readiness is such that attaining inherent geometric and geodetic accuracy in the acquired images is a real possibility and the necessary research and analysis to define more clearly the options and requirements is warranted.

RESEARCH NEEDS

GEODYN Updates

The GEODYN orbit propagator should be modified to compute nadir orientation and orbital position relative to a triaxial ellipsoid rather than an oblate spheroid for improved geodetic accuracy.

Atmosphere Dynamics/Updates

Continuing research in atmosphere modeling is needed to predict more accurately the short-term variations in drag-related parameters. The capability to allow frequent updates to the atmosphere model is warranted. Drag will constitute the major orbit prediction uncertainty for typical low- altitude Earth observation missions.

Geopotential Model Development

Procedures need to be developed for creating in routine fashion specialized geopotential models which take advantage of the repetitive nature of typical Earth observation orbits to improve prediction accuracy. Thus if an orbit is modified to provide a different coverage pattern, a new geopotential model of comparable accuracy will shortly ensue.

Imaging Platform

Research is needed to assure that for both free flyer and Shuttle or Space Platform missions, the capability will exist to provide a 10^{-5} deg/s or better platform stability and pointing control accuracy or knowledge as a minimum to 0.001 deg for a nadir-oriented imaging platform.

Orbit Dynamics

Methods of control for orbit dynamics are needed to define the requirements and limitations on frozen orbits, constant altitude orbits, minimum altitude variation orbits, coverage pattern maintenance, and active orbit shaping using onboard propulsion.

Image Geometrical Characteristics

A detailed investigation is needed to determine the precise geometrical characteristics of acquired images on a representative Earth surface for accurately modeled orbits, showing geographical dependence and the effects of typical off-nominal mission characteristics.

Variable Instrument Parameter Development

There is a potentially high payoff in acquired image quality if dynamic variation of instrument parameters can be implemented in a practical way. Significant research is warranted to find a reliable mechanization for variable focal length for imaging distance compensation on spaceborne telescope-type instruments of the kind envisioned for Earth observation missions. Similarly, a mechanism is needed to provide commanded focal plane rotation one cycle each orbit for thousands of orbital revolutions. This mechanism would be used to maintain image line parallelism in image frames.

Dynamic variation of image line exposure time is simple to implement in principle. However, there are doubtless unforeseen implications in the resulting variation of data acquisition rates and possibly some image radiometry implications as well. Research is needed to find an acceptable implementation scheme, thus allowing free variation in orbit altitude and image resolution without distortion in pixel shapes.

CONCLUSIONS

It has been shown that significant aberrations can occur in acquired images which, unless compensated on board the spacecraft, can seriously impair throughput and timeliness for typical Earth observation missions. Conceptual compensations options were advanced to enable acquisition of images with inherent geometric and geodetic accuracy. Research needs were identified which, when implemented, will provide inherently accurate images. Agressive pursuit of these research needs is recommended.

REFERENCES

1. "Application of Solid-State Array Technology to an Operational Land-Observing System," JPL Internal Report No. 715-82, Jet Propulsion Laboratory, Pasadena, CA, 31 October 1980.

2. Driver, J.M., "A Flexible Approach to an Operational Land Observing System," AIAA Paper 81-0315, 19th Aerospace Sciences Meeting, St. Louis, MO, January 12-15, 1981.

3. Driver, J.M., "Stereosat: A New Astrodynamics Challenge," AIAA Paper 80-0237, 18th Aerospace Sciences Meeting, Pasadena CA, Jan. 15-16, 1980.

4. Driver, J.M., and Tang, C.C.H., "Earth Application Orbit Analysis for a Shuttle-Mounted Multispectral Mapper," AAS Paper 81-182, AAS/AIAA Astrodynamics Specialist Conference, Lake Tahoe, NE, Aug. 3-5, 1981.

5. Tang, C.C.H., "Imaging Spectrometer Development Program: Preliminary Orbit Characteristics Document," JPL Internal Report No. 715-145, Jet Propulsion Laboratory, Pasadena, CA, October, 1981 (in publication).

6. "Imaging Spectrometer Progress Report," JPL Internal Report No. 715-143, Jet Propulsion Laboratory, Pasadena, CA, October, 1981 (in publication).

7. Van Riper, R., "High Stability Shuttle Pointing System," Reprint from Proc. Soc. Photo-Optical Instrumentation Engineers, Vol. 265 (Shuttle Pointing of Electro-Optical Experiments), Los Angeles, CA, Feb. 9-13, 1981.

8. Iwens, R. P., et al., "Design Study for Landsat-D Attitude Control System," TRW Defense and Space Systems Group, Contract NAS5-21188, Prepared for Goddard Space Flight Center, Greenbelt, MD, Dec. 15, 1976.

9. Martin, T.V., et al., "GEODYN System Description," EG&G/Washington Analytical Services Center, Inc., Contract No. NAS 5-22849, Riverdale, MD, 1976.

Table 1. Perceived Operational Mission Needs

- **DATA CONTINUITY**
  - CONTINUOUS DATA ACQUISITION
  - NON-DISRUPTIVE DATA TYPE CHANGES
- **DATA PROCESSING EFFICIENCY**
  - QUALITY (PIXEL-LEVEL PRECISION)
  - TIMELINESS (QUICK-LOOK, THROUGHPUT)
  - PRODUCTION FACILITY (INFORMATION EXTRACTION, DISPLAY)
  - ECONOMY (PURCHASE, PROCESSING)
- **OPTIMAL COVERAGE STRATEGY**
  - MULTIPLE ASPECT VIEWING
    - ORTHOGRAPHIC } NEAR-GLOBAL,
    - STEROSCOPIC } CONTINUOUS
    - OBLIQUE (MESOSCALE, INTERMITTENT)
  - CLOUD FREE, SYNOPTIC, GLOBAL
  - RAPID, SEASONAL, AND ANNUAL REPEAT COVERAGE
  - OPTIMAL LIGHTING
  - CONTIGUOUS SEQUENTIAL SWATHS
- **TASKING CAPABILITY**
  - MISSED SCENE RECOVERY
  - SELECTED AREA IMAGING
  - SELECTABLE IMAGING OPTIONS (IFOV, SWATH, BANDS, BANDWIDTHS)
  - OPTIONAL THEME SELECTION
- **IMPROVED IMAGING PARAMETERS**
  - SPATIAL RESOLUTION (10 TO 30 m IFOV)
  - SPECTRAL RESOLUTION ($\Delta\lambda \approx 20$ nm)
  - RADIOMETRIC SENSITIVITY ($NE\Delta\rho \approx 0.5\%$)
  - ADDITIONAL SPECTRAL BANDS (15 OR MORE)
- **NEW TECHNICAL CAPABILITIES**
  - SHORT WAVE INFRARED (SWIR)
  - THERMAL INFRARED (TIR)
  - MICROWAVE IMAGERY

Table 2. Instrument Capabilities

	ORTHOGRAPHIC & OBLIQUE	STEREOGRAPHIC
SPECTRAL BANDS (λC)	30 CONTIGUOUS IN VNIR 30 CONTIGUOUS IN SWIR	SINGLE BAND BETWEEN 0.8 AND 1.0 μm
SELECTABLE BANDS	ANY 6 OF 60 AVAILABLE	NONE
BANDWIDTHS ($\Delta\lambda$)	20 TO 120 nm IN VNIR 30 TO 120 nm IN SWIR	100 nm
SPECTRAL REGISTRATION	INHERENTLY PRECISE (DISPERSIVE IMAGING)	N/A
SWATH WIDTH (SW)	60 km MAX., SELECTABLE	50 TO 60 km FIXED
INSTANTANEOUS FIELD OF VIEW (IFOV)	15, 30, 45 OR 90 m	15 m
TASKABLE PARAMETERS	SW, IFOV, λC, $\Delta\lambda$ IMAGE SITE FOR OBLIQUE	B/H, IFOV mix

Table 3. Coverage Characteristics

	ORTHOGRAPHIC	STEREOGRAPHIC	OBLIQUE
INSTRUMENT ORIENTATION	NADIR ORIENTED	23° FORE AND AFT	POINTABLE ±55° (CROSSTRACK)
COVERAGE EMPHASIS	CARTOGRAPHY	TOPOGRAPHY	AGRICULTURE AND EPISODIC EVENTS
COVERAGE EXTENT	-- NEAR GLOBAL --		GLOBAL SAMPLING
COVERAGE CONTINUITY	-- CONTINUOUS OVERLAND -- DURING DAYLIGHT HOURS		INTERMITTENT
REPEAT COVERAGE FREQUENCY	-- 50 TO 60 DAYS --		NEXT DAY ANYWHERE NEXT ORBIT AT HIGH LATITUDES
ADJACENT SWATH COVERAGE	-- NEXT DAY --		ANY SITE ON ANY DAY
SPECIAL FEATURES	UNINTERRUPTED COVERAGE, LIMITED TASKING	NEAR-GLOBAL STEREO DUAL BASE-TO-HEIGHT	• RAPID REPEAT COVERAGE • UNLIMITED TASKING • FREQUENT SITE CHANGES

TABLE 4. ORTHOGRAPHIC IMAGE ABERRATIONS

Error Types	Principal Cause	Expected Magnitudes
	INTRAFRAME	
Image Scale	Variable Altitude w/fixed focal length	2.4%
Pixel Shape	Variable Altitude w/fixed exposure time	2.4%
Keystone Distortion	Nadir Orientation on Spherical Earth	1 m @ SW=61 km 19 m @ SW=185 km
Frame Skew	Earth Rotation w/fixed S/C heading	4 deg
Image Line Rotation	Frame Skew Removal by Spacecraft Yaw	21 m @ SW=61 km 187 m @ SW=185 km
Image Line Overlap	Earth Curvature	0.07% @ SW=61 km 0.6% @ SW=185 km
Random Distortion	Platform Stability	15 m @ 10^{-4} deg/s for SW=61 km 45 m @ 10^{-4} deg/s for SW=185 km
	INTERFRAME, SWATH-TO-SWATH, AND GEODETIC	
Orbit State	Tracking Capability	10 m GPS 150 m TDRSS
Image Scale	Altitude Variation	1.7%
Displacement	Attitude Control	154 m @ 0.01 deg
Rotation	Attitude Control	11 m @ 0.01 deg for SW=61 km 32 m @ 0.01 deg for SW=185 km

TABLE 5. STEREOGRAPHIC IMAGE INTERFRAME ABERRATIONS

Error Types	Principal Cause	Expected Magnitude
Image Scale	Orbit Dynamics	900 m @ SW=61 km 1700 m @ SW=185 km
	Earth Flattening	180 m @ SW=61 km 550 m @ SW=185 km
	Attitude Control	20 m @ .01 deg for SW=61 km 60 m @ .01 deg for SW=185 km
Image Displacemen	Earth Rotation	27/55 km
	Attitude Control (0.01 deg)	
	Yaw	69/138 m
	Pitch	385 km
	Roll	156 km
	Yaw Mechanization w/fixed cameras	1.7 km
Image Line Rotation	Yaw Mechanization w/fixed cameras	4.3/8.6 mrad

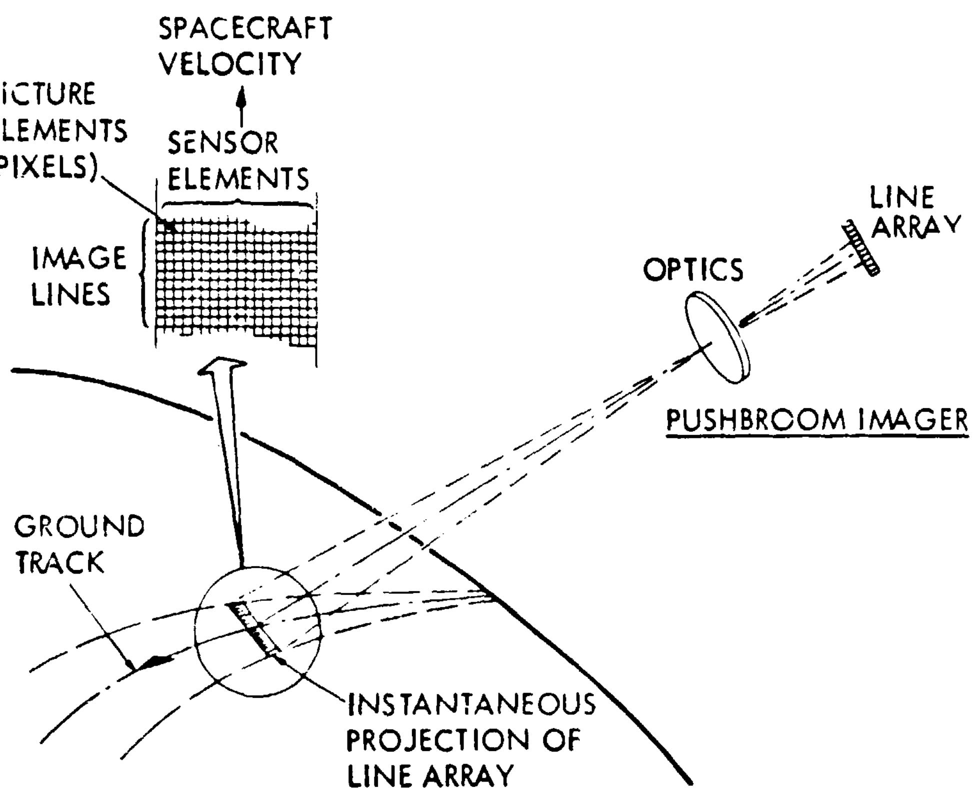

Fig. 1. Pushbroom Imaging Concept

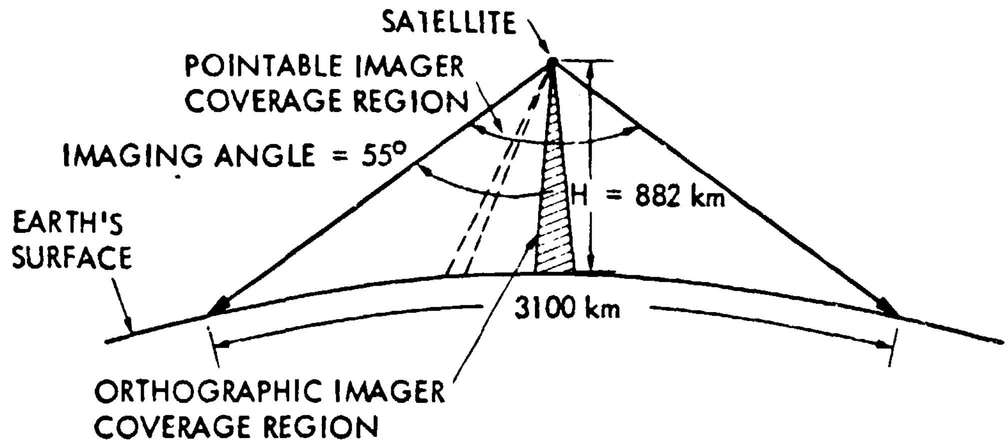

Fig. 2. Pointable Imager Coverage

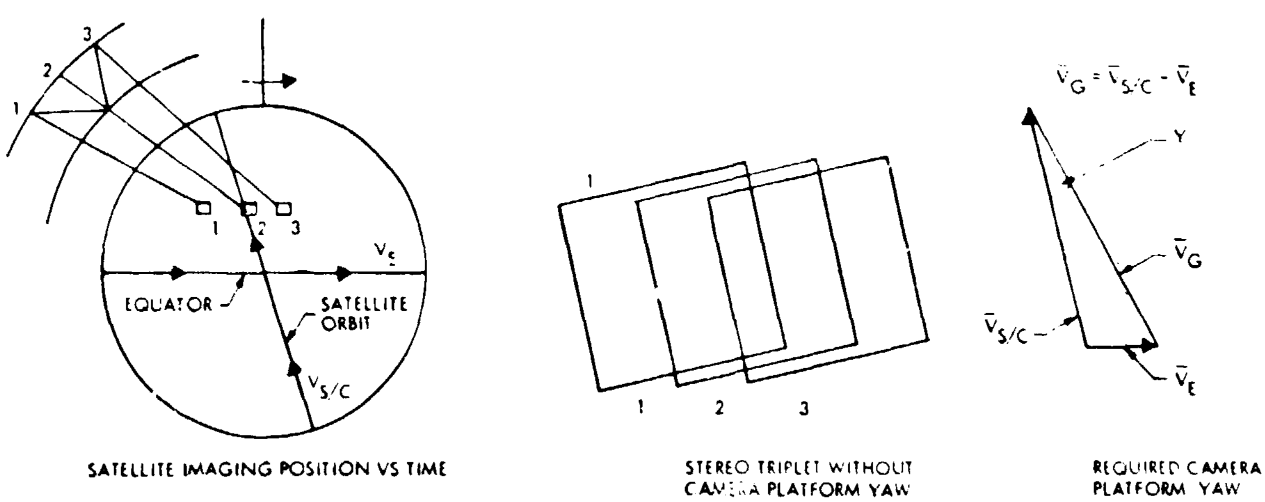

Fig. 3. Earth Motion Impact on Stereographic Imagery

ORIGINAL PAGE IS
OF POOR QUALITY

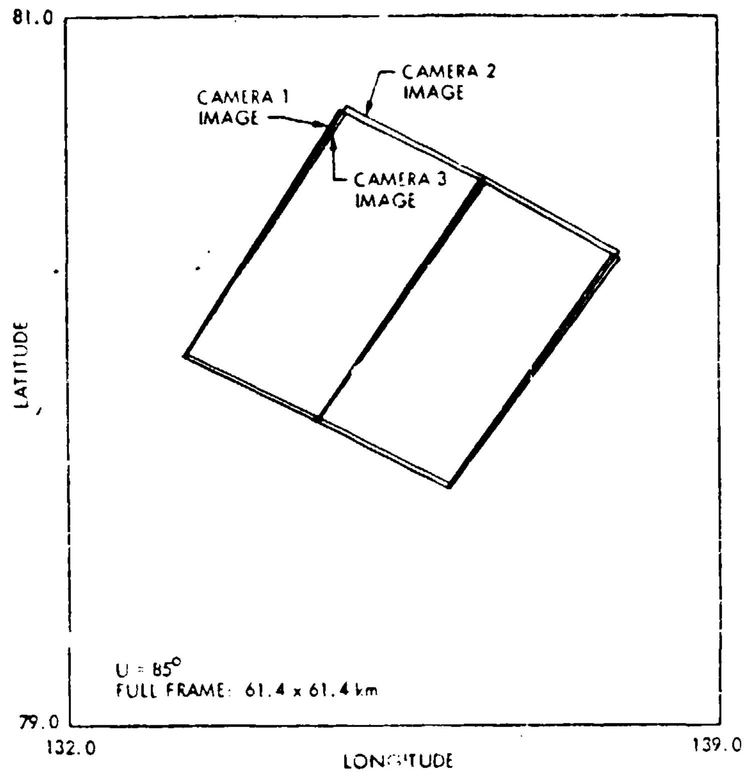

Fig. 4. Stereographic Image Compensated for Earth Motion by Platform Yaw

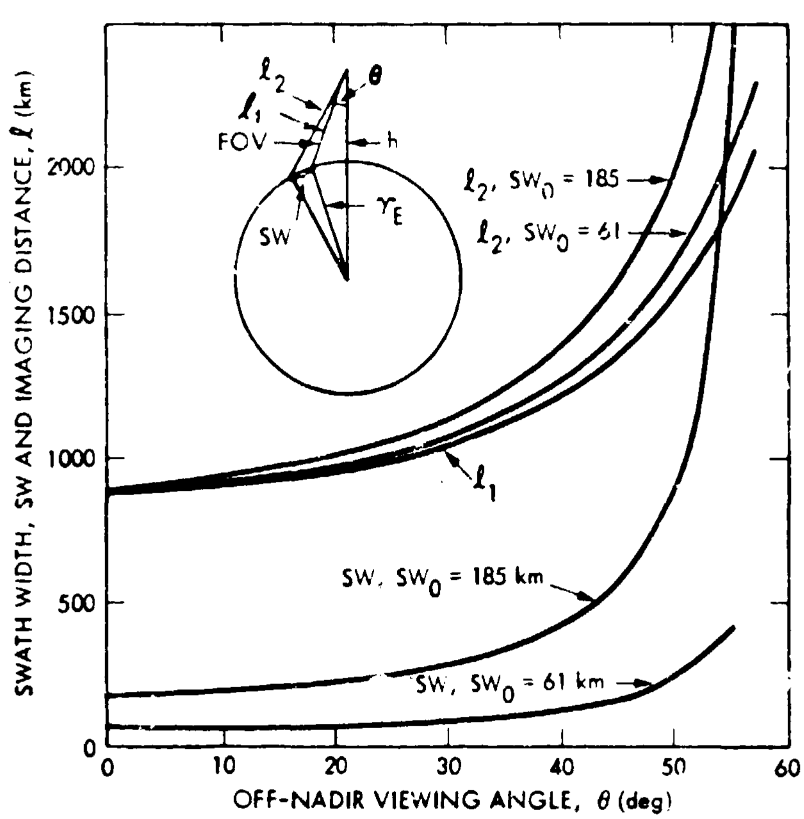

Fig. 5. Image Scale Dependence on Off-Nadir Viewing Angle With Fixed Imager Field of View

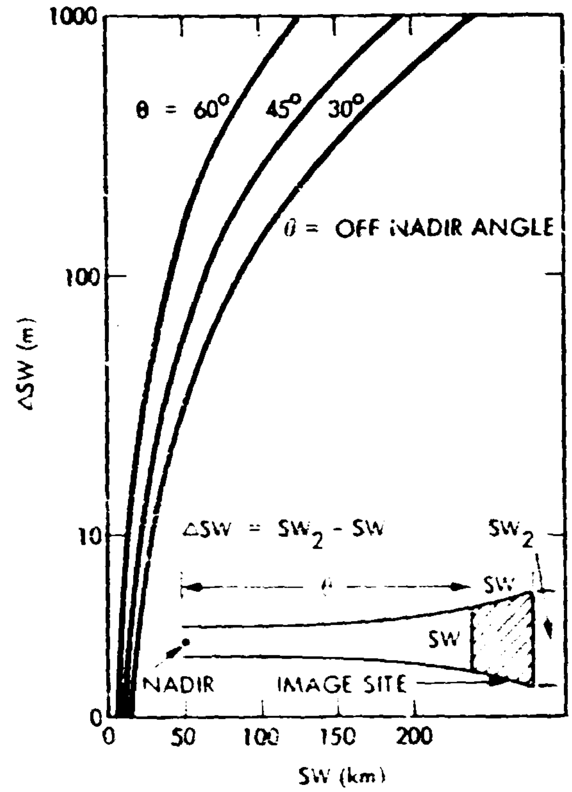

Fig. 6. Keystone Distortion Due to Off-Nadir Imaging on a Spherical Earth

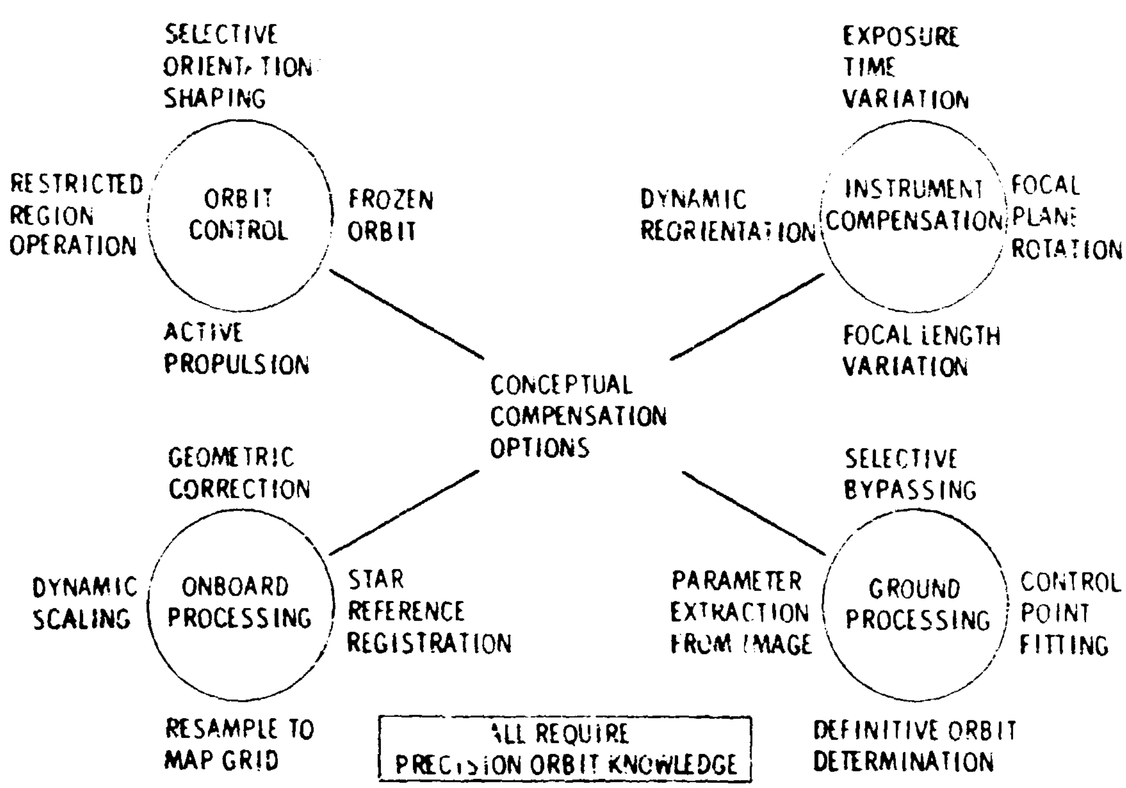

Fig. 7. Options for Compensating Orbit Dynamics Impact on Image Geometry