

The USGS Plan for Quality Assurance of Digital Aerial Imagery

Greg Stensaas¹, George Y.G. Lee², Jon Christopherson³
(Draft version 0.9, June 2008)

Abstract

The U.S. Geological Survey (USGS) Plan for quality assurance of digital aerial imagery introduced here is in response to the recommendations made to the USGS by the ASPRS Camera Calibration Panel in the year 2000. It has been developed and reviewed in consultation with major federal agencies, industry, and academia. Described herein is the Plan's four-part process that the USGS believes will ensure that high-quality digital aerial imagery can be procured and produced. The four parts are grouped into two major areas, and are:

1. Data Procurement Area:
 - a. Specification Guidelines for Digital Aerial Imagery
 - b. Acceptance Standards for Digital Aerial Data
- and
2. Data Generation Area:
 - a. Sensor Type Certification
 - b. Data Providers Certification

By focusing on the processes involved in procuring and generating digital aerial data, the USGS Plan seeks to ensure quality at each major step and place the responsibility for maintaining quality with those most directly able to affect it. The USGS and its partner agencies hope to encourage the ability of digital aerial imaging systems to meet the needs of providers and consumers of aerial data.

Introduction & History

The USGS has the primary responsibility for camera calibration in the United States and has been performing this function for film-based cameras in its Optical Science Laboratory (OSL) in Reston, VA since 1973. The USGS calibration policies were imposed to ensure that photography acquired through contractors would meet the mapping quality needs in its photogrammetric production methods. The OSL provides a

¹ Gregory Stensaas is the Remote Sensing Technologies Project Lead for the US Geological Survey at the USGS EROS, 47914 252nd St., Sioux Falls, SD, 57198. (stensaas@usgs.gov)

² George Y.G. Lee is the Digital Raster Coordinator with the US Geological Survey's Geospatial Information Office, 345 Middlefield Rd, Menlo Park, CA, 94025. (gylee@usgs.gov)

³ Jon Christopherson is with SGT, Inc. contractor to the US Geological Survey's EROS, 47914 252nd St., Sioux Falls, SD, 57198. (jonchris@usgs.gov)

USGS Report of Calibration for cameras submitted. This USGS Report of Calibration is recognized as the official aerial camera certification in the United States (Tayman, 1984), and the requirement for a current calibration report has become the *de facto* requirement of other Federal agencies, as well as State and county governments. For a camera to be current, it must have been calibrated at the OSL within the past three-years.

In 1998, the USGS asked ASPRS to convene a panel of experts to look into the future of camera calibration. This panel took a broad view of the industry and its evolving needs and made recommendations to the USGS in the year 2000 that included:

1. The USGS Optical Science Laboratory (OSL) should continue to calibrate film mapping cameras using the present calibrator and the Simultaneous Multiframe Analytical Calibration (SMAC) program.
2. Initiate the design, development, and implementation of a digital, camera calibration capability at the USGS (estimated required investment - \$4 M).
3. Conduct research efforts in order to support a reliable and cost effective transition to digital acquisition systems (estimated required investment - \$1 M).
4. Initiate the design, development and implementation of an in-situ (flight) calibration process.
5. A calibration/verification process must be established for satellite imagery.
6. Develop a U.S. Standard for camera and sensor calibration.
7. Adequate funding should be sought in order to ensure the continued operation of the Optical Science Laboratory (OSL), as well as to provide for the improvements and extensions described in the preceding recommendations.

This paper describes how the USGS proposes to address items (2), (3), (4), and (6) above.⁴

Benefits and Problems of the Present System

The USGS Report of Calibration provides the camera calibration parameters (interior orientation parameters and distortion coefficients) necessary to create higher-order products from aerial film. Without the calibration parameters contained in the report the film could not accurately be worked into orthophotos or other higher-order products. Thus, it was necessary that the USGS calibration report be delivered with the film.

The USGS has also established minimum standards for camera parameters and performance.⁵ These standards have identified sub-standard cameras and helped the U.S. aerial remote sensing industry maintain a high overall quality level of the cameras in use today.

⁴ The USGS has addressed numbers (1) and (7) by continuing to operate the OSL and modernizing its systems so that it can continue to serve the users of film cameras for the foreseeable future. Item (5) has been addressed by the formation of the Joint Agency Commercial Imagery Evaluation group in partnership with NGA, USDA, and NASA to evaluate commercial satellite imagery.

⁵ Minimum specifications for USGS calibration, sample reports and other information about the USGS Optical Science Lab can be found at: <http://edclxs22.cr.usgs.gov/osl/index.html>

Over time, the contractual requirements for the USGS Report of Calibration has become a standard feature of all contracts for aerial film and products; it has become a “boilerplate” feature in contracts from federal, state, and local governments and even from private firms. This continues, even though the industry has evolved so that the procuring customers rarely order base film images, but instead procure higher-order products that have been produced by the data providers. Thus the end-user has little need for the USGS Report of Calibration and its calibration parameters but the contractual requirement to deliver a USGS Report of Calibration remains. The USGS Report of Calibration has taken on the aura of a “certification” of quality that is, perhaps, larger than its initial purpose. However, due to the maturity of the aerial mapping industry, a general similarity of cameras and technologies, and the professionalism of the data producers, the quality of aerial film and film-derived products in the U.S. have remained quite high.

The USGS also recognizes that as cameras evolved beyond film to digital technology and were integrated with airborne global positioning system (GPS) and inertial measurement unit (IMU) systems, the new digital sensors required that a total system calibration approach be used.

Today, these and other new technologies hold great promise for the aerial mapping industry, most particularly in the potential for direct digital imaging from the air using advanced digital cameras or sensors.⁶ These many and varied new digital sensors are not calibrated by the USGS. However; the standard boilerplate requiring the USGS Report of Calibration remains in many contracts, effectively precluding digital systems from those contracts. This has inhibited the use of digital systems and slowed the development of the digital industry.

State of the Digital Industry

The growth in capability of the digital imaging industry is impressive. New technological developments are unfolding so rapidly that the industry, both producers and consumers, are having trouble “keeping up” with them. Technologies vary greatly and range from sensors showcasing technologies formerly seen only in satellites to home-made systems using cheap off-the-shelf technologies that were not initially developed for aerial mapping. The range of technologies is exceeded only by the claims made for these systems, with the average person having difficulty separating the superb systems from the unacceptable. Indeed, some have likened the state of the digital aerial industry today to its “Wild West” phase of rapid change, amazing potential, and perhaps a few shady characters.

Traditional methods of conducting business must adapt to this evolving landscape of aerial imaging in the 21st century. The USGS recognizes that there are numerous data

⁶ Throughout this paper the terms “camera” and “sensor” are used interchangeably. The term “sensor” is more correct for the broad variety of digital imaging systems, some of which function in a significantly different manner than traditional film cameras.

providers, using a wide variety of sensor systems, providing geospatial products to the user community under different contract specifications and requirements. Further, the USGS also recognizes that simply implementing capabilities to calibrate digital sensor systems does not ensure the overall quality of geospatial products.

In order to meet the broad needs of the federal consumers of aerial imagery, the USGS established the Inter-Agency Digital Image Working Group (IADIWG) to deal with a broader range of issues when contracting for digital imagery products. The IADIWG consists of fourteen federal government agencies and represent the largest purchasers of data in the nation. Additionally, the USGS has described the components and philosophy of this plan at various venues, including ASPRS conferences, and held IADIWG workshops with government, manufacturers, and data providers to review these ideas and provide feedback to the USGS.

Quality as a Process

The USGS Plan addresses the procurement and generation of digital aerial data as a process comprising four major quality elements, two in the Data Procurement domain and two in the Data Generation. The two domains and four individual elements of the Plan are illustrated in Figure 1.

The Data Procurement domain contains the initiation and conclusion of the entire process. The Data Procurement element is the processes of clearly and concisely specifying the aerial products needed and then entering into a contractual agreement for those products. Data Assessment and Inspection element includes the processes used to determine that the delivered data meet the requirements as specified in the contract. In general, this domain can be thought of as the “Customer Domain”.

The Data Generation domain is divided into the Digital Aerial Sensors element which includes the development, vending, and support of the digital aerial sensor. The Data Providers element encompasses the operation of sensors and development of products from the sensor outputs. This domain can be generalized as the “Industry Domain”.

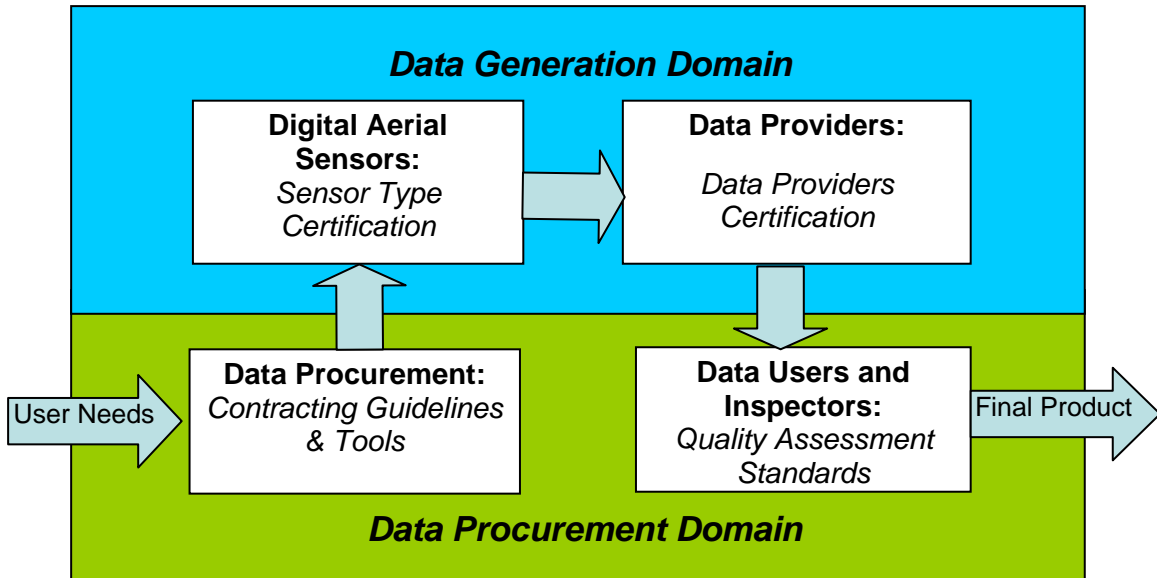


Figure 1. End-to-End Process for Procuring Aerial Data

These four elements comprise the end-to-end process of aerial imaging, from specifying the initial need to the satisfaction of that need. The next section describes how the USGS addresses quality assurance in each of the four parts

The USGS Plan for Quality Assurance of Digital Aerial Data

Data Procurement Domain:

The data procurement domain consist of two parts that are intimately related. Neither element stands alone - each relies on the proper performance of the other in order for a successful procurement.

The first element in the procurement domain is also the initial step in procuring digital aerial data. This is the process of clearly, concisely, and quantifiably specifying what is desired in a business agreement with a data provider through a binding contract. Digital aerial imagery, while maintaining most or all of the technical qualities of film aerial imagery, offers new capabilities and qualities. It is critical that each of the desired qualities be clearly, concisely, and correctly specified in the initial contract before a data provider can acquire, produce, and deliver the final products. Digital aerial imaging presents many new capabilities and a few limitations, as well as adding a wealth of new terms and concepts to the lexicon of aerial imaging. A common lexicon is needed to reduce ambiguity and misunderstanding between all parties involved in the requesting, procuring, production, and inspection of the imagery. Similarly, there should be open, understandable, and repeatable methods and metrics for assessing data. These assessments should be able to clearly measure whether the imagery products meets the initial specifications.

Contracting Guidelines and Tools

The first step in digital aerial imaging is the identification of a need by a customer. Digital aerial imaging presents many new capabilities and a few limitations, as well as adding a wealth of new terms and concepts to the lexicon of aerial imaging. Differences in terminology and expectations have given rise to numerous misunderstandings and problems in the contracting process for digital imagery and have hindered procurement of digital aerial products.

To help alleviate these issues and to promote common usage of terms and expectations the USGS, in conjunction with its partners in the IADIWG, has developed initial Contracting Guidelines for the procurement of Digital Aerial Imaging. Further developments will include detailed technical specifications for various technical capabilities of digital imaging along with informative explanations of these capabilities. This will help the potential users and their procurement officials understand what can and cannot be done with digital aerial imaging so that they are better able to choose and properly specify the products that they need.

This guideline is available now in document form and will soon be made available in an Internet Web-based tool that potential customers of digital aerial data can use to help generate portions of the statement of work and specifications that can be used in the procurement of digital aerial products.

Data Procurement Domain: Quality Assessment Standards and Tools

This portion of the USGS Plan deals with the process of determining whether or not the data delivered under contract from a Data Provider meets the quality specified in the initial contract. To this end the USGS and its IADIWG partners have developed standard methods and metrics for use in measuring digital aerial data product quality. This guideline will be available in printed form and as an Internet Web-based tool describing how to independently verify data product characteristics.

The Contracting Guidelines for Digital Aerial Imaging are based on the experiences of the largest purchasers and providers of digital products and will be updated as needed to reflect the evolving industry and new capabilities. The web tool is primarily designed to support purchasers with limited to no experience in the acquisition of both film and digital aerial imagery while providing still excellent imagery examples and appropriate applications for these examples.

Data Generation Domain:

Type Certification of Aerial Sensors

The second step in the process of the USGS Plan is the “type certification” of digital aerial sensors for their suitability to high-quality aerial imaging needs. The USGS will visit the manufacturer of a digital aerial sensor system and learn of the design, development, and testing of that sensor as well as the manufacturer’s intended operational constraints and required support needed to ensure that the data generated by

the system is of consistent quality. Included in this process is a total review of the manufacturer's recommended calibration, operation, and maintenance requirements for the system after sale.

It should be noted that this USGS type certification is intended to ensure that the sensor system has been designed to reliably, repeatedly, and routinely deliver an output product of consistent quality. The certification will provide customers and users of digital imagery a verification of manufacturer specifications and claims. This type certification does not imply that systems produced by different manufacturers, each receiving this certification, are capable of delivering data of identical quality or characteristics. The USGS has steered clear of attempting to judge the capability of systems; that is for the free market to decide what mix of capabilities, usability, and value best meet the needs of Data Providers. Rather, the USGS type certification simply endorses that the system, when operated in accordance with the manufacturer's parameters, has a high likelihood of reliably producing products that meet the claims of the manufacturer for that system.⁷

Data Generation Domain: Data Providers Certification

The third element of the USGS Plan involves the Data Providers; a term used to describe those who fly the digital aerial systems referenced in the previous section and/or process its output into the final product for the customer. A Data Provider can be viewed as one entity, although in practice the work involved may be split among several firms. For example, a Data Provider may contract out portions of the flying or the data processing and product generation to other flyers/producers and combine the work of others into the final product. For the purposes of the USGS Plan, the Data Provider is assumed to be the person/firm that has the contractual responsibilities to the procuring customer. As such, they have the responsibility to ensure that the requirements of the Data Providers certification are met by all subcontractors and business partners.

The USGS Plan will offer certification of Data Providers. During the certification process the USGS will inspect the Data Provider's processes from mission planning and flying, down to product generation and final delivery processes. Of primary concern to the USGS is that the Data Provider has a well-documented process and follows a quality plan⁸ governing all operations from data collection to product delivery. The USGS will also assess a sample orthoimage from data collected over a known range. This certification assures the potential contracting officer that this firm has a high likelihood of repeatedly delivering consistent quality data.

⁷ An illustrative analogy can be made with the FAA requirement for airworthiness certification of aircraft. This certification is required of both the Cessna 172 and the Boeing 777, although each is designed for totally different needs and markets. Likewise, the airworthiness certification process is tailored to each system based on its design and intended uses. (Thanks to Gerry Kinn for this helpful analogy)

⁸ The USGS does not require an ISO-type company certification for the Data Provider. However, many (but not all) of the same requirements and expectations of the USGS Data Provider's Certification would be met by an ISO or ISO-like certification of company practices.

Benefits of the USGS Plan

The USGS Plan has been written to do more than simply replace the calibration report issued for aerial film cameras. This plan, developed jointly with partner agencies across the U.S. Federal Government, asks that consistent processes and standards be used by those buying and using data, and it expects that high standards for quality be demonstrated by those involved with the production of digital aerial data.

This plan, while more comprehensive than the past USGS standards for film cameras, will result in less government burden for manufacturers and flyers. Instead of sending every camera sold in the U.S. through the USGS OSL, this plan transfers the expectations and burden of calibration and maintaining quality to those most capable of ensuring those high standards: the manufacturers and users of digital aerial systems. Manufacturers are the best designers of calibration methods for their respective systems. Data Providers can best control the processes that generate digital aerial products.

As for calibration of the sensor systems themselves, the USGS expects the manufacturers to develop means of calibration for their systems. This can range from factory-provided calibration services to self-calibration methods designed to be performed by the sensor owners/operators, or combinations of the above. The USGS is aware of exciting advances in the capabilities for self-calibration techniques that can be performed by the operators of the system. Such methods will allow for greater accuracy, less “downtime” and expense by the flyers, and the likelihood that calibrations will be performed more frequently – all contributing to the goal of promoting the availability of high-quality digital aerial imaging products.

Two parts of the Plan bear further explanation due to the demands that they place on industry. The manufacturer’s certification initially seems like a new burden for them. However, all film cameras sold in the US today are sent through the USGS OSL for a calibration report. This incurs an expense to the manufacturer for each and every camera sold. The new certification process will impose a one-time burden on the manufacturer for all cameras/sensors of that type that will be sold in the U.S., thus reducing the overall burden on a manufacturer who sells multiple digital systems in the U.S. when compared to multiple film camera sales. This also removes shipping costs and risks and the time needed to deliver the camera/sensor to the manufacturer’s customer.

Data Providers Certification also seems like an increased burden on Data Providers compared with the traditional film camera calibration requirement. In some respects this is true, as the USGS asks for better visibility and understanding of the processes under the Data Provider’s control and assurances that the Data Provider is operating the digital system in accordance with its intended capabilities. However, this certification effort should provide little actual burden on any firm operating according to high quality standards today. Additionally, this new certification does not require the Data Provider to take expensive sensor systems out of service, expend the costs and time to deliver them to a USGS lab, or run the risks of letting their systems out of their immediate control. Instead, this plan allows systems to remain in service while the Data Provider demonstrates their internal quality assurance plans to the USGS. The Data Providers

Certification also covers all of the operations by that Data Provider, regardless of the number of systems they operate, thus reducing fees and burden for those operating more than one camera/sensor.

Each part of the four-part plan is written for one specific group. The individual parts of the Plan and their respective targeted communities are:

<u>Plan Part</u>	<u>Targeted Community</u>
Contracting Guidelines.....	Contracting Officers and those attempting to purchase data
Manufacturers Certification.....	Manufacturers of digital aerial sensors and supporting systems
Data Providers Certification	Aerial digital sensor flyers and digital aerial data producers
Acceptance Standards.....	Data users and those receiving data on their behalf

However each group benefits from the Plan parts that are targeted at others. Table 1 shows some of the benefits gained by each community from their own standards along with the benefits they gain from the remaining standards.

Draft

	Contracting Agents / Officers (COs)	Digital Aerial Sensor Manufacturers (MFRs)	Digital Aerial Data Providers (DPs)	Digital Aerial Data Product Consumers
Contracting Guidelines	<ul style="list-style-type: none"> • Standardized terms and descriptions make contracting easier and clearer • Guidelines help acceptance of digital aerial data and its benefits • Standardized terms and guidelines help COs more accurately describe their users' needs 	<ul style="list-style-type: none"> • Clearer, easier contracting build greater demand, for digital aerial products, thus greater demand for sensors/systems. • Better understanding and expectations of digital aerial products by purchasers drives greater satisfaction. 	<ul style="list-style-type: none"> • Clearer, more precise contracting language and expectations mean fewer misunderstandings and problems with customers. • Common specifications are more directly communicated • Improves ability to meet customer expectations. 	<ul style="list-style-type: none"> • Clearer contracting standards mean greater likelihood of receiving data products that meet consumer's needs • Clearer language helps COs more precisely and consistently buy the data consumers need
Manufacturers Certification	<ul style="list-style-type: none"> • CO knows if D.P. is using high-quality systems to generate data. • COs better able to determine if system can produce desired data 	<ul style="list-style-type: none"> • Independent certification helps promote sensor system. • Substandard systems are less likely to enter marketplace; data quality remains high • Increased acceptance of digital systems leads to greater demand. 	<ul style="list-style-type: none"> • DPs are assured that sensor systems can meet MFR claims • DPs have operation and maintenance requirements clearly laid out • Calibration is designed and done by those who designed systems 	<ul style="list-style-type: none"> • Data consumers know that data products originated from high-quality systems • High-quality data encourages continuing demand
Data Providers Certification	<ul style="list-style-type: none"> • CO can see that a D.P. has met minimum standards for quality processes. • Helps COs build trust of certified DPs 	<ul style="list-style-type: none"> • DPs are expected to operate MFR's systems in accordance within specifications • Holds DPs to maintenance standards of MFR systems 	<ul style="list-style-type: none"> • Independent certification helps promote DPs and their capabilities. • One certification for DP; not for each camera • DP no longer taking cameras out of service, expense of shipping, etc. 	<ul style="list-style-type: none"> • Data consumers know that data products originated from high-quality systems • High-quality data encourages continuing demand
Acceptance Standards	<ul style="list-style-type: none"> • COs understand how the products they are ordering will be judged • COs know that the products can be fairly measured. 	<ul style="list-style-type: none"> • Clearer understanding of digital sensors capabilities encourages use; grows end-customer base & demand 	<ul style="list-style-type: none"> • DPs understand what is being required and the standards to which their products will be judged; customer expectations clearer 	<ul style="list-style-type: none"> • Data consumers have common standards by which to judge data products • Clearer standards develop clearer expectations

Table 1. Benefits of the USGS Plan

Schedule & Status

In January 2006, the USGS began its certification efforts with digital aerial system manufacturers. This initial effort was limited to several of the major producers of digital aerial sensors and was undertaken with their support and cooperation to help further develop and refine the standards and methodology used by the USGS in this process. As of mid-2007, the USGS had visited four of the major manufacturers and awarded certification to aerial systems from Applanix, Intergraph, Microsoft/Vexcel, and Leica. The USGS is currently refining its certification process and will determine the reimbursable pricing structure for future system certifications.

The USGS and its IADIWG partners have also developed an initial draft of Guidelines for Digital Aerial Data Contracting and made this available in document form via the Web. Further development to the contracting technical specification standards is in work with teams from the USGS and its partners developing these in concert with the corresponding acceptance standards for each technical criterion.

The Data Providers Certification process is in work within the USGS and IADIWG. At this time the detailed plans for this are not ready for review.

For Further Information and Contacts

The USGS hosts a Web site for the IADIWG partners to post current information on the activities of the working group. The Web site also includes information on current sensor calibration policy and services, product characterization procedures, research reports, and guidelines. See <http://calval.cr.usgs.gov/>

These guidelines are developed by USGS with support from the IADIWG under the USGS Remote Sensing Technologies (RST) Project within the Land Remote Sensing Program. The USGS invites comments and recommendations to these guidelines and the overall project. Questions and comments may be directed to either of the two contacts below:

Gregory L. Stensaas
Remote Sensing Technologies Project Lead
USGS EROS Data Center
47914 252nd Street
Sioux Falls, SD 57198
605-594-2569
stensaas@usgs.gov

George Y.G. Lee
Raster Theme Lead
USGS Menlo Park Campus
345 Middlefield Road, M/S/ 531
Menlo Park, CA 94025
(650)329-4255
gylee@usgs.gov

Acknowledgments

The USGS wishes to acknowledge the participation of digital sensor manufacturers for participating in the initial Manufacturers Certification process and its contribution to the overall geospatial community. Specifically, the USGS acknowledges Leica Geosystems, Z/I Imaging, Vexcel, and Applanix for their participation and insights. Also, the USGS

thanks the following agencies and their representatives that comprise the IADIWG for their contributions and dedication to this effort:

Bureau of Land Management
Bureau of Reclamation
US Army Corp of Engineers
Department of Agriculture
Department of Transportation
Environmental Protection Agency
National Aeronautics and Space Administration
National Coast & Geodetic Survey
National Geospatial-Intelligence Agency
National Institute of Standards and Technology
National Oceanic and Atmospheric Administration
Natural Resources Conservation Service
US Fish & Wildlife Service
US Department of Agriculture, Farm Service Agency
US Forest Service
US Geological Survey

References

- Light, D., 1992, The New Camera Calibration System at the U.S. Geological Survey, *Photogrammetric Engineering & Remote Sensing*, 58(2): 185-188.
- ASPRS, 2000, Camera Calibration Panel Report: *Photogrammetric Engineering & Remote Sensing*, 66(3): 239-245.
- Lee, G.Y.G., 2004, Camera calibration program in the United States: past, present, and future, *Post-Launch Calibration of Satellite Sensors*, ISPRS Book Series, Volume 2, A.A. Balkema Publishers, New York.
- Tayman, W. P., 1974, Calibration of Lenses and Cameras at the USGS, *Photogrammetric Engineering*, XL(11): 1331-1334.
- _____, 1984. User Guide for the USGS Aerial Camera Report of Calibration, *Photogrammetric Engineering and Remote Sensing*, 50(5): 577-584.
- Various materials from the USGS/IADIWG Focus Group Meeting on August 3-4, 2005 available at <http://calval.cr.usgs.gov/crs/iadiwg.php>