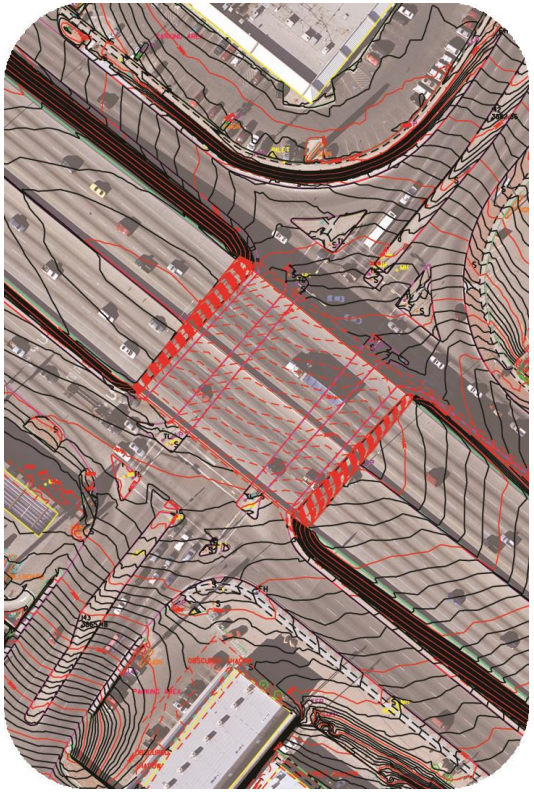
COLORADO
Department of Transportation



CDOT Survey Manual
Chapter 4 Aerial Surveys - Update

Survey Manual-Chapter 4 Aerial Survey Update

BACKGROUND

- All CDOT aerial mapping is contracted out to aerial mapping consultants

<u>Purpose of Chapter 4</u>

- To define the specifications to be followed by aerial mapping consultants conducting aerial surveys and geospatial data processing under authority of a CDOT Region Survey Coordinator
- To provide general information and guidelines to ensure CDOT staff are well-equipped to determine best application of aerial mapping.
  - Strengths and limitations of applied technology
  - Economies of application
  - Engagement and oversight of the mapping consultant

Survey Manual-Chapter 4 Aerial Survey Update

Previous Chapter 4 content – *dated* October 2003

- Specifications/guidelines assumed application of mature technologies
  - Procedural guidelines aligned with assumptions
  - Guidelines specific to analog cameras
  - Included references to deliverables no longer regularly sought, such as film, photographic prints and hardcopy maps
  - Ground control guidelines designed to accommodate aerial imagery lacking any geo-referencing data
- Specifications didn't consider application of newer technologies
  - Digital cameras
  - Airborne GPS
  - LiDAR

Survey Manual-Chapter 4 Aerial Survey Update

Objectives of Current Update – June 2015

- To update the specifications recognizing of technology advances:
  - Acknowledge current camera technology
  - Acknowledge Airborne GPS to benefits to ground control requirements
  - Introduce LiDAR
- To provide updated information and guidelines to CDOT staff applying current and latest aerial mapping technology

Survey Manual-Chapter 4 Aerial Survey Update

Chapter 4 Aerial Surveys – Update Summary

- 4.1 General - updated
- 4.2 Aerial Ground Control for Aerial Surveys - updated
- 4.3 and 4.4 – Aerial Control Vertical/Horizontal Survey - minor editing
- 4.5 Aerial Control Survey Report – minor editing
- 4.6 Aerial Topo Mapping Standards – re-write to replace TMOSS/PICS with Bentley MicroStation deliverables
- 4.7 Aerial Mapping Tolerances – updated and referenced to ASPRS Positional Accuracy Standards for Digital Geospatial Data
- 4.8 Aerial Surveys and Photogrammetric Mapping Specifications – updated acknowledging new digital imagery & LiDAR
- 4.9 Deliverables - updated

Survey Manual-Chapter 4 Aerial Survey Update

<u>Overview:</u> What didn't change

- Engagement and oversight of the aerial mapping consultant by the CDOT Region Survey Coordinator

- The Chapter provides a set of guidelines and specifications to apply to large scale aerial mapping, historically referred to as 1"=50' mapping with 1' contours, representing the majority of CDOT aerial mapping

- Variations from above should be done in consultation with a professional aerial surveyor such as an ASPRS Certified Photogrammetrist, Mapping Scientist or state licensed aerial surveyor and receive approval from the CDOT Region Survey Coordinator

- Project Scope of Work and deliverables should be reviewed at the Pre-Survey Conference – Aerial Surveys. The contract scope of work should clearly list required deliverables and their due dates

Survey Manual-Chapter 4 Aerial Survey Update

<u>Overview:</u> What changed

- Accuracy requirements and expressions used to define accuracy to align with:
  - American Society of Photogrammetry (ASPRS)
  - USGS National Standard for Spatial Data Accuracy (NSSDA)
- Aerial specifications updates to accommodate application of digital cameras and LiDAR
- Ground control specifications that acknowledge the benefits of Airborne GPS
- A move away from TMOSS to CDOT CADD Standards for aerial mapping deliverables
- Updated list of deliverables: some items removed, others added, e.g.:
  - Hardcopy maps (removed)
  - Aerial Survey Report (added)

Survey Manual-Chapter 4 Aerial Survey Update

Photogrammetry defined as:
"The science of deducing the physical measurements on or above the earth's surface from photographs."

- Includes the earth surface itself

Photographs are two (X, Y) dimensional images containing distortions as a result of the missing third (Z) dimension.

Photogrammetry solves for the 3rd dimension through trigonometry making X, Y, Z measurements possible

NEED:

- At least 3 control points visible in at least two overlapping images
- Known, calibrated camera and lens parameters (focal length, size of frame)

Survey Manual-Chapter 4 Aerial Survey Update

Photogrammetry Early Advances - 20th Century

Precision Camera Calibration:

- Precise lens focal length determination
- Lens distortion definition
- Exact image frame dimensions

Aerial Triangulation (aerotriangulation):

- A process that propagates additional secondary control throughout a block of overlapping images based.
  - Image coordinates are recorded at control points
  - Additional image coordinates are recorded at like-points on all images
  - Trigonometry and least-squares adjustment provides a 3D solution for the entire block.

Survey Manual-Chapter 4 Aerial Survey Update

Line 1 - 8 frames, 7 models

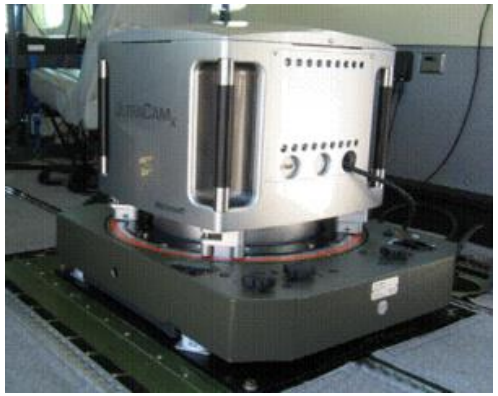
Line 2 - 8 frames, 7 models

Survey Manual-Chapter 4 Aerial Survey Update

<u>Photogrammetry Now</u>

Today's Technology:

- Direct geo-referencing
  - ABGPS (Airborne Global Positioning System)
  - IMU (Inertial Measurement Unit)
  - **Precise measurement of time**
- Digital Cameras Aerial Cameras
- angulation

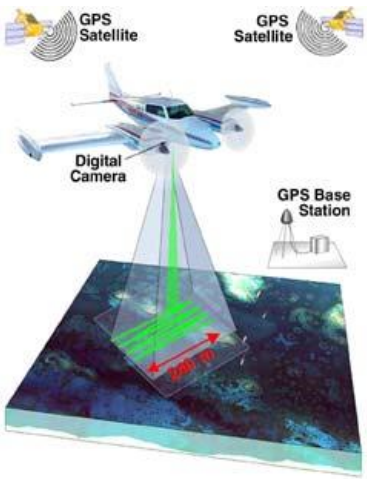


Survey Manual-Chapter 4 Aerial Survey Update

NOAA defines LiDAR as:

- ***L**ight **D**etection **A**nd **R**anging*—is a remote sensing method used to examine the surface of the Earth
  - Records sensor location and attitude relative to satellites and ground stations along with time of each pulse return
  - Can also be used to examine/measure objects
  - Different band-widths for topographic (red) and bathymetric (green) applications
- Same technology developments impacting photogrammetry have advanced LiDAR as a mainstream tool in aerial mapping
  - Airborne GPS (GNSS)
  - IMU
  - Precise measurement of time
  - Computer processing speed and data storage capabilities
  - Software development

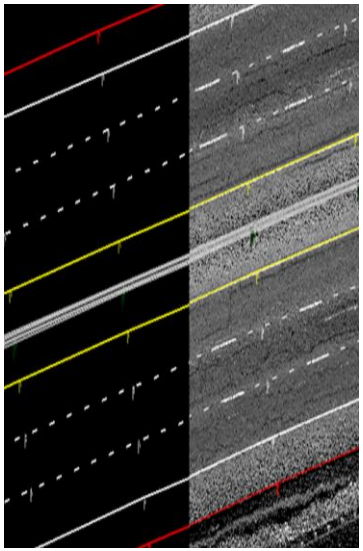
Survey Manual-Chapter 4 Aerial Survey Update



Aerial LiDAR

A rapidly developing 21st century tool:

- Repetition rates increased from 5 kHz to 400 kHz in less than 15 years
- Multi-point in air capabilities
- Duel sensor configurations
- Application principally DTM, can extend to full map feature extraction



Survey Manual-Chapter 4 Aerial Survey Update

Section 4.1 – General

- Definitions for acronyms added
- Purpose updated
- Photogrammetry Advantages and Disadvantages
- LiDAR Advantages and Disadvantages

Photogrammetry & Aerial LiDAR - Summary of Advantages

Provides a permanent record at time of survey

Images can be used for general communication purposes

Multiple CDOT applications; recon., pre-design, environmental, ROW

Data sets contain additional information that can be acquired as needed

Accomplish topo DTM - time and cost efficiency

Can be accomplished in places presenting access and safety challenges

Reduces ground survey effort

Aerial LiDAR

Can cost-effectively provide a more detailed DTM

Can offer 3D point cloud visualization for line of sight and alignment study

Better opportunity for receiving ground surface data in vegetated areas

Can be flown without lighting considerations

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.1 – General

- Definitions for acronyms added
- Purpose updated
- Photogrammetry Advantages and Disadvantages
- LiDAR Advantages and Disadvantages

Photogrammetry & Aerial LiDAR – Summary of Disadvantages

Both have flying condition dependencies, LiDAR to lesser degree for lighting and clouds, greater degree for PDOP conditions

Both are affected by flying altitude, photogrammetry somewhat more so

Heavy vegetation obscures ground measurements

Identification of planimetric feature types limited; E.g. specific types of curb/gutter, type/construction of fences, signs

Underground utilities cannot be located, measured or identified

Right of Way and property boundary monuments cannot be located, measured or identified

Data is collected from a plan view. Buildings are measured around overhangs and eaves rather than footprints.

Raw digital photo imagery and LiDAR point cloud files can be very large & require some data management considerations

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.2 – Ground Control for Aerial Surveys – Updated

If ABGPS/IMU not applied: Control for preliminary design unchanged:

- Map area perimeter
- Inter-visible control point targeting at 1500' intervals
- Wing and center point configuration

If applied: Updated to consider application of AGPS technology

- Map area perimeter *(project minimum of 5 points)*
- ***Up to 1 mile intervals & at line ties with heading change***
- ***Acquisition not more 25 miles from a GPS base-station***
- ***Collection of redundant data - multiple base-stations***
- ***PDOP below 3.0 during acquisition***

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.2 – Ground Control for Aerial Surveys – Updated

Additional supplemental detail relating to:

- Photogrammetry control requirements
- Aerial triangulation
- Control point placement and targets
- LiDAR control requirements

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.3 – Aerial Control Horizontal Survey – minor editing principally to change references from “Photo” to “Aerial”

- Key Statements added regarding NGS and the NSRS

“The National Geodetic Survey defines and manages the National Spatial Reference System (NSRS). The NSRS is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States and is designed to meet the nation’s economic, social, and environmental needs. The NSRS has traditionally been defined by survey marks in the ground. More recently, the horizontal datum is defined by the continuously operating reference stations (CORS).”

“The current datums are the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88). NAD 83 (2011) epoch 2010.0 is the latest realization of the horizontal datum. Both the horizontal and vertical datums will be replaced around 2022.’

Section 4.4 - Aerial Control Vertical Survey – minor editing

Section 4.5 - Aerial Control Survey Report– minor editing

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.6 – Aerial Topo Mapping Standards

Replaces TMOS / PICS with **CDOT CADD Standards**

- Aerial Mapping to be delivered in **MicroStation/InRoads DGN, DTM, and TIN format** applying CDOT's current configuration files
- CDOT configurations will provide seed files, cell libraries and set-up MicroStation Level menus.
- Downloads to configure for a number of MicroStation V8 versions are available here:

https://www.codot.gov/business/designsupport/cadd/microstation-inroads-configuration

- Level structure designed to allow multiple layers of feature description
  - "Level" names beginning with a category, followed by feature name, and finally a feature descriptor.
  - Levels with "Miscellaneous", "Other" or "Unknown" descriptors that shall be used for photogrammetric feature compilation.
- Supplemental field surveys will adhere to the CDOT Level Structure

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.7 – Aerial Mapping Tolerances

ASPRS Positional Accuracy Standards for Digital Geospatial Data

Horizontal Accuracy - ASPRS 0.25' Class

Horizontal Accuracy Class	RMSEx or y	RMSEr	Horizontal Accuracy at the NSSDA 95% Confidence Level
0.25'	0.25'	0.35'	0.61'

Supersedes previous horizontal tolerance of 1' @ 95% confidence

- Higher horizontal accuracy is supported by:
  - Better sensors, more direct process from sensor to finished products
  - Applied to digital data rather than hard-copy maps

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.7 – Aerial Mapping Tolerances

ASPRS Positional Accuracy Standards for Digital Geospatial Data

Added: Orthophotos - ASPRS 0.5' Class *

Horizontal Accuracy Class	RMSEx or y	RMSEr	Orthoimage Mosaic Seamline Maximum Mismatch	Horizontal Accuracy at the 95% Confidence Level	Nominal GSD of Source Imagery
0.5'	0.5'	0.71'	1.00'	1.22'	0.13 to 0.25'

Designed to meet ASPRS Standard Mapping and GIS Work

- *Assumes orthophotography is secondary product, not an aerial survey source
- Default ground pixel resolution: 0.25'
- Orthophoto RMSEx and RMSEy in terms of pixels: 2 pixels
- Orthophoto mosaic seamline maximum mismatch: 4 pixels

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.7 – Aerial Mapping Tolerances

ASPRS Positional Accuracy Standards for Digital Geospatial Data

Vertical Accuracy - ASPRS 0.25’ Class

ASPRS - Vertical Accuracy Class RMSE	Vertical Accuracy at the 95% Confidence Level	
	NVA - Non-Vegetated Vertical Accuracy	VVA - Vegetated Vertical Accuracy
0.25’	0.49’	0.74’

Supersedes previous vertical tolerance of 0.5’ @ 95% confidence

- Vertical accuracy tolerance is not significantly changed
  - Accuracy stated as NVA & VVA

Section 4.7.5 Vertical Accuracy Testing - Method of Verifying Accuracy Tolerance: Additional detail provided for DTM and TIN development using either photogrammetry or LiDAR and application of vertical accuracy testing.

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.8 – Aerial Surveys and Photogrammetry Specifications

<u>Substantially updated to acknowledge new technology application</u>

- Emphasis on planning and design by qualified personnel working closely the CDOT Region Survey Coordinator when determining the aerial mapping specifications. Specifications to include:

1. Camera/Sensor(s)
2. Film or digital imaging requirements, for example: 3-band (RGB), 4-band (RGB&NIR)
3. Scanner type and resolution if film used.
4. Aircraft *
5. Crew *
6. Photogrammetry/geospatial data processing equipment and software

** Only required for flights below 1,000' Above Ground Level (AGL) and flights in FAA designated "Special Use Airspace" or those requiring a written Prior Permission Request (PPR) to land at a military airport.*

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.8 – Aerial Surveys and Photogrammetry Specifications

- Subconsultant should have a Certified Photogrammetrist with experience in the approach overseeing the work
- Subconsultant bears responsibility for:
  - Aerial survey project design
  - Adherence to accuracy tolerances and specifications
  - Ensure that aerial surveys are conducted in accordance with equipment manufacturers recommendation's and stated limitations
- Project Location and Limits: The CDOT Region Survey Coordinator or designee is responsible for determining the aerial survey location and limits. (KMZ, shapefiles, DGN, hardcopy map all acceptable.)
  - Detailed in Subsection 4.8.3 including additional provision for aerial LiDAR collection over-edge requirements

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.8 – Aerial Surveys and Photogrammetry Specifications

<u>4.8.4 Aerial Survey Field Conditions – Updated to additional considerations for new technology:</u>

- PDOP lower than 3.0
- 6 GPS (GNSS)satellites must be available at 10 degrees or more above the horizon
- Space weather considerations: Flights shall not be conducted when the predicted K-index exceeds 4.0

<u>4.8.5 Flight Plans: - Additional provisions added to include:</u>

- Nominal GSD
- Statement describing the intended data acquisition and map production approach to be applied
- Manufacturer's Specification sheets for digital cameras or LiDAR systems planned

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.8 – Aerial Surveys and Photogrammetry Specifications

4.8.7 Aerial Data Acquisition – Updated

- Similarly updated for to consider AGPS/IMU and aerial LiDAR

4.8.8 Raw Data – Updated to include:

- Digital imagery
- Digital image file naming convention
- Aerial Triangulation – Accuracy guidelines per ASPRS Positional Accuracy Standards for Digital Geospatial Data:

Product Accuracy (RMSEx, RMSEy, RMSEz)	AT Accuracy	
	RMSEx and RMSEy	*RMSEz
0.25’	0.13’	0.13’

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.8 – Aerial Surveys and Photogrammetry Specifications

4.8.8 Raw Data – Updated to include LiDAR application for DTM production

- Collect at a minimum of 8 points per meter (ppm)
- Supplement with photogrammetrically compiled breaklines
- Buffer data points within 1’ of breaklines
- If flown independently, consultant will describe and evidence measures taken to ensure relative accuracy

While it is recognized that broader applications to include breakline and planimetric data extraction is possible, the specifications for that approach are not detailed in Chapter 4 at this time.

Custom specifications must be approved by the CDOT Region Survey Coordinator

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.8 – Aerial Surveys and Photogrammetry Specifications

4.8.8 Raw Data – LiDAR

- ASPRS Positional Accuracy Standards for Geospatial Data
- Raw data will be:
  - Calibrated point cloud in delivered LAS 1.2 or later format
  - Include digital record of LiDAR data calibration results
  - At minimum, LAS classifications to include:
    - ✓ 1 – Unclassified
    - ✓ 2 – Ground
    - ✓ 8 – Key Point – LAS 1.2 & 1.3 - Bit 1 Classification Flag for 1.4

Vertical Accuracy Class	Absolute Accuracy		Relative Accuracy		
	RMSEz Non-Vegetated NVA RMSE	VVA at 95th Percentile	Within Swath Hard Surface Repeatability (Max. Diff.)	Swath-to-Swath Non-Veg. Terrain (RMSEz)	Swath-to-Swath Non-Veg. Terrain (Max. Diff.)
0.25’	0.25’	0.75’	0.15’	0.2’	0.4’

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.9 – Deliverables

- Updates to list of typical deliverables that may be called for in an aerial survey contract scope of work
- Hardcopy deliverables references removed, added LiDAR products
- Updated orthophoto deliverable description – semi-ortho or “rubber sheet” product removed

Recognizing that special projects may require modified or other deliverables not described here.

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.9 – Deliverables

4.9.1 General – Updated list & reference for descriptions/specifications

1. Pre-survey Conference – Aerial Survey Form - (See Section 4.1.8)
2. Photo Control Survey Report - (See Section 4.5.2 and 4.9.9)
3. Flight Plan - (See Section 4.8.5 and 4.9.9)
4. Camera Calibration Report - (See Section 4.8.5 and 4.9.9)
5. Camera Calibration File - (See Section 4.8.5 and 4.9.11)
6. Original Images - (See Section 4.8.8 and 4.9.11)
7. Aerial Triangulation Data (See Section 4.8.8.3 and 4.9.11)
8. Photo Index - (See Section 4.9.2 and 4.9.10)
9. Analytical Aerial Triangulation Report - (See Section 4.9.9 and 4.9.10)
10. LiDAR Data Calibration (See Section 4.8.8.7 and 4.9.10)
11. LiDAR Point Cloud – (See Section 4.8.8.8, 4.8.8.9 and 4.9.10)
12. LiDAR Tile Index – (See Section 4.8.8.9 and 4.9.11)
13. Planimetric Features - (See Section 4.6.4, 4.9.3, 4.9.4 and 4.9.10)
14. TMOSS Supplemental Survey - (See Section 4.6.5)
15. Triangulation Irregular Network (TIN) - (See Section 4.9.6 and 4.9.10)
16. Digital Terrain Model (DTM) - (See Section 4.9.5 and 4.9.10)
17. Contours - (See Section 4.9.7 and 4.9.10)
18. Orthophotography - (See Section 4.9.8 and 4.9.10)
19. Orthophotography Tile Index – (See Section 4.9.8 and 4.9.10)
20. Vertical Accuracy Report (See Section 4.7.5 and 4.9.9)
21. Aerial Survey Report (See Section 4.9.9 and 4.9.10)
22. Any other mapping or aerial survey products defined in the project scope of work

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.9 – Deliverables

Key addition: Naming Conventions

Digital Product	File Type	File Name	Explanation
Photo Control Survey Report	PDF	XXXXXAS_Control.pdf	*Project codeAS_control.pdf*
Aerial Survey Planimetrics	MicroStation	XXXXXAS_50.dgn	*Project code*AS_*scale denominator*.dgn
Aerial Survey Contours	MicroStation	XXXXXAS_50_con.dgn	*Project code*AS_*scale denominator*_con.dgn
Aerial Survey DTM	InRoads	XXXXXAS_50.dtm	*Project code*AS_*scale denominator*.dtm
Aerial Survey TIN	InRoads	XXXXXAS_50.tin	*Project code*AS_*scale denominator*.tin
Ortho Tile Index	MicroStation	XXXXXASortho_index.dgn	*Project code*ASortho_index.dgn
Orthophotography	JPG compressed TIF/TFW	XXXXXASortho_.5.tif/tfw	*Project code*ASortho_*pixel resolution in feet*.tif/tfw
Aerial Survey Report	PDF	XXXXXASreport.pdf	*Project code*_surv_aerial_report.tin

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.9 – Deliverables

Key addition: Aerial Survey Report

1. CDOT Project name
2. CDOT Project number
3. CDOT Project Code number
4. Highway number
5. Beginning and ending mile post
6. Consultant name and contact information
7. Report date
8. Executive Summary
9. Table of Contents
10. Project Area illustration/description
11. Scope of Work Summary
12. Spatial Reference System
    a) Vertical and Horizontal Datum
    b) Units
    c) Coordinate system
    d) Geoid applied to ellipsoid elevations
13. Project Accuracy Specifications
14. Reference to Aerial Control Survey Report
15. List of Aerial Ground Control points and their coordinates

Survey Manual-Chapter 4 Aerial Survey Update

Section 4.9 – Deliverables

Key addition: Aerial Survey Report - continued

16. Flight Plan – Flight line diagram and description of aircraft & aerial system deployed
    a) Flying height
    b) If aerial photography: Nominal GSD
    c) If LiDAR flown: Point density and applied system parameters
17. Aerial Triangulation (AT) Summary Report
    a) Narrative
    b) Control diagram – referenced to project boundary and imaged area
    c) Summary of final adjustment results
    d) List of X, Y and Z control point coordinates and AT adjustment X, Y, Z residuals at each
    e) List of X,Y and Z checkpoint coordinates and AT adjustment X, Y, Z residuals at each
    f) Index of final photo-centers and/or flight trajectories (Graphic and digital formats.)
    g) Copies of flight logs
    h) Camera and/or sensor Calibration Reports
18. DTM verification test results for random checkpoints or cross sections (Vertical Accuracy Report)
19. Certification or statement of accuracy by ASPRS Certified Photogrammetrist or state licensed aerial survey professional.

Survey Manual-Chapter 4 Aerial Survey Update

Thank You!