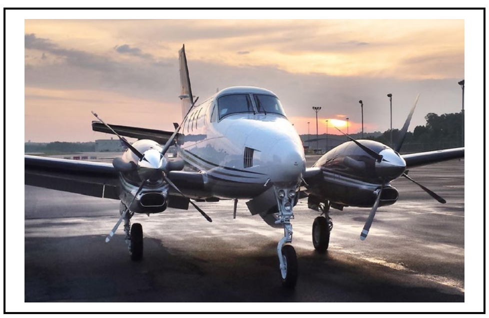
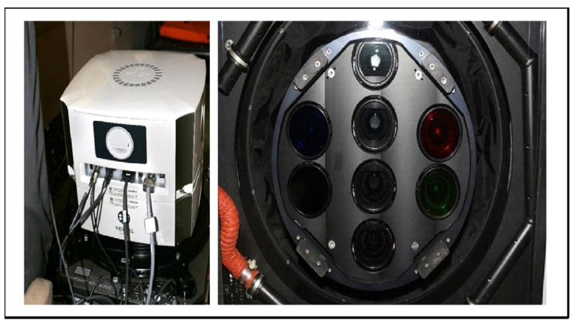
Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

Student Activity Sheet – Photogrammetry: Flight Planning for 3-D Stereo Imagery

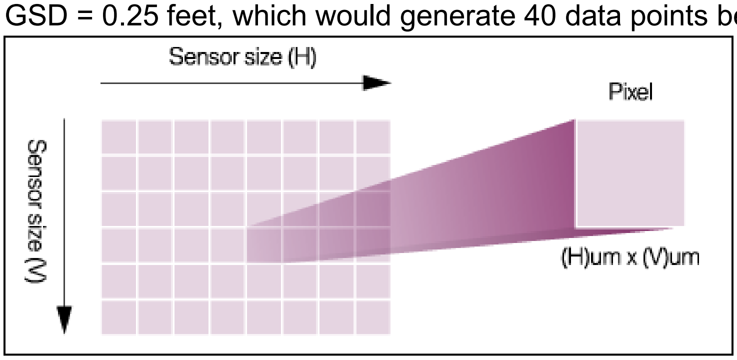
In partnership with WAKE TECH, WAKE COUNTY PUBLIC SCHOOL SYSTEM, WakeEd PARTNERSHIP

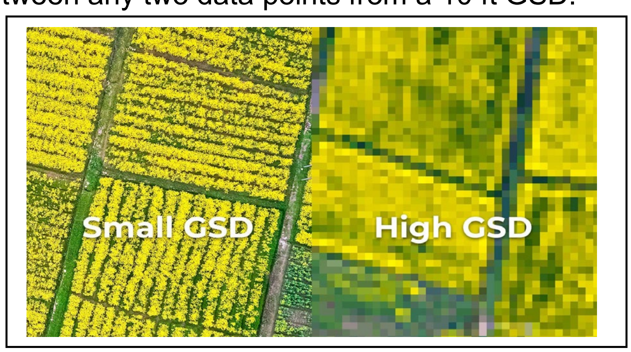
When roadways are damaged from severe storms and other disasters, NC DOT Photogrammetry Unit begins planning a flight plan to take digital imagery of the affected area for other NC DOT units to propose a repair plan and projected costs. Million-dollar cameras are mounted to aircrafts and very precise flights paths are designed to collect the digital photographs needed to overlap images in order to create 3-D models. Each camera has its own specs, such as a focal length and a CCD element size. The focal length is a property of the camera lens and is measured in millimeters (mm). The CCD element size is the length of one pixel on the image and is measured in micrometers (μm). Below are example figures displaying one NC DOT airplane and camera.



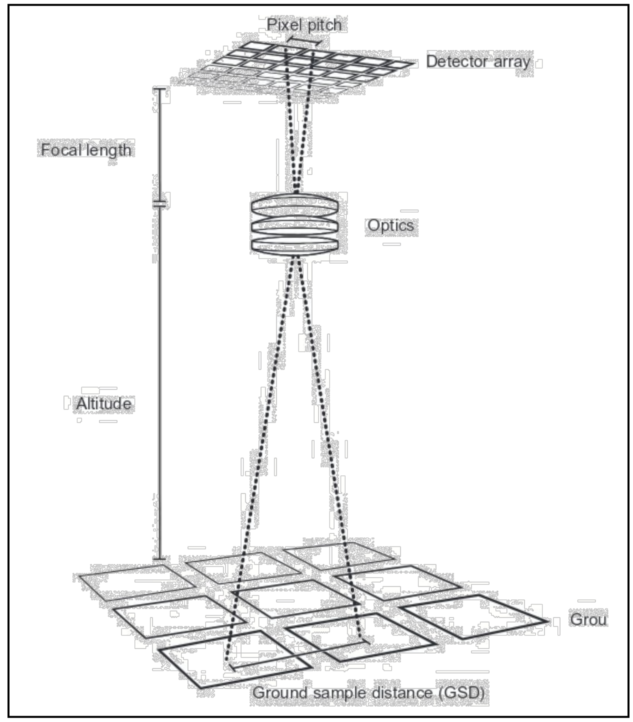


The figure below shows an example of a CCD element size (pixel size on a camera sensor H μm x V μm) on a camera sensor size H x V. The CCD, the camera focal length, and the flying height of the airplane determines the ground sample distance (GSD). The GSD is the distance between two adjacent pixels centers measured on the ground. The smaller the GSD, the more precise data is gathered on the ground and the better resolution of the ground image. For example, if GSD = 10 feet, then each adjacent data point collected on the ground would be 10 feet apart and no data would be gathered between these two 10 feet apart centers. Compare that to a GSD = 0.25 feet, which would generate 40 data points between any two data points from a 10 ft GSD.





1. How many data measurements (ground squares or pixels on above right figure) on the ground for an image with GSD = 0.25 feet would fit in a 10 ft by 10 ft area on the ground?



2. The flying height, focal length, CCD element size, and GSD are all related by the formula $GSD = \frac{H \cdot CCD}{f}$, where H is flying height in feet (ft.), CCD element size in Microns (µm), and *f* is focal length in Millimeters (mm). Using the given units above, what units would result for GSD and how could you simplify it?

NC DOT along with its industry partners has used each of the cameras that are specified in the table below.

Manufacturer	Camera Name	Camera Type	CCD Element Size (µm)	Focal Length (mm)
Vexcel	UltraCam Eagle M1 80	Frame	5.2	80.0
Vexcel	UltraCam Eagle M1 210	Frame	5.2	210.0
Vexcel	UltraCam Eagle M3 100	Frame	4.0	100.5
Leica	DMC I	Frame	12.0	120.0

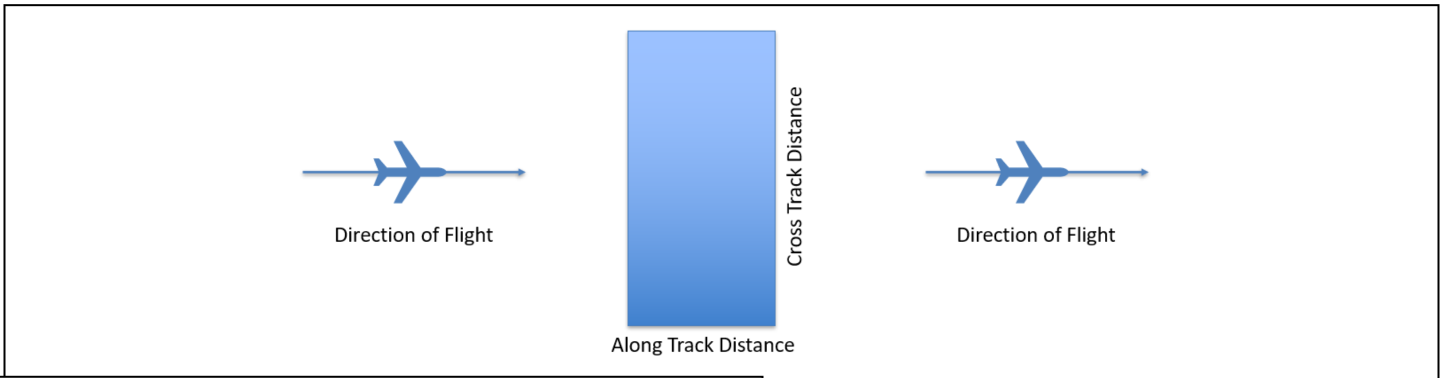
3. Which camera in the above table would you expect to be the least expensive and why?

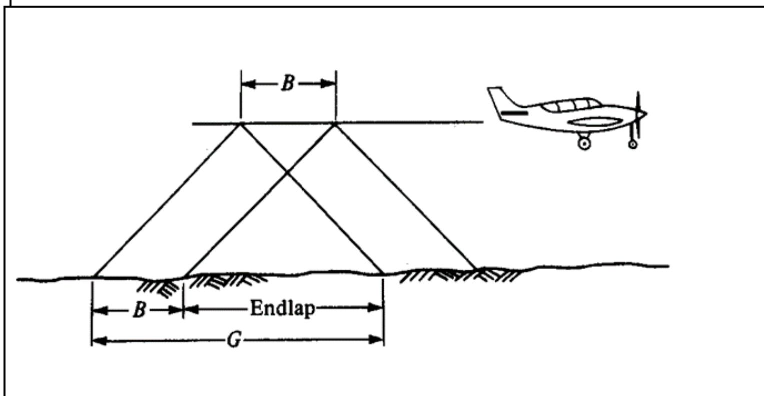
4. If the desired GSD = 0.5 feet, determine the flying height of the airplane for each camera above.

5. For the Eagle M1 80 camera, explain the changes in the GSD if the flying height were to increase.

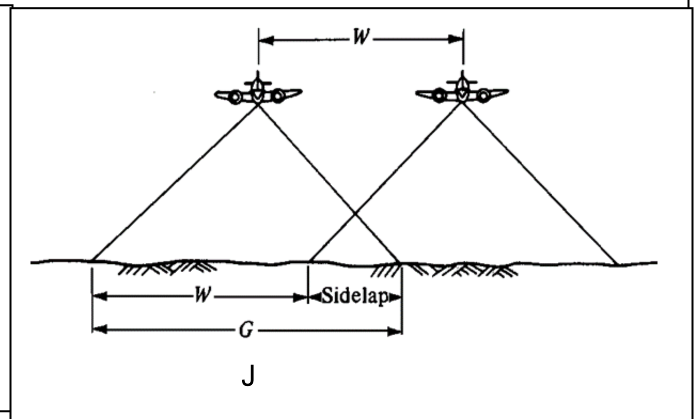
6. What happens when we change cameras from the Eagle M1 80 to the Eagle M1 210. At the same flying height, what changes would occur in the GSD? Would this change improve the resolution of the photograph? Why or why not?

Knowing the camera specs for *f* and *CCD* is not enough information about the cameras to determine the ground area covered on each image collected, called a footprint. Camera's also have specs on the number of sensor pixels in line of the flight direction and across the line of the flight direction. To be able to plan a flight, the ground area covered by each collected photograph, specifically the along track distance and cross track distance, needs to be computed. In addition, collected photographs need to overlap each other to be able to view the area in 3-D stereo. For the along track distance, collected photographs need to have a 60% forward overlap. For the cross track distance, collected photographs need to have a 30% side overlap. In planning the flight, the airplane travel distance between consecutive collected photographs (B) and the width distance between each flight line (W) needs to be determined. See each figure below for terminology support. The base of each triangle (G and J) is the footprint of a collected photograph.





Forward Overlap



Side Overlap

7. Using a GSD = 0.5 feet, find the along track distance (G), the cross-track distance (J), the travel distance between consecutive collected photographs (B), and the width distance between flight lines (W) for each camera below. Extend the table below to include the four additional columns.

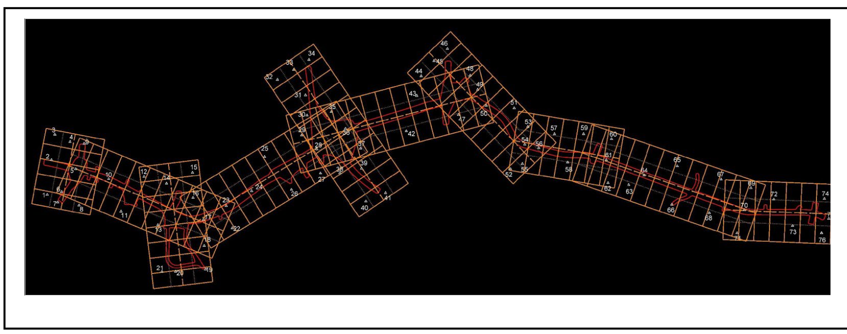
Manufacturer	Camera Name	Focal Length (mm)	No. Pixels Along Track	No. Pixels Cross Track
Vexcel	UltraCam Eagle M1	80	13,080	20,010
Vexcel	UltraCam Eagle M1	210	13,080	20,010
Vexcel	UltraCam Eagle M3	100	17,004	26,460
Leica	DMC I	120	7,680	13,824

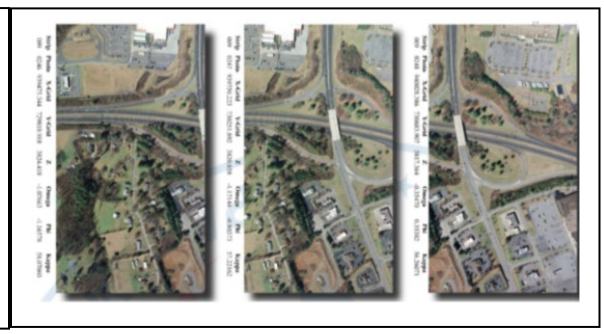
8. If the resolution of the image needs to double, what would be the new GSD and what changes would occur in the above table of computed values.

9. If the airplane needs to fly at a height of 3000 feet, find the along track distance, the cross track distance, the travel distance between consecutive images, and the width distance between flight lines for each camera below.

Manufacturer	Camera Name	Camera Type	CCD Element Size (µm)	Focal Length (mm)	No. Pixels along track	No. Pixels cross track
Vexcel	UltraCam Eagle M1 80	Frame	5.2	80.0	13,080	20,010
Vexcel	UltraCam Eagle M1 210	Frame	5.2	210.0	13,080	20,010
Vexcel	UltraCam Eagle M3 100	Frame	4.0	100.5	17,004	26,460
Leica	DMC I	Frame	12.0	120.0	7,680	13,824

Now you are ready to design a complete flight plan for a given area to be viewed in 3-D stereo. 3-D stereo requires the entire area to be covered by overlapping images like the 3 shown below. NCDOT Photogrammetry Unit will create a flight plan like the one shown where each small rectangle represents the overlap of two consecutive photographs.

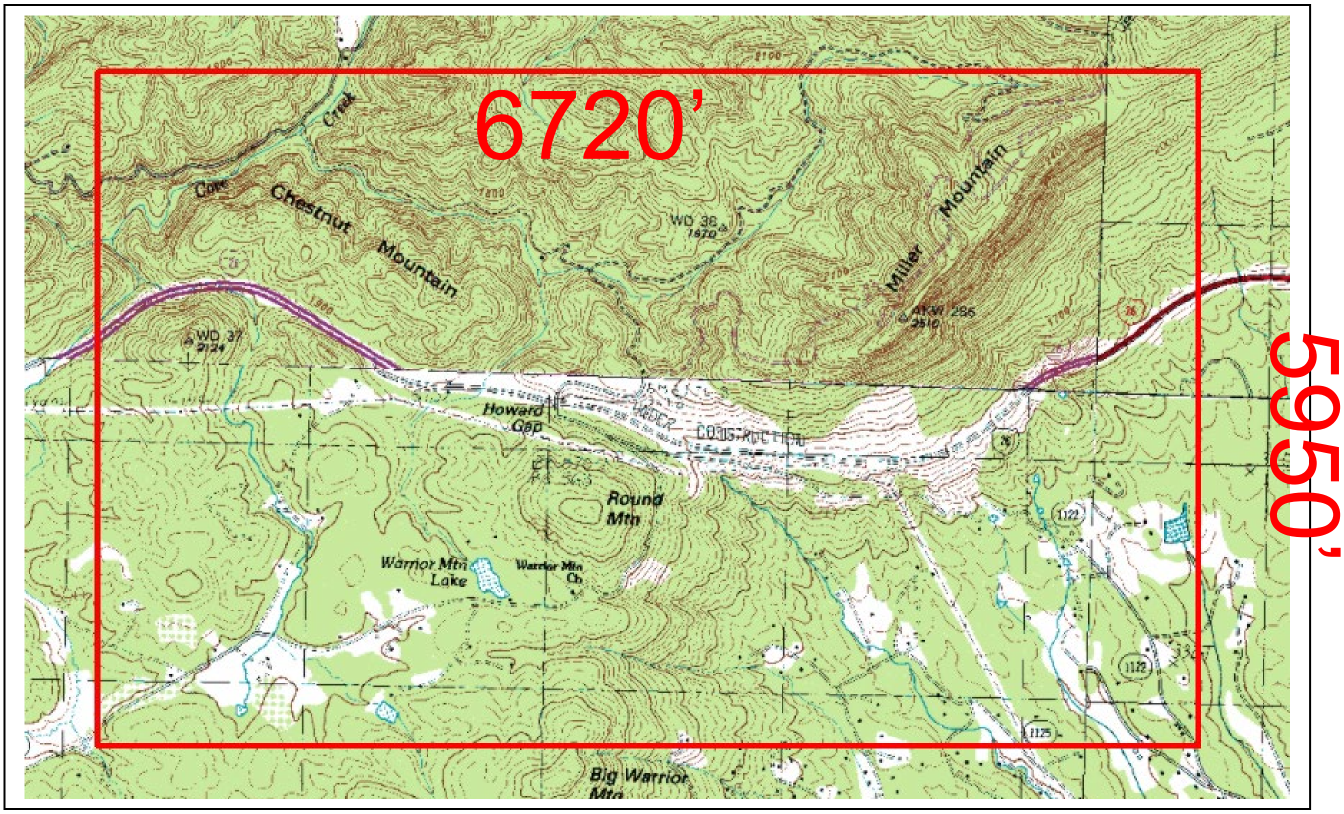




10. Your final task is to determine the minimum number of photographs needed to create 3-D stereo coverage of the area enclosed in red on the topographical map below. This area that needs imagery data collected is from a landslide in western NC that took out sections of a heavily travel road. The area needing photographing is the red rectangle shown below on the topographical map where the landslide occurred. The area is 6720 feet by 5950 feet. The flight plan will be using an UltraCam Eagle Mark 3 with a focal length of 100.5mm.

Assume the following parameters:

- Side Lap 30%
- Forward Lap 60%
- Desired GSD = 0.119 feet
- CCD Element Size = 4 µm
- Average Ground Elevation = 425 feet
- # of Pixels Along Track = 17,004
- # of Pixels Cross Track = 26,460


6720’
5950’
Chestnut
Mountain
Miller
Mountain
WD 37
2124
WD 36
Howard
Gap
Round
Mtn
Warrior Mtn
Lake
Warrior Mtn
Ch
Big Warrior
1122
1125