Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

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

In partnership with
WAKE TECH
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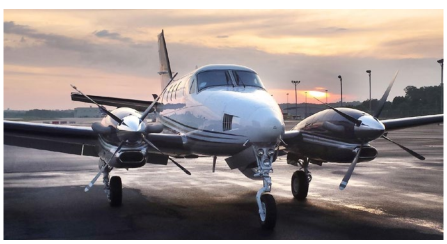
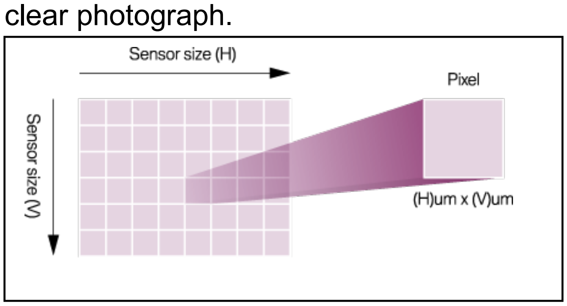
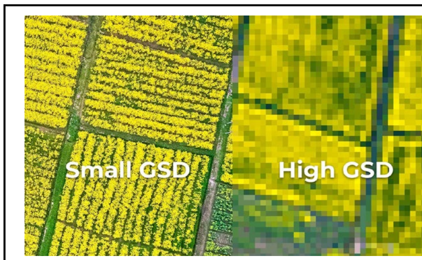
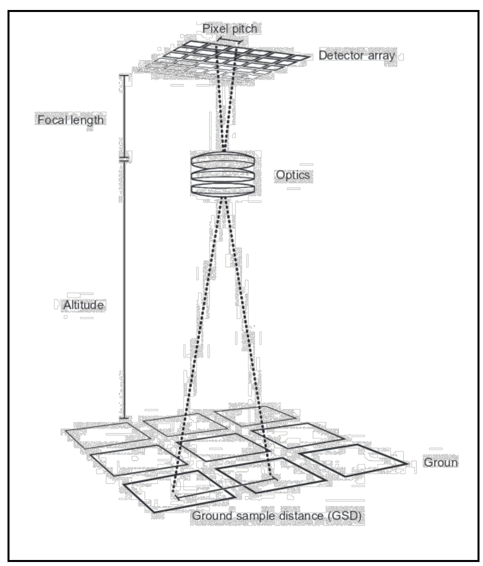
When roadways are damaged from severe storms and other disasters, NC DOT Photogrammetry Unit begins planning a flight plan to take digital imagery of the affected area for other NC DOT units to propose a repair plan and projected costs. Million-dollar cameras are mounted to aircrafts and very precise 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 (um). 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 camera image). 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 consecutive pixel centers measured on the ground. The smaller the GSD, the better resolution of the image. For example, if GSD = 10 feet, then each pixel would be 10 feet by 10 feet and the photograph would be very blurry, as compared to a GSD = 0.25 feet, which would generate a very clear photograph.







1. How many pixels in an image with GSD = 0.25 feet would fit in one pixel of an image with GSD = 10 feet?

40 x 40 = 1600 pixels of size .25 by .25 would fit in one 10 ft by 10 ft pixel.
The flying height, focal length, CCD element size, and GSD are all related by the formula below.

$GSD = \frac{H \cdot CCD}{f}$, where H is flying height in feet, CCD element size in um, and f is focal length in mm.

2. Determine the simplest units of GSD that the above formula will result.

Converting um into mm would cancel out mm leaving feet from the height. GSD in feet.

NC DOT has used each of the cameras that are specified in the table below.

Manufacturer	Camera Name	Camera Type	CCD Element Size (um)	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?

Based on the formula CCD/f part, 12/120 = .1, which is the largest of all the cameras and therefore making the largest GSD, which would result the most blurry photograph. So, DMC I should be the least costly.

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

In order top to bottom, 7692.3 ft, 20192.3 ft, 12562.5 ft, 5000 ft

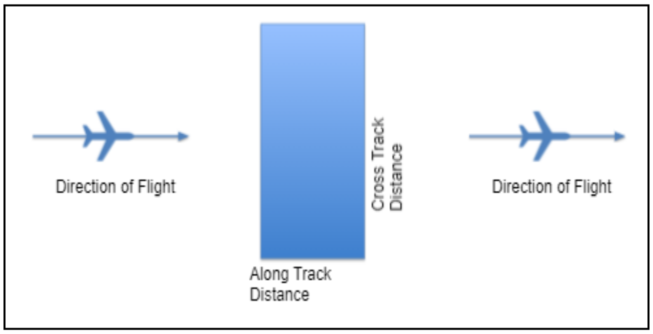
5. For the Eagle M1 80 camera, explain the changes in the GSD if the flying height were to increase.

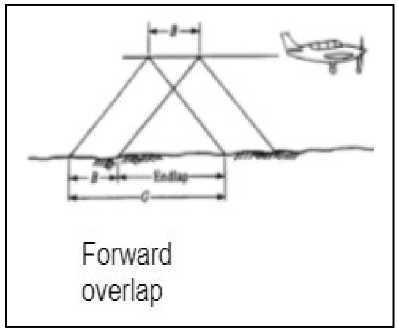
If the height were to increase, the GSD would also increase and the photo would be more blurry.

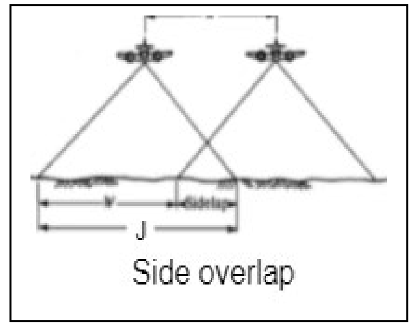
6. NC DOT has recently changed from the Eagle M1 80 to the Eagle M1 210. At the same flying height, what changes would occur in the GSD? Would this change improve the resolution of the photograph? Why or why not? 7692 ft *.0052 mm / 120 mm = .19 feet

New GSD for a height of 7692.308 results .19 feet. Lowering the GSD from .5 to .19 would improve the resolution of the photograph. A pixel size would decrease from .5 by .5 to .19 by .19. You can fit almost 9 of the smaller pixels into one pixel .5 by .5

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







7. Using a GSD = 0.5 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. 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

Focal Length (mm)	No. Pixels Along Track	No. Pixels Cross Track	Along track	Cross Track	Forward Distance	Width Distance
80	13,080	20,010	6540	10005	2616	7003.5
210	13,080	20,010	6540	10005	2616	7003.5
100	17,004	26,460	8502	13230	3400.8	9261
120	7,680	13,824	3840	6912	1536	4838.4

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.

New GSD = .25 and each distance in the above table would be cut in half.

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.

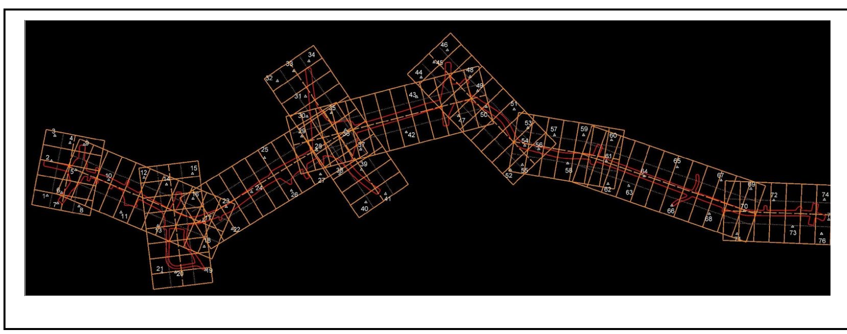
Manufacturer	Camera Name	Camera Type	CCD Element Size (um)	Focal Length (mm)	No. Pixels along track	No. Pixels cross track
Vexcel	UltraCam Eagle M1 80	Frame	5.2	80.0	13,080	20,010

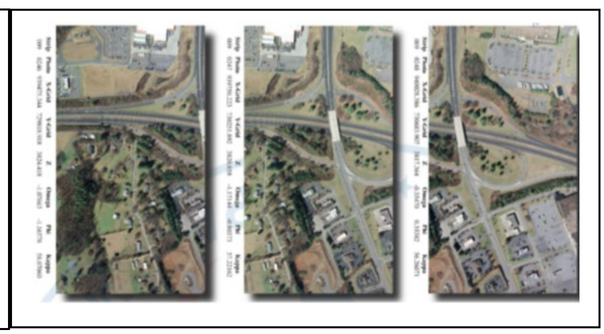
Vexcel	UltraCam Eagle M1 210	Frame	5.2	210.0	13,080	20,010
Vexcel	UltraCam Eagle M3 100	Frame	4.0	100.5	17,004	26,460
Leica	DMC I	Frame	12.0	120.0	7,680	13,824

CCD Element Size (um)	Focal Length (mm)	No. Pixels along track	No. Pixels cross track	Along track	Cross Track	Forward Distance	Width Distance	GSD
5.2	80	13,080	20,010	2550.6	3901.95	1020.24	2731.365	0.195
5.2	210	13,080	20,010	971.6571	1486.457	388.6629	1040.52	0.074286
4	100.5	17,004	26,460	2030.328	3159.403	812.1313	2211.582	0.119403
12	120	7,680	13,824	2304	4147.2	921.6	2903.04	0.3

Calculate the GSD first using H=3000.

Now you are ready to design a complete flight plan for a given area to be imaged in 3-D stereo. 3-D stereo required the entire area to be overlapped or covered by at least two images. Photographs, like the 3 shown below, need to have overlap to be able to generate digital 3-D models. NC DOT Photogrammetry Unit will create a flight plan like the one shown where each small rectangle is a footprint of one single photograph.





10. Your final task is to determine the minimum number of photographs needed to create a 3-D stereo model of the area enclosed in red on the topographical map below. 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 um

- Average Ground Elevation = 425 feet
- # of Pixels Along Track = 17,004
- # of Pixels Cross Track = 26,460

If GSD = 0.119 ft then

Footprint Along Track = 2024 ft
Footprint Cross Track = 3149 ft

Base Length = G – End lap = 2024 – (0.6 * 2024) = 809.6 ft

Number of images per strip = 6720 / 809.6 = 8.30 or 9 images + 1 = **10 images needed**

W = J – Side lap = 3149 – (0.3 * 3149) = 2204.3

# of strips needed = 5950 / 2204.3 = 2.699 or **3 strips**

30 images total is needed.