Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

Flight Planning for 3-D Stereo Imagery-Teacher Notes

An Exploratory Task

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

Purpose: Following a natural disaster that impacts road travel, NC DOT first puts their Photogrammetry Unit at work. They are tasked with collecting 3-D data in the damaged area for a design plan for renovation to be completed. This unit will design a flight plan for aircraft to get imagery in the damaged area, so that the digital pictures meet the overlapping specifications needed for 3-D data to be collected with their specialized computer technology. In this activity, students will design a flight plan and number of images needed to collect data from a land slide in Western North Carolina that wipe out a mile of roadway.

Career Field: Civil Engineering and Geomatics, NC DOT

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NC Math 4 Standards:

> *None specifically, however it requires students to use a function of 3 inputs where units are important. Critical thinking and problem solving are required in this activity.*

Unit Alignment:

Indicate where this lesson would be used in the course

NC Math 4 – Week 1-2 Critical thinking, functions, and introduction into industry applied math

WTCC Math 121 – Week 2-3 – Involves solving fractional equations resulting from a formula that comes from similar triangle proportions

Common Core State Standards for Mathematical Practice

Indicate which of the standards are highlighted in this lesson

1. **Make sense of problems and persevere in solving them.**
2. **Reason abstractly and quantitatively.**
3. Construct viable arguments and critique the reasoning of others.
4. **Model with mathematics.**
5. Use appropriate tools strategically.

6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

Prerequisite Skills

List any prerequisite skills that may need to be addressed in a warm-up

- Unit conversations like microns into millimeters
- Understand combination of units of parameters in a function of several inputs
- Solving proportions for any unknown
- Terminology understanding of all parameters in the given formula

Time Required

The time required to complete this activity is approximately 90 minutes.
Task 1 (questions 1-6) is an introduction into the relationship between the pixel size on the image in the camera (CCD in microns) and the actual distance on the ground of the corresponding image pixel size (GSD in feet). It is encouraged to take some time to discuss the parameters in the given function and what they represent in the corresponding figure. Task 2 (questions 7-9) is encouraged to use excel to build a table of values by creating a formula and copying. Again, it would help to discuss the new terminology in this section on the corresponding figure. Task 3 (question 10) puts it all together to design the flight plan. There is information given that is not needed to solve this task but offers other extension questions to be posed and solved.

Materials Needed

- Students Activity Sheet
- Spreadsheet technology is useful but not required

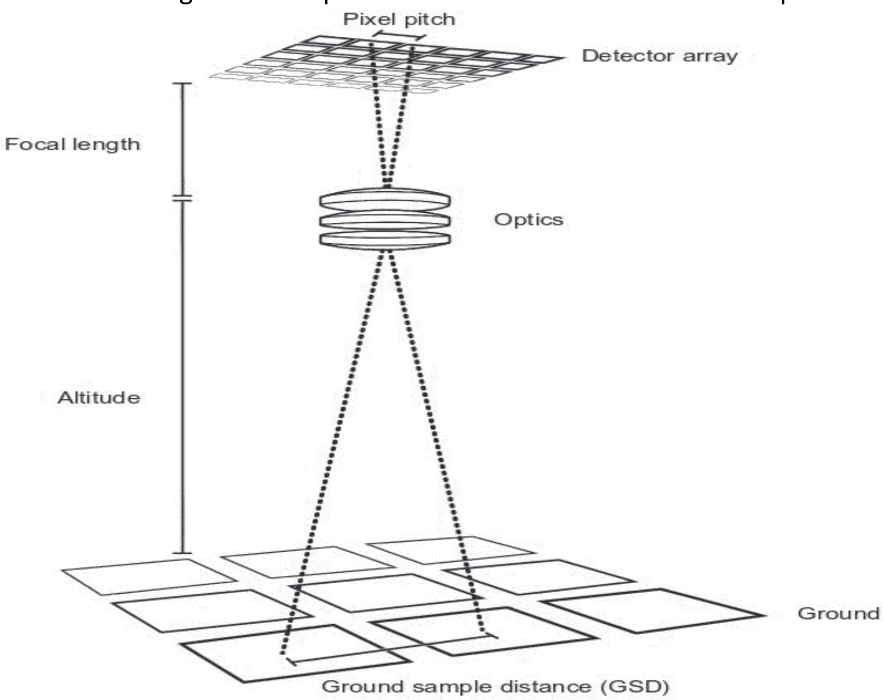
Vocabulary

- GSD - Ground sample distance
- CCD – pixel width on camera image
- Along track overlap
- Cross track overlap
- Footprint – ground area covered by a photo
- Microns and Millimeters

The Teaching Cycle:

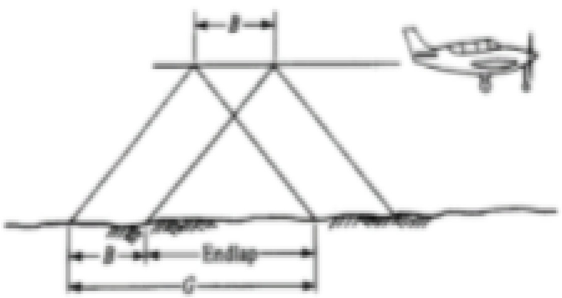
Maybe the Desmos Launch could be done for homework the night before you plan to start the activity. Or use the last 20 minutes of the previous class for students to individually complete the Desmos launch. Keep in mind that the Launch Video is in the Desmos, so you may want to show that to the class as a whole prior to students doing the Desmos activity.

Launch: Following the Desmos activity, discuss the Purpose (explained above in the initial paragraph) of the Photogrammetry Unit at NC DOT. To plan the new road design, precise land measurements are needed to be collected in the digital photographs. Using the diagram below (also on student task sheet), explain what each parameter represents (CCD, GSD, f, and H) in the given formula $GSD = \frac{H \cdot CCD}{f}$. Also, explain what units are normally used for each parameter. You could ask: “Is this diagram drawn to scale?” “What would it look like if it were drawn to scale?” “Are there units in the formula that could reduce?” “What and could be changed and how should it change to make the GSD smaller?" "Would NC DOT want a small GSD or large GSD? And why?" These questions will get students thinking about the parameters in the formula and will help them in Task 1.

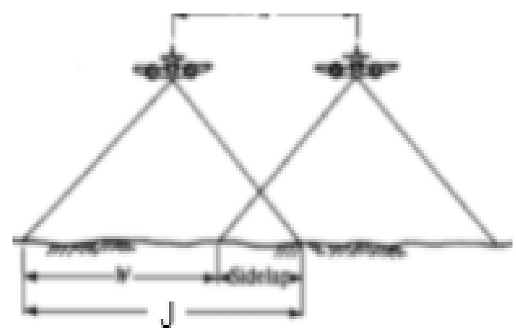


Explore Task1: Task 1 is an introduction into the relationship between the pixel size on the image in the camera (CCD) and the actual distance on the ground of the corresponding image pixel size (GSD). This function is given to the students, but it is derived from proportions of similar triangles with each triangle ratio of height to base. $\frac{GSD}{H} = \frac{CCD}{f}$. Students do not need to derive this formula to apply it, but they do need to understand what each parameter represents and keep track of units when using the formula. CCD is normally given in microns and the camera focal length, f , is given in millimeters. The units of the fraction of CCD to f will need to be reduced by converting microns into millimeters. For example, 5.2 microns is .0052 millimeters. After this conversion, the formula $GSD = \frac{H \cdot CCD}{f}$ will have the airplane flying height, H, and the ground sample distance, GSD , will both be in the same units (normally feet) because the CCD and f units of millimeters will divide each other. For question 3, a camera that would produce a smaller GSD (in other words a higher resolution image and more detailed digital data) would be a more expensive camera. So, setting the airplane flying height at a constant and computing GSD for each camera would rank the 4 cameras in terms of quality and price. Questions 4, 5, and 6 are each solved by considering changes in parameters in the given function for GSD. Increases in the numerator (flying height and or camera CCD) for a fixed focal length will generate larger GSD values and decreases in the numerator (flying height and or camera CCD) for a fixed focal length will generate smaller GSD values. Increase in the camera's focal length, f , keeping the numerator values constant will generate smaller GSD values and decreases in the camera's focal length, f , keeping the numerator values constant will generate larger GSD values.

Explore Task2: Questions 7, 8, and 9 all pertain to finding the ground coverage (a large rectangular area on the ground) for each photograph. Then knowing what how much each photograph must overlap frontwards and sidewards, the flight plan can be designed, and the number of photographs needed for a large area can be determined. All area needing digital data MUST have overlapping images to be able to be viewed in 3-D using computer software and special glasses. Specifically, when the plane is traveling forward along a flight line, then each image must overlap by 60% (called forward overlap). When the plane is traveling along a second flight line parallel to an adjacent line, then each image must overlap by 30% (called side overlap). The two figures below help explain this idea. With the forward overlap, after an image is taken, a second image will need to be taken after 40% of the forward distance of the first image is traveled (distance B in the figure). After one flight line is traveled, the adjacent flight line needs to be 70% of the side-to-side distance from the previous flight line (distance W in the figure). Both B distance and W distance can be computed after knowing the actual ground rectangle dimensions of each photograph. In question 9, you must first calculate the GSD (which is given in question 7) before finding all the other values. Excel is encouraged to use in both questions 7 and 9 so that formulas can be created and then copied down for the remaining cells. Question 8 is asking students to understand the inverse relationship between GSD and resolution. In detail, the smaller the GSD, the better the resolution of the image and more digital data is collected from the photograph.



Forward overlap



Side overlap

Explore Task3: This final task in question 10 brings together all the ideas used in Task 1 and 2 (questions 1-9). To design a flight plan, we only need to know how many images must be taken using forward and side overlapping percentages to cover the large disaster area of 6720 feet by 5950 feet. First, using the camera specs provided for the flight and the required given GSD of .119 ft, you can compute the length and width of each image. The camera will take 17004 pixels along the flight path and knowing each pixel corresponds to .119 feet on the ground, you can multiple .119 * 17004 to get 2024 feet (called a footprint along track). Similarly, the camera will take 26460 pixels across (or perpendicular to) the flight path and knowing each pixel corresponds to .119 feet on the ground, you can multiple .119 * 26460 to get 3149 feet (called a footprint cross track). Using the forward overlap of 60%, take 40% of the 2024 feet, which is 809.6 feet, along track to get the distance traveled by the plane before taking the next photograph. So, if we must cover 6720 feet, we only need to divide 6720 by 809.6 to get the number of photographs needed along one flight track. This division results 8.3, so we need 9 photographs cover the 6720 total feet of distance. BUT, knowing that the initial 40% of the first image taken is not being overlapped, we must add 1 more photograph to get full overlapping coverage along the first flight track. So, 10 photos are needed along each flight line. Now we just need to determine how many flight lines are needed to cover the 5950 feet of the original disaster area width. Using a similar approach, it takes 3 flight lines with a 30% side overlap to cover the 5950 feet. Therefore needing 10 photos on each of the 3 flight lines equals 30 photographs need to be taken. Students may want to consider flight lines going in the other direction to cover the 5950 feet. Logically thinking, the flight lines should be in the direction of (parallel to) the longest side of the area to be photographed. Some groups may want to compute both options to confirm the least number of photos.

There are several good extension questions that could follow up to this task. To completely design the flight plan, the pilot would need to know the altitude to maintain. She would also need to know at what time

intervals to take the photographs. Of course, they would need to know the airplane velocity to compute the time interval between each photo. Questions below are great follow ups.
“What is the flight altitude of the airplane?”
“How many minutes does the photographer need to wait between the taking of each photograph?”
“If the airplane maintains a speed of 50 mph, how many minutes between photos?”

Discussion: Students will share their results and compare what they arrived at compared to other groups. Groups can explain their process they used at arriving at their result. You could have groups trade their answers and have groups compare their results with the results of the paper they are reviewing. Again, time is a factor in how you handle the discussion part of the activity. Do at least have each group explain to some degree how they arrived at some part of their results. The last task on the number of photographs could be the starting point of the whole class discussion. You could have each group put their recommended number of photographs on a small piece of paper and turn it in to you with their group name. For each different number of photographs, choose a group to defend (validate) their recommended number. Of course, the extension questions above could extend the discussion about the total communication from the NC DOT Flight planners to the actual flight team taking the photos.

OnLine Class Option: Below find the blackboard post for this activity assignment for an online class. The discussion part of this schematic could be assigned as the Discussion part of an in class face to face class.

Group Project - Photogrammetry

Group Project - Photogrammetry

Attached Files:

- Student Activity Sheet_Flight Planning for 3-D Imagery.docx Student Activity Sheet_Flight Planning for 3-D Imagery.pdf - Alternative Formats (696.455 KB)

Project Steps

Step 1: **GOAL COMPLETION BY WEDNESDAY, June 1 at 11:59pm.**

- Complete the Launch Desmos Activity (This part individually): "Photogrammetry - Flight Planning" Desmos Link: https://student.desmos.com/join/E36S3K
- The Industry Video from NC DOT is embedded in the Desmos Activity

Step 2: **GOAL COMPLETION BY FRIDAY June 3 at 11:59pm. MUST BE COMPLETE BY MONDAY June 6 @ 11:59 PM.**

- Explore the task as a group.
- This does not mean, divide up the tasks into individual pieces but as a group, discuss the problem and agree on the best solution to the problem.
- As part of the explore phase, your group will be expected to solve the problem and submit one copy of your answers as a group via blackboard.
- ONLY submit your answers with your math supporting work and explainations. Please number your solutions corresponding to the numbers on the student activity sheet.
- I strongly encourage you to set up at several teams meetings to work through this as a group. Please invite me to any group teams meetings you have. I will attend as many as I can.

Step 3: **MUST BE COMPLETE BY MONDAY June 6 @ 11:59 PM.**

- There is a discuss portion of this task at the end.
- The discuss portion is important to this project because it allows you to see how other students approached their problems and whether or not you all had the same thought process.

- Your group will produce an electronic explanation of your complete approach and methods and solutions to question #10 ONLY on the student activity sheet.
- You can choose from the following list for the discuss portion of the project:

- A video
- An MS Teams meeting recording (invite me to it and record it for posting on blackboard)

Exit Ticket: Find the GSD for a camera with CCD of 4.8 microns and focal length of 140 mm for a flying height of 5700 feet. If the camera has a detector array of 15000 pixels by 18000 pixels (pixel number on the camera image), determine the footprint of one photograph. (Answers: GSD = .19543 feet with footprint 2931 feet by 33517 feet)

This activity could be extended into a visit (field trip) to NC DOT in Raleigh. An actual visit would allow students to experience the 3-D glasses and realistic computer images that the overlapping photographs produce. Virtual engagements are also possible with the NC DOT Photogrammetry Unit, but that would not allow 3-D viewing possible.