A Study of Fluvial Processes in Desert Morphology

AiS Challenge

Final Report

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Team # 79

Santa Fe High

Team Members

Teresa Davis (Captain)

Laura Stupin

Jennifer Bartels

Robert Mansfield

Teacher

Anita Gerlach

Mentors

David Stupin

Dave Carrington

Table of Contents

Executive Summary

Our goal is to model the motion of a single grain of sand moved by the wind over a sand dune. This program would be useful for studying the movement of sand dunes and to control their migration into populated areas. We chose to research this topic because the movement of sand dunes has never been successfully modeled.

Grains of sand are lifted by the wind and carried a certain height and distance that depends on the velocity of the wind and the mass, density and shape of the particle of sand. Sand grains on the surface of a dune do not generally move to the peak of a dune in a single jump. Instead, they make a series of smaller jumps, which is a process known as saltation. Sand grains are ejected into the wind stream when another grain, already in the wind stream, lands on the dune. The impact causes the grain laying on the dune to be ejected up into the wind stream. (Bagnold)

Our C++ program calculates the height, horizontal distance traveled, and time of flight for one of these jumps, taking into consideration the dimensions of the sand grain, the velocity of the wind, and the air drag on the sand grain. We break the path of a sand grain into two parts: as it ascends and as it descends. Each of these parts is then broken into intervals of vertical velocity. For example, if the sand grain is given an initial vertical velocity of 2 m/sec, our program calculates the time it takes to for the velocity to decrease from 2 m/sec to 1.9 m/sec, and then from 1.9 m/sec to 1.8 m/sec, and so on until the grain reaches a vertical velocity of 0 m/sec at the top of its arc. During each of these periods the program also calculates (1) how far the grain rises vertically and (2) the distance the grain travels in the horizontal wind stream. Once the time of the ascension is found, this can be used to determine how far horizontally the grain has traveled. A similar process is followed to find how long it takes the grain to hit the ground from it's highest point and how far horizontally it travels during this time.

Our model demonstrates some general behaviors of sand grain motion. We found that increasing the wind velocity causes the horizontal distance that the grain travels to increase very rapidly, while the vertical distance increases slowly. Our program could be used as a stepping stone toward more advanced programs that would simulate dune behavior.

Introduction

The objective of this project is to achieve a greater understanding of the movement desert sand dunes. In places where people live near deserts, the migration of dunes can pose a serious problem. A greater understanding of the movement of dunes could help to better control dune migration into populated areas. We chose this topic for our project because the movement of sand dunes has not been modeled successfully.

Nevertheless, the movement of an entire dune cannot be understood without a basic understanding of the movement of the grains of sand that make up that dune. Therefore, we focus on the movement of individual grains of sand. Individual sand particles are lifted by a stream of air off the face of the dune and carried to a certain height and a horizontal distance that depends on the size and density of the particles and the velocity of the wind. However, sand grains on the surface of a dune are generally not lifted and carried to the peak of a dune in a single leap, instead, they make several smaller jumps--this is known as the process of saltation. (Bagnold)

A sand grain is lifted into the air either from turbulence in the air stream or it is knocked into the air stream by the energy of another falling sand grain that collides with it. The latter case creates a chain reaction where falling grains knock static grains into the air, and these in turn fall and knock other static grains into the air.

Description

In our program we have made a few assumptions. We assume that all sand grains are perfectly spherical, of uniform density, and made of quartz. We also assume that wind speed and direction are constant, and that erosion of the sand grain does not occur in the air or upon impact with the dune. Our model shows the path of a sand grain over a flat horizontal dune surface.

Our first program calculates susceptibility. Susceptibility is a ratio of air resistance to gravity. (Please see Appendix A for the equations we used in our programs.) Thus, if the grain is falling towards the earth and the susceptibility is greater than one, then the air resistance is greater than gravity and the grain will slow down. If the susceptibility is less than one, the gravity is greater than the air resistance and it will speed up. If it is equal to one, the air resistance equals the gravity and the grain will travel at a constant velocity known as terminal velocity. (Bagnold)

Our current program calculates the distance, height and time of the grain's trajectory, given the wind velocity and the susceptibility of the grain on a flat horizontal surface. (Please see Appendix B for our C++ code.) A sand grain will fly in an asymmetrical arc once lifted off the ground, rising on a path with a steep incline until it reaches the top of its path and then falling at a gentler incline to the ground. Our program breaks this path into two parts--as it ascends and as it descends. Each of these parts is then further divided into intervals of vertical velocity. For example, if a sand grain is given an initial vertical velocity of 2 m/sec, the program calculates how long it will take for the velocity to decrease from 2 m/sec to 1.9 m/sec, and them from 1.9 m/sec to 1.8 m/sec until the vertical velocity reaches 0 m/sec at the peak of its trajectory. As it descends, a similar process is followed. Again, we divided up the descent into intervals of vertical velocity, except this time, the program stops calculating when the sand grain falls back to the ground, or when the vertical height is zero. We find the sum of the times for each step to find the total time it takes for a grain of sand to complete its path, as well as how far horizontally it has traveled. We assumed that a sand grain would immediately take on the horizontal velocity of the wind as soon as it began moving. Bagnold found in his experimentation that the vertical velocity of a sand grain was often one fifth of the horizontal wind velocity, and we assume this ratio in our program also.

Results /Conclusions

Our model demonstrates some general behaviors of sand grain motion. We found that increasing the wind velocity causes the horizontal distance traveled to increase very rapidly, while the vertical distance increases slowly. We have assumed that if a strong wind is blowing parallel to the earth, then it carries a grain of sand with it, parallel to the earth for a short distance. We have neglected the more unpredictable forces such as turbulence and varying wind directions that cause the upward path of sand particles. We have assumed a constant susceptibility, which makes the results that much more inaccurate. Susceptibility should increase with the increasing velocity of the grain.

In the future we want to add more realistic dunes surfaces and shapes, a changing susceptibility, an inclined surface that a grain might bounce up, making several arcs, and simulate the movement of an entire dune. Our programs can be easily modified to fit these future desires.

Recommendations

We embarked on this project with the goal of simulation of a moving three-dimensional sand dune. Hindsight allows us to see that this was an unreasonable goal because no one in our group had had prior programming experience. What saved us was narrowing it down to just working with a single grain. Although we did not achieve a three-dimensional dune, we could use our program to show the motion of individual grains, and use the supercomputer to follow the paths of a large number of grains.

Furthermore, we feel that our results are not very accurate. We made too many assumptions. The worst of these assumptions is that susceptibility is a constant number, which it is not. At the very least, it changes as the velocity of the grain changes. So, in reality, the susceptibility would change for each 0.1 m/sec step of our program. We used a constant value of susceptibility because we could not find a reliable way to calculate the resistance coefficient in the equation for susceptibilty. The resistance coefficient is related to air drag. It is usually found by experimentation, and cannot really be calculated by any formulas we found. We also assumed that the horizontal velocity of the sand grain is constant. We need to include the horizontal acceleration of the sand grain in the wind stream.

Acknowledgements

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Resources

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Appendix A

Equations Used in our Program

$D = \frac{1}{2} cpav^2$

D = air resistance

c = resistance coefficient

p = air density

a = cross-sectional area of sand grain

v = relative velocity

$L = (u^2 - v^2) / (2a)$

L = vertical distance

u = initial velocity

v = final velocity

a = acceleration

S = D/mg

S = susceptibility

D = air resistance

m = mass of sand grain

g = gravity

t = (u -v)/a

t = time

u = initial velocity

v = final velocity

a = acceleration

a = g (1 + s)

a = g (1-s)

a = acceleration

g = gravity

s = susceptibility

d = t*w

d = horizontal distance

t = time it takes grain to fall

w = wind velocity

Appendix B

Our C++ Code

```
include <iostream.h>

int main ()

{
float u, s, v, a, l, t, w, d, totall, totalt, totald, kilt;

cout << "What is the velocity of the wind in meters per second?"  << endl;
cin  >> w;
u = w/5;
cout << "What is the susceptibility?"  << endl;
cin  >> s;

totall = 0;
totalt = 0;
totald = 0;
a = 9.81 * (s +1);

do {
v = u - .1;
l = (u*u - v*v)/ (2*a);
t = (u -v)/a;
d =t*w;
totall = totall +l;
totalt = totalt + t;
totald = totald + d;
u = v;
} while (v >= .1);
```

```
kilt = totall;

u=0;
a= 9.81*(1-s);
do {
v = u +.1;
l = (v*v - u*u)/ (2*a);
t = (v -u)/a;
d =t*w; totall = totall - l;
totalt = totalt + t;
totald = totald + d;
u = v;
} while (totall >= 0);

cout << "The grain will rise " << kilt << " meters." << endl;
cout << "The horizontal distance the grain will travel is " << totald << " meters." << endl;
cout << "The time it will take to travel this distance is " << totalt << " seconds." << endl;

return 0;

}
```