October 1, 1998

The van had left late today, so I ended up arriving at the Physics Building around 1:45 or so. I had no idea where the lab was although Dr. Behringer had sent me directions to the lab in his e-mail; he said to take the stairs down one floor and to turn left or right or somewhere until I reached his office. He gave me the room numbers for his office and for one of the labs he worked in; it was 1:50 when I found his office, but he wasn't there. I walked around the corner to look for his lab, but it turned out that his lab was a conglomerate of seven rooms in a suite-like arrangement right next door.

This lab area was once used for Low-Temperature Physics research; the first room I walked into contained a sensor in the middle about 3-4 meters high and I asked the person working there if he had seen Dr. Behringer today. He said he hadn't seen him recently, so I walked out of the room and ran into Dan Howell, one of the graduate students working in Dr. Behringer's lab. He told me that he would be working with me most of the time, and took me around for an extended tour of the Nonlinear Dynamics wing, which consisted of the six rooms of the lab and all the closets in between. I saw a large, flat two-dimensional Plexiglas panel that much resembled a chalkboard raised off the floor by a frame; the top half contained a "funnel" created with two Plexiglas panels mounted at an angle to each other, and the bottom half contained a holding area that resembled the top funnel, but was smaller and in the form of an inverted funnel. The top half and bottom half were sandwiched between two 3' by 5' Plexiglas panels. In totality, the entire device resembled a picture frame with the figure of an hourglass in the center; the hourglass consists of the funnel on top and the holding area on the bottom. The top half would be used to hold 1 cm disk-like photoelastic beads that would fall through the top of the hourglass into the holding area below. Between the two halves of the hourglass was a metal strip that had been inserted from one side; its purpose was to allow the beads to fall through once it was removed.

<u>Photoelasticity of Beads</u>

When polarized light shines on a photoelastic polymer, the light is reflected from the polymer in ways that depend on the pressure exerted on it. When one of the photoelastic beads are held up against a polarized screen and is subsequently compressed, by the fingers for example, a line of light can be seen running through the bead in a direction perpendicular to that of the force exerted on it. Because light is emitted along lines where there is stress in the material, these photoelastic beads allow an observer to see lines of stress that are formed when a bead is compressed by the weight of neighboring beads. When many beads are allowed to pile up in the holding area in this fashion, stress chains can be observed that run throughout the pile.

<u>Photoelasticity as applied to the 2-D funnel</u>

When the metal strip is removed and the beads are allowed to fall, the beads begin to form a pile in the holding area at the bottom of the hourglass. While falling, there is a force exerted on the beads (the gravitational force), but this force does not act to compress the beads, so no stress lines are produced within the beads. When a bead hits the floor of the holding area, the force applied by the floor on the bead to change its direction and magnitude of motion (the normal force, which changes the bead's velocity) produces a temporary stress line in the bead parallel to the floor. When more beads begin to pile, the weight of the upper beads compresses the lower beads and produces stress chains that run throughout the pile. When all beads have come to rest in the holding area, the beads and stress chains remain stationary. We know this because there is a video camera that records the formation of the bead pile. To track the position of the beads, a tiny strip of black tape was stuck to the center of each bead so that the bead appeared to be divided into hemispheres. Using the video and video analysis software, we can gain position data and see how position of the beads affects the formation of the stress chains.

While Dan was explaining the 2-D funnel to me, a tall man with gray hair walked in and perused the funnel. After he left, I later found out that he was a theorist and did very few experiments. He had come by to judge the soundness of this device, to see if it had been built properly so that substantial error would not be introduced into the system. The first thing he noticed was that then the metal strip was removed, the beads would begin to fall from the right side of the neck (the strip was slid to the left to remove it), and after the strip was removed would the beads fall uniformly through the neck. This meant that the pile would be made in a somewhat unbalanced fashion; a slightly larger amount of beads would fall to the right of the pile than to the left. He also asked whether Dan had made sure if the funnel was level and not tilted horizontally, because this would also create problems with the falling of the beads. He tested how well the funnel could be rotated vertically (once all the beads had fallen to the holding area at the bottom of the funnel, the beads had to be made to fall back through, much like how an hourglass is tilted back over to get the sand back into the upper half), and found that the funnel was okay in this respect. The biggest problem with this setup was the metal strip, and so we figured that cutting a hole into the Plexiglas into the neck of the funnel and sliding the strip through the neck there would eliminate our problem.

There were other granular material experiments in the other rooms; one grad student had built a cylindrical device that contained a cylinder with an etched surface on the inside, surrounded by water containing little metallic specks. He wanted to determine how changing the shape of the inner cylinder's surface would affect the flow of fluid around the cylinder; for this purpose, metallic specks were thrown into the water so that the change in direction of water currents could be observed on video. Another experiment involved hexagonal, not disk, photoelastic beads placed on the surface of a rotating horizontal turntable. Beads moving away from the slowly moving center region to the more quickly moving outer region of the turntable interacted with and compressed other beads on their way; many pictures of the resulting force chains had been taken and were scattered all over the walls outside this particular lab room. An adjacent room housed an experiment that did not involve granular materials but cloud formation.

One of the three remaining rooms contained four computers. One was a Silicon Graphics computer, two were Suns that ran Unix, and the last ran Linux. This room was the "hang-out" area of the lab, with pretty decent sitting arrangements and desk space; at least 2 grad students and as many as 6 would be there at one time on the average day. Another room was the "shop" room of the lab; all the basic tools one would normally find in a toolbox were kept here. The last room on my list was the room between the lounge room and the shop room, a room that was messier than the lounge but more orderly than the shop. This room was where I would carry out my first experiment that had already been set up for me before I arrived.

Bob Hartley, grad student and good friends with Dan Howell, also had an experiment in this room--a camera fastened to a small, flat Plexiglas container recorded the movement of colored sand particles held inside at various time intervals. The container and sand resembled an ant farm; it was shaken vertically about three times a second which produced motion throughout the entire granular system. Over time, the sand particles on the surface and just underneath would migrate, forming a hill that changed position in several-hour intervals. On the other side of the room was my setup--a large three-dimensional metal funnel supported by metal beams over a flat surface with a pressure sensor built into it. The pressure sensor measured the force exerted on its surface by measuring the capacitance as the top plate begins to creep the tiniest distance toward the bottom plate of the sensor, which changes the capacitance between the two plates. Dan explained that through a series of equations, the force exerted on the sensor was proportional to the capacitance between the two plates.

This experiment was designed to measure the force underneath the base of a sand pile at various distances from the center of the pile. One would expect that when a pile of sand or other granular material is formed, the greatest force at the base of the pile would be at the pile's center (the peak) since there are more beads at the center than at the periphery, which means more mass at the center (and more force due to the weight of the pile that is exerted on the base). However, previous experiments have shown that the greatest force at the base of a sand pile is not actually at the center, but at some distance just away from the center. This means that there is a dip in the force at the center of the pile. My experiment was to confirm this "dip." The apparatus was slid at various distances away from the pressure sensor so that the sensor would measure the force at various distances away from the mouth of the funnel where the beads would later fall from. The distances tested were x = 0, 5, 10, 15, 20, 25, then 35-95 in increments of 10 (45, 55, etc.). The experiment involved measuring out a set mass of plastic disk beads and pouring them into the closed funnel. A layer of plastic beads was made beneath the mouth of the funnel, extending over the pressure sensor, and continuing along for a short distance to provide a surface that would dampen the bounciness of the falling plastic beads. The capacitance of the sensor was measured, then re-zeroed to account for the layer of beads just placed over it. Then, the computer was prepared to receive sensor data through the following steps on DOS:

1. Bring up the remove file command (rm).
2. Make a new 25k file.
3. Call the streamer program, but before pressing Enter, make sure that the funnel has been loaded and the surface of the layer over the sensor has been flattened out.
4. Press Enter.
5. Open the latch at the bottom of the funnel so that the beads start to fall out.
6. Wait at least ten seconds after the end of the run and press Ctrl-Esc.
7. Record the capacitance reading and the run number in the lab notebook.
8. Bring up the unpack command and increment the number of the file by 1 for the number of the run (run 45, 46, etc.).
9. Repeat steps 1-7 for each new run.
10. Do 7 runs for each distance setting; after 7 runs, move the funnel so that the center of the sensor is 10 more mm from the center of the funnel.

October 8, 1998

I did a few more runs of the 3D funnel experiment; in entirety, I completed the runs for the distance intervals 45, 55, and 65 mm from the center of the pile. Dan, Bob, and I went to a lecture in the LSRC auditorium at 3:45 today; the lecturer was a man from France, and the topic was the history of how our models of the universe have changed. Subjects ranged from main-sequence stars to general relativity to the Big Bang theory and theories on the geometry of space. We sat near the back so that we could leave whenever 4:30 came around without rousing much attention; before the lecture started, I happened to see Dr. Kolena walk in a few rows below us and he waved hello--this must have been a very popular lecture among the astrophysics community and the general physics community as well. The lower area of the auditorium were nearly filled to capacity, but we had plenty of free space.

I had never seen the inside of the LSRC or any part of it up close; it is certainly a beautiful building. The beauty of this building compared to the Physics building (or Biology floor compared to Physics floor at Science and Math) brought up an interesting thought. For some reason physics labs are often in more of a state of disarray than the average biology lab, and physicists' offices are jungles of paper and equipment that one would be pressed to find in the average biologist's office. The LSRC had carpeting, actual painted walls, wonderful architecture, spiraling stairways. The Physics building has three floors from what I've seen so far, two staircases, no carpet, bare parched walls, and the last renovation done on this building must have been during the first day Duke built it. In the shop adjacent to my room in the lab, there are huge planks of lumber with a gray coating of thick dust on the top and extending somewhat down the sides; Dan and I joked that these planks were left over from the day the Physics building was built back in the late 1800's or so (actually, it was probably built earlier this century, although I wouldn't be so sure).

However, the strangest thing is that if the Physics building actually looked as nice as the LSRC, I think it wouldn't be much of a bonafide Physics building. The mess is integral to doing physics; the only order that is found in physics is in the math and minds of physicists (maybe). A mess in the lab is worth two good theories in the head, it appears. Therefore, in a way, I think the Physics building is beautiful--it's what's on the inside (of the building) that really counts. The LSRC has lots of new stuff, yes, but the Physics building feels more lofty and important; when I walk through the front door, I feel like I'm walking into a place where stuff is actually getting done, where there is a dedicated, scholarly pursuit of knowledge, and where the people who work there feel that they're doing something important. That really matters, because the worst kind of professor or researcher is the one who doesn't feel dedication to their work. There are people in the Physics building who have been there for twenty plus years.

Back to the auditorium--I was supposed to leave at 4:30, but I took a gamble and told Dan that I was going to stay until 4:45. We both kept looking at out watches up until then. I couldn't quite leave just yet, because the lecturer was finally getting into Einstein's theory of general relativity and theories on the geometry of the universe, and I didn't want to miss that part. 4:45 came around, and we left Bob and walked out the auditorium and back to the Physics building. We passed by the TUNL (Triangle Universities Nuclear Laboratory) and saw part of the FELL (Free-Electron Laser Laboratory), where I was originally going to do work at except that Dr. Guenther was unable to find a safe position for me to work in, on the way back. Dan went back to lab and I waited for the van to come by; it finally came by at about 5:00, and I was quite disappointed because I could have stayed to hear the rest of the lecture (the lecture ended at 5:00). The last time, the driver was late by ten minutes, so I felt I could take a reasonable 15-minute gamble; I could have taken a 30-minute one in this case. Well, I suppose that when I go to college, I will not have to worry about missing out on lectures (!).

I collected everyone's cards on the way back and then gave them to Ms. McCoy after I filled in my card, and that was the end of the day.

October 15, 1998

We had a different Thursday schedule (Monday) today because Fall Break had just ended; therefore, I couldn't go to lab today. I sent Dr. Behringer an e-mail about this as soon as I realized this on Sunday.

October 22, 1998

Dr. Behringer is still in the Middle East, and has left all the grad students in the Nonlinear Dynamics wing of the Physics Building to fend for themselves. Dan had a new project for me to work on as soon as I walked in; he had made a new two-dimensional funnel of Plexiglas for our next experiment, and now the only task remaining was to design a stand for this funnel, which was huge. The device in its totality was three feet wide, five feet long, and an inch thick, almost like a 60-pound picture frame. At its upper half, if you turn it so that its length is parallel to the ground, there is a large groove made up of sandwiched layers of Plexiglas that contained 1 cm wide hexagonal photoelastic beads. This groove is shaped like a two-dimensional funnel; at the "neck" of the funnel there was a metal strip that had been inserted across the neck through a slit cut into the Plexiglas; when the entire apparatus is stood up, removing the metal strip will allow the beads to fall through the funnel. At the bottom half of the device was a holding area for the beads that had fallen through.

We were doing an experiment that required for me to be there for 20 minutes; we planned to start at 4:00, but we actually didn't get started until 4:15. After the experiment, I had to gather up all the data on the computer; I could have started earlier, but seeing how the last two vans came about 10-15 minutes past the time the driver said he would be here, I thought that being a few minutes late wouldn't hurt much. I wanted to be as early as possible after I finished gathering the data; I ran up the stairs and walked out the door, and right across the street was the gray van. The students told me that they had been waiting 20 minutes for me; supposedly, the driver came early to pick everyone else up, and I was the last person on the route. Since I got out there at 4:45, either they got there at 4:25 or they were exaggerating the time a bit, I guess. Anyhow, when we got back to school, the last van later arrived at 5:20, which marks a new NCSSM record for the earliest time that all the students have gotten back in.

October 29, 1998

Today, as I walked into the room containing my 3-D funnel experiment, I noticed that the funnel had been moved off the table and that the table was almost completely cleared, except for packages of plastic beads, round sand, and rice. This could have meant only one thing--a new experiment was about to be started. All the runs for the 3-D funnel had been completed, and now it was time to do cylinder experiments.

The "cylinder" was a 1' high, 4-5" wide PVC cylinder with a square piece of plastic with round holes cut into it that was taped across one end of the cylinder. Its purpose was to contain plastic beads as they fell through the round holes in the grid. Previous experiments had shown that as the beads form a pile as they fall from the cylinder, there is no central dip in the force vs. Distance graph as there is when beads form a pile as they fall from the mouth of the 3-D funnel. However, we would not be able to do the experiments today, since Dan had found a problem with the cylinder and its grid--the beads would not fall through when the cylinder was filled. They kept clogging up, and had to be shaken through for the beads to even move.

I arrived there at 1:25, and around 1:30 we decided to search the ND (nonlinear dynamics) lab area and adjacent shop rooms and closets for anything that resembled a grid with holes large enough for the beads to pass through. News came in that there was a talk that would be given at 2:15 by Dr. Bob Ecky from Los Alamos, NM, so we had to find the grid before the talk started. We found nothing in the Physics parts room, which contained just about anything one would need to build any mechanical device. Dan did decide that he wanted to build an assembly that would slowly lift the cylinder up from the pressure sensor, allowing the distance between the top of the pile and the grid to remain constant as the pile became taller. We didn't find any gears there, however. Another man walked in and found three boxes of what he needed before we had finished searching the room, so we walked back to the lab area and looked around again. After talking to Bob, who first suggested that we tie together some wire we saw in the parts room in the manner of chicken wire, we all decided that it would be easier to go to a hardware store and get some chicken wire.

We asked a guy sitting in front of one of the computers in the computer room where the nearest hardware store was, because Dan only knew of the Home Depot all the way out in Chapel Hill. He said that there was one off of Guess Rd., so we got ready to go and drove off campus in that general direction. Dan told me that this guy was notorious for giving bad directions, but after a few turns, we finally found the place. I never knew that there was a hardware store that close to Science and Math--there's lots of stuff I want to get if I could ever manage to get back over there. We went all the way to the rear of the store after asking where the chicken wire was, and when we got there, I couldn't believe how many different kinds of chicken wire there were. We ended up getting the kind with the finest mesh, although the width of the holes appeared to be the same as the diameter of the holes on the previous grid that didn't work. There must have been some 10-15 feet of chicken wire in that roll, but it didn't cost much, and we figured that since the holes were square, not round, there was certainly more room for the beads to fall through than with a grid with round holes.

On the way back, we saw a crowd of people standing beside a person who had been riding his or her bike when he or she had gotten hit by a car, and it looked as if the person had gotten hit pretty badly. By the time we got out of the car, it was 2:14, so we went back to the lab, dropped off the chicken wire, and then tried to find out where the lecture was supposed to be given. Dan said that it could only be given in two places, so we went to the first on our list and we turned out to be lucky; we were just two minutes late. We inadvertently sat in the seats right behind the overhead projector, so whenever there was an interesting transparency to be seen, we had to bob up and down and lean left to right to see the whole picture.

The talk was about the nonlinear dynamics of soap films, and lasted from 2:15 until 3:15. It was a very interesting discussion, introducing new concepts that I hadn't heard of, such as Fourier transforms, "k-space," that increasing the Reynolds number allowed for more vortices to form behind a stationary object as a fluid passed around it, that swirls formed behind this object and as the speed of the surrounding fluid increased, the swirls broke off from behind this object in alternating fashion, and that as the speed increased even more, an area of turbulence was created behind the object and became smaller as the speed increased more. I learned that a vortex had positive vorticity if the flow was counterclockwise and negative vorticity if the flow was clockwise, and that enstrophy (not entropy, as I had thought) was the mean square value of the vorticity (I write all of this here because next Thursday, I'm going to ask for further insight as to what all of this means).

A funny side note: Dr. Ecky was giving an outstanding, coherent lecture for quite a while now; he had a very outgoing personality, was quick to answer questions, and was quick to say "I'm not quite sure" if he didn't know the answer to a question. All these things identified him as a talented speaker--he didn't talk too quickly or too slowly, and kept his audience attentive (however, to my left and beside Dr. Behringer I saw this old physicist with his head leaned back and eyes closed, clearly asleep for several minutes). Then, Dr. Ecky put up a transparency of a graph labeled "Energy vs. Enstrophy." Sitting behind the projector, I leaned around to make sure I was seeing what I was seeing--the graph was clearly titled "Energy vs. Enstrophy." I was sitting there, puzzled. I thought at first that he made a typo by including an extra "s," but then I looked again and realized he must have made two typos, by including an extra "h" too. Even Dan was duped--he looked at me and asked, "What's enstrophy?" We read further down the page and saw the word again, with the same spelling, and were still trying to figure out whether one of the most famous nonlinear dynamics physicists in the world had managed to make the same typo two times in a row, and then he put up another transparency and here was the word again. Finally, after we sort of figured out that "enstrophy" had to be a real word, Dr. Ecky gave a short definition of enstrophy--the mean square value of the vorticity. (The grad students and I had many a laugh about enstrophy after the lecture.)

That was the lecture, and we returned to the lab to continue our work. Dan checked his e-mail and I went to work on cutting the chicken wire to form a new grid. I taped the grid onto the end of the cylinder so that the beads could escape only by passing through the grid, and then Dan showed me how to run the first experiment. Using the same base plate with the pressure sensor embedded in the middle that was used for my 3-D funnel experiments, but with the funnel removed, a layer of beads was put over the pressure sensor. Then, two steel "rails" were used to hold the grid just above the layer of beads. The layer of beads served the same purpose as in the funnel experiments: they helped to reduce the bounciness of the falling beads with the plate by absorbing their elasticity. He ran out to get something really quick, and by that time I had gotten everything prepared. The only thing left to do was to load the beads into the cylinder. Dan came back and asked me, "Did it work?" and I said that I hadn't tried it yet. We both watched as I got ready to lift the cylinder--this was the moment of truth--I put my hand around it and lifted it up ever so gently. I lifted it up about a centimeter high off the layer, then about an inch high, and we didn't hear anything. Not the first bead fell. Dan couldn't believe it, and Bob, working next to us, was laughing at Dan's surprised look. "No, it's not working, no! It's got to work--please work--please--no!" All of us were just laughing, and then he came around and raised the cylinder up higher. He shook it once and nothing came out. He shook it a bit more vigorously, and then the beads started falling through, and when he stopped, so did the beads. It turned out that after all of today's work, we still ended up with the same problem we had before. Now, this was real science--nothing works the first time. When it does work, there's a celebration, and when it doesn't work, it's downright hilarious. This didn't work, so we all just stood around laughing. He shook out all of the beads, and then I cleared the plate and put some rice in to see if the rice would fall through. That didn't work either. Dan had an idea that would fix the problem (hopefully)--if we cut out parts of the grid in an alternating pattern, which would serve to enlarge the mesh size, the beads just might fall through.

I spent the last 15 minutes cutting out alternating parts of the grid while Bob explained what a logistic graph was. He said that these graphs were used as models of predator-prey relationships, and also were really neat things to look at. The graph uses as its base a simple parabola, and revolves through and around the parabola in a pattern that is dictated by the value of i. When the value of i lies between 0 and ~3.6, the graph proceeds upward in an initial staircase pattern and then spirals inward in an inverted staircase pattern, similar to what the end of a new fern leaf looks like. When i is greater than 3.6 and less than 4, the graph proceeds infinitely in the pattern of a closed staircase. Bob had written a program that creates logistic graphs with a number between 0 and 4 that the user enters, and if the number is greater then 3.6, the program automatically terminates after 10-15 seconds (since the graph is infinite, for user convenience it has to stop sometime). After looking at the program, I went to find Dan to get him to initial my attendance card, told him what I had done with the grid, and put the new paper he had ran off for me to read in my backpack. He gave me the card and had just remembered to ask me if I would write a "student" recommendation for him to put into his teaching portfolio (he plans to become a professor, and needs a good recommendation from a student). I said that I would write one, and in turn I asked if he would write me a teacher recommendation to Duke and UNC (I plan to go to college, and I need a good recommendation from a teacher). He said he had a whole list of good things to say about him in my recommendation. I thought that this was a pretty good arrangement--this will give me some experience in writing recommendations, since I'll probably have to do this more often in the future. At least the teacher recommendation portion of my college applications will be good and solid. I will do a great job on his recommendation, since he seems to be very knowledgeable in his field and has excellent teaching skills.

November 5, 1998

Bad news--although Dan had finished cutting out an alternating pattern of holes in the chickenwire mesh, and had taped the new grid securely onto the cylinder, when we tried to pour beads through the mesh nothing came through as before. We tried rice; nothing happened. My next assignment was to cut out a new piece of chicken wire, this time cutting out square holes two original squares wide, untaping the old one, and retaping the new one onto the end of the cylinder. We were absolutely certain that this was going to work; I had created holes in the grid large enough for me to stick my pinky through, and the beads weren't that big. Surely, we tried filling up the cylinder again with beads and they came flowing through.

We had tried so long to find a material that would evenly distribute the flow of beads over a wide area unlike how a funnel distributes them; now that we had the perfect size grid, we decided to call today Cylinder Experiment Day. For the majority of my time I did reruns of my cylinder experiment which consisted of seven runs for each distance from the center of the bead pile tested. The procedure was this:

1. Take one measured cupful of beads and mass it to make sure it is of the necessary mass. Sit this cupful aside.
2. Take another cupful of beads and set this one aside. Do not mass.
3. Smoothen out the leftover beads on the plate over the pressure sensor.
4. Take the cylinder, turn it over, and align the center of the cross-strings that run across the end of the cylinder like an X with the center of the future bead pile. Pressing the cylinder lightly into the smoothened layer of beads, create an indentation to mark the location of the cylinder's circular end.
5. Remove the cylinder and place two steel bars opposite each other and at tangents to the circle just created.
6. Place the cylinder on the steel bars in such a way that the gridded end faces downward, and is supported by the bars.
7. Zero the capacitance value; then fill up the cylinder with the massed beads from the first cup.
8. From the unmassed second cupful of beads, pour these beads into the first cup and mass them to make sure the necessary mass is available. Pour this cupful into the cylinder.
9. Prepare the computer for taking data. When ready, raise the cylinder by lifting up together at constant velocity both ends of the steel bars. Once all the beads have fallen through to form a pile, stop data collection and record the final capacitance value.
10. Repeat this experiment seven times for each value of distance being tested.

I ran my experiment 14 times today, doing two runs which had taken quite a while to do. After I finished my two runs for this week, Dan gave me another paper to read over the following week. This paper was at least 45 pages long, but he said I didn't have to finish reading it and comprehend everything I've read in one week. The paper explained some of the simple math involved in calculating stresses, or tension/compression forces, acting on objects.

November 12, 1998

Today is the day this journal is due, so I won't be able to write down this week's experiences here. I have my recount on my computer, however. One thing I'll write here is that I learned a whole lot of math today. I learned the most easiest integral in the world while going over my math paper from last week; it doesn't take long at all. Here's the integral:

y = integral of 1 / (1 + x^3) dx, integrated across the limits 0 and x.

Try this one to test your cal knowledge--I was so surprised at how easy it is to integrate!