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Understanding Misconceptions/Preconceptions
About How Airplanes Fly

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Abstract

It is important to determine what an individual’s conceptions are about a topic before attempting to design lessons on the topic. By understanding what individuals already think, or believe, about a topic, the teacher can customize lesson content and activities to increase to probability of a successful lesson. The author, a certified technology teacher and licensed private pilot, examines what misconceptions/ preconceptions students and teachers might have about how an airplane flies and how wings develop lift. In addition, consideration will be given to the role that cognitive development may play in the ability to understand flight and aerodynamic lift, based on Jean Piaget’s theories. A review of pertinent literature is given, as well as three interviews of a high school student, a pre-service science teacher, and a high school physics teacher, in which those individuals’ conceptions of how airplanes fly are probed. The individuals’ level of cognitive development will be gauged by administering the Arlin Test of Formal Reasoning.

Understanding Misconceptions/Preconceptions About How Airplanes Fly

Introduction and Statement of Problem

A topic in technology and science education that has widespread misconceptions is that of how airplanes fly. Many people have no idea whatsoever about how a wing generates lift, despite this topic being covered to one degree or another in K-12 curricula. Even those one would think should have a clear understanding of lift, such as pilots (including the author), have misconceptions that are perpetuated through incomplete and often misleading descriptions of the physical phenomena that generate lift. In the review of the literature, the author discovered that he too has misconceptions about lift, despite teaching about air transportation in secondary technology classes for three years, and earning his private pilot's license in 1985.

This study grew out of an earlier paper written for a course titled “Inquiry in the Classroom”, part of the Master of Science in Mathematics, Science, and Technology Education (GMST) program at St. John Fisher College in Rochester, NY. For that paper, an interview was conducted with an adult colleague of the author, who had experience teaching topics in computer science and also held a New York State School Administrator certification. That interview showed that an educated adult, who had flown on airplanes many times, harbored misconceptions about how airplanes fly and wings generate lift, and really had no idea about the correct scientific explanation of flight and aerodynamic lift.

The author and his academic advisor felt that building on the earlier paper by interviewing 3 participants- a secondary student, a pre-service teacher, and a high school science teacher, would be interesting for the capstone research project in the GMST program. However, these new interviews would not simply probe the participants’ preconceptions/misconceptions about how airplanes fly, but would also consider the participants’ responses within the theoretical framework of concept formation and development. Hence, the original literature review, which focused strictly on sources which described the incorrect explanations of aerodynamic lift in science textbooks, was expanded to consider the theories of cognitive development put forth by Jean Piaget and others.

In order to apply the theories of cognitive development to this study, an additional facet was added to the interviews of the participants. Prior to probing their misconceptions, the Arlin Test of Formal Reasoning (ATFR) was administered, which established the participants' level of cognitive development based on Piaget's theories. A full description of the ATFR is provided in the Literature Review and Methodology sections. Upon analysis of the interviews, a comparison was made between the participants' responses and their level of cognitive development as determined by the ATFR, to see if any pattern(s) could be observed between the interview responses and the ATFR results. Note that the term "correlation" is purposely avoided, as that term implies a statistically significant, causal relationship between two variables. Not only do 3 interviews not constitute a statistical study, but the aim of this project is qualitative, not quantitative. The goal is to provide a starting point for consideration of misconceptions in an area of science and technology education that has not been studied at length previously.

Additionally, this study does not make an attempt to fully consider the cognitive development theories of Piaget as they may relate to understanding how airplanes fly. Piaget's theories primarily relate to cognitive development from birth through adolescence and it is only the latter phases, entering into formal/logical reasoning, that are of interest for this study. It is recognized that the concept of aerodynamic lift is an abstract one, involving physical phenomena which are difficult to get a concrete grasp on. Thus, the author saw no need to interview children younger than 12, even though it is possible that more advanced youngsters may actually have entered the formal reasoning stage earlier than average. Following is a consideration of the misconceptions surrounding how airplanes fly and aerodynamic lift is generated.

The common way to explain how a wing generates lift is to apply Bernoulli's principle, which states that, as a fluid increases in velocity, its relative pressure decreases.

The explanation goes like this- because a wing is more curved on the top than on the bottom, the air traveling over the wing must go farther than the air passing under the wing, and thus must speed up to meet the under-wing air at the back edge of the wing. Often, an analogy is made to a carburetor, in which a narrowing of the intake throat causes an increase in the velocity of the air being drawn into the engine; the resulting decrease in pressure allows fuel to be “sucked” into the air stream, and thus into the engine cylinders.

The application of Bernoulli’s principle is not incorrect, but it is not the entire explanation of how a wing generates lift, either. Not all wings are curved more on top than on the bottom, and some are, in fact, curved more on the bottom than on the top. Planes can fly upside down, if they are structurally designed for it (as in aerobatics.) Anyone who has stuck their flattened hand out the window of a moving car knows that by tilting their hand, it has a tendency to lift up, yet there is no curvature that would cause air going over the top of the hand to speed up. In addition, the commonly taught concept that the two halves of a parcel of air that’s divided at the leading edge of the wing, one half going over and the other half going under, have to meet up again at the back edge of the wing, is totally incorrect. The air flowing over the top of a standard wing actually gets to the back edge before the air going under, and they never meet up again! (This fact was a revelation to the author!)

Tens of thousands of people fly in airplanes every day, yet most don’t even have a basic grasp of the physical forces that give an airplane’s wings lift. A Discovery Channel/TLC program titled “Understanding Flight” featured a segment in which a “man-on-the-street” style interview about how airplanes fly was given to passengers in an airport terminal; answers ranged from rising air currents to the jet engines alone causing lift. Even those who might be expected to have a clearer comprehension of the forces acting on a wing, namely pilots and teachers, often do not have a full understanding of how lift is generated. The author believes that interviews exploring misconceptions about this phenomenon, that most everyone has experienced to one degree or another, would be quite valid. The questions in the interview will focus on “how do airplanes fly?” and/or “why/how does an airplane wing create lift?”

The overall questions to be asked in this study are: Is there any noticeable difference in the understanding (preconceptions) of how airplanes fly and wings produce lift among an average high school student, a pre-service science teacher, and a high school science teacher? Also, can any pattern(s) be observed between the participants' answers and their score on the Arlin Test of Formal Reasoning?

Literature Review

The review of literature will be broken down into two parts: a review of the literature concerned specifically with misconceptions about how airplanes fly and wings develop aerodynamic lift, and a review of the literature concerning cognitive development as relate to the abstract reasoning needed to understand the concepts of flight.

The literature sources found regarding flight state that there are misconceptions about how airplanes fly and specifically about how airplane wings generate lift. Airfoil Lifting Force Misconception in K-6 Textbooks makes the following statements:

> **HOW DO AIRPLANE WINGS *_REALLY_* WORK?**
> Amazingly enough, this question is still argued in many places, from elementary school classrooms all the way up to major pilot schools, and even in the engineering departments of major aircraft companies. This is unexpected, since we would assume that aircraft physics was completely explored early this century. Obviously it must be spelled out in detail in numerous old dusty aerodynamics texts. However, this is not quite the case. Those old texts contain the details of the math, but it's the **interpretation** of the math that causes the controversy. There is an ongoing "religious war" over the way we should understand the functioning of wings, and over the way we should explain them in children's textbooks.

The author goes on to explain that there are two ways to explain lift. One is the “pro-Newton” or “attack angle” argument which basically says that “wings are forced upwards because they are tilted and they deflect air downwards.” The second argument is the “pro-Bernoulli” or “airfoil-shape” which states that “wings do not deflect air; instead they are sucked upwards because the "airfoil" shape has a longer surface on top. Airfoils are curved on top and flat below, and therefore the air follows a longer path above than below. Air that is divided at the leading edge of a wing must rejoin at the trailing edge.

Since the upper surface of the wing is longer, it causes the air to flow faster over the upper surface, which (by Bernoulli's principle) creates lower pressure above.” The author believes that both arguments need to be incorporated into the explanation of how wings generate lift. He states that relying on the commonly accepted Bernoulli Principle explanation is invalid, because many wings do not have different curvatures on the top and bottom, such as certain aerobatic planes as well as balsa wood gliders.

The author also points out that the Newtonian “attack angle” argument has misunderstandings:

> There is one major error associated with the "attack angle" explanation. This is the idea that only the LOWER surface of the wing can generate a lifting force. Some people imagine that air bounces off the bottom of the tilted wing, and they come to the mistaken belief that this is the main source of the lifting force. Even Newton himself apparently made this mistake, and so overestimated the necessary size of man-lifting craft. In reality, air is deflected by both the upper and the lower surfaces of the wing, with the major part being deflected by the upper surface.

This article offers a great deal of detailed explanation as to how the two seemingly competing explanations can be used together to generate a clear understanding of how wings generate lift.

At this point it will be helpful to give a brief explanation of Bernoulli’s Principle: “(Bernoulli’s) equation says that the pressure plus ½ times the density times the velocity squared must always equal a constant value (in an open, continuous flow of fluid)”. (Smith, 1985). Thus, the density of the fluid (whether gas or liquid) also plays a part.

Airfoils and Airflow offers an extremely detailed analysis of the generation of lift and includes diagrams of wind-tunnel tests which show decisively the conclusions put forth in all the sources. It also presents some higher-order mathematics to defend its arguments. However, it was noticed that there is a statement within the article that goes against a generally accepted principle of physics. The article states at one point that “Another thing to notice is that suction acting on the top of the wing is vastly more important than pressure acting on the bottom of the wing.” The other sources state that there is really no such thing as “suction”, but rather only a difference in pressure. One side of a wing experiences lower pressure than the other, and the side with the higher pressure gets “pushed”.

How Airplanes Fly: A Physical Description of Lift is part of a Web site published by the Aeronautics Learning Laboratory for Science, Technology, and Research. The first paragraph states that:

> Almost everyone today has flown in an airplane. Many ask the simple question "what makes an airplane fly"? The answer one frequently gets is misleading and often just plain wrong. We hope that the answers provided here will clarify many misconceptions about lift and that you will adopt our explanation when explaining lift to others. We are going to show you that lift is easier to understand if one starts with Newton rather than Bernoulli. We will also show you that the popular explanation that most of us were taught is misleading at best and that lift is due to the wing diverting air down.

A Physical Description of Flight actually turns out to be How Airplanes Fly: A Physical Description of Lift in journal form, but this version is more recent and does include some additional graphics that illustrate the concepts more completely.

Based on the above descriptions of the generation of lift by an airplane wing, involving a differentiation of pressure (due to changes in air density) between the upper and lower surfaces of a wing, as well as the air creating a Newtonian action-reaction force on the wing, it is accurate to state that the concepts involved are abstract in nature:

> The concept of relative density (defined as weight per unit of volume or, more exactly, the ratio of mass to volume) … involves… combining two concepts to form a more abstract concept. … Density is a ‘second order’ concept, i.e., composed of two other previously formed concepts – in this case, weight and volume. While ordinary ‘first order’ concepts are induced or abstracted from concrete instances, ‘second order’ concepts are derived from two or more regular concepts. They are, therefore, even further

> removed from the concrete and even more abstract than regular concepts. (Gorman, 1972)

Further,

> Turning to the next degree of abstraction, one would include whatever concepts cannot be determined directly by the systematic manipulation and arrangement of objects, but require an ordering and comparison of at least two sets of values which derive directly from the manipulation of objects. Such an analysis would contrast properties such as heat, specific gravity or acceleration, with properties like length, number, speed, or temperature. This level is required to succeed with the problems discussed by Inhelder and Piaget (1958) several of which are concerned with reciprocity and inverse functions (law of moments in the balance, relation between size of object and distance from light source in projection of shadows, etc.). (Lunzer, 1979)

“Abstract thinking (is defined as) thinking that is removed or disengaged from the concrete; characterized by the ability to form pure abstractions and to reason on a purely verbal level.” (Gorman, 1972) The purpose of the current study is to not only probe individuals’ preconceptions/misconceptions about these abstract concepts, but also to consider the possible impact of the individuals’ level of cognitive development on their ability to think about these abstract concepts. The literature review for this aspect of the study focused primarily on Jean Piaget’s theories of cognitive development, drawn through the writings of several sources who have studied his work.

Piaget’s interest was primarily on the development of cognitive processes from infancy through adolescence. This current study does not concern itself with Piaget’s theories regarding early childhood thought processes (sensory-motor in infants and pre-operational in young children), but rather with the later stages of cognitive development, primarily formal/logical reasoning and its precursor, concrete operational thought. Concrete operational thought is defined as “The internal manipulations of objects that are (or have been) perceived; thinking that is dependent on the concrete, real world.” (Gorman, 1972). In other words, this level of thinking deals with manipulating real objects and seeing with one's own eyes what the effects are of that manipulation. Formal thought, however, involves notably different cognitive processes:

> Inhelder and Piaget characterize formal thought as essentially hypothetic-deductive. Its most distinctive property is the reversal of direction between reality and possibility. Specifically, the formal stage implies the ability to engage in abstract thought, that is, to deal with propositions, to generate hypothesis and subject them to empirical investigation, and to employ proportionality and combinatorial systems in problem solving (Arlin, 1975)

Additionally,

> …from 11-12 years to 14-15 years a whole series of novelties highlights the arrival of more complete logic that will attain a state of equilibrium once the child reaches adolescence at about 14-15 years. …The principal novelty of this period is the capacity to reason in terms of verbally stated hypotheses and no longer merely in terms of concrete objects and their manipulation. (Piaget, 1972)

Gorman (1972) continues this line of thought: The "ability to form pure abstract ideas, those which have no direct basis in the perceivable world, is one of the distinct advances of the adolescent over the concrete thinker." Other researchers in psychology have gone on to theorize that cognitive development continues beyond the fourth stage of the Piagetian model- formal/logical operations. They advance the possibility that cognitive development does not "level off" in the mid-teen years, but goes on throughout adulthood:

> This newly hypothesized fifth stage was named the *problem-finding* stage. Processes characteristic of this new stage would include creative thought vis-à-vis 'discovered problems', …the formulation of generic problems, …the raising of general questions from ill-defined problems, …and the slow, cognitive growth represented in the development of significant scientific thought.. (Arlin 1975)

However, it has been noted by researchers that not all adults move into even the fourth stage of Piaget's theory: "It has been widely demonstrated that only 50% of the adult population ever attains the Piagetian stage of formal operational thinking, the problem solving stage" (Arlin, 1975). Piaget (1972) noted in his later years that the transition into adulthood poses additional questions regarding cognitive development:

> …from a cognitive point of view, the passage from adolescence to adulthood raises a number of unresolved questions that need to be studied in greater detail.
>
> The period from 15 to 20 years marks the beginning of professional specialization and consequently also the construction of a life program corresponding to the aptitudes of the individual.

By this Piaget was referring to the fact that as adolescents approach adulthood, they begin to more clearly define their own areas of interest and expertise, and to start laying out their life course. This "specialization" likely has an impact on the further cognitive development of the individual.

This study will attempt to assess the participants' cognitive development levels and compare them to their responses in an interview regarding their understandings about how airplanes fly. The assessment of cognitive development will be made using the Arlin Test of Formal Reasoning (ATFR) (Arlin, 1984), which will place the participants into one of five cognitive development levels- concrete, high concrete, transitional, low formal, or high formal. Descriptions of these levels, from the ATFR test manual, follow:

> The levels are based on Inhelder and Piaget's (1958) description of performance by subjects on their formal reasoning tasks. In general the levels can be described as follows.
>
> CONCRETE represents performance on the formal tasks which is best described as providing no evidence of abstract reasoning and some difficulty with reasoning skills that are problem specific.
>
> HIGH CONCRETE represents performance on the formal tasks which is best described as providing some evidence of a systematic approach to problems but not evidence of forming a general rule or abstraction from

the problems. This level indicates some ability to classify and organize information but little evidence of the ability to make inferences.

TRANSITIONAL represents performance on the formal tasks which is best described as providing evidence of a systematic approach to the problems and some use of abstractions and inferences but the performance is quite inconsistent. The subtest score patterns of students who receive transitional scores (about ten percent of those tested) need to be analyzed individually to determine if the concrete or formal categories are best applied to their performance. If there is evidence of two or three schemes being present as represented by scores of 3 or 4 within each of the schemes, the subject is showing some evidence of formal reasoning. If the pattern is very inconsistent across the subtests then the subject is classified as high concrete. In all cases, rigid classification of students by levels who have received transitional scores should be avoided because of the inconsistency of their performance.

LOW FORMAL represents a performance on the formal tasks which gives clear evidence of three-to-five of the formal schemes being present in their thinking. They are capable of abstraction and of making inferences but need to be provided opportunities to develop thinking skills with respect to the other formal schemes.

HIGH FORMAL represents a performance on the formal tasks which gives clear evidence of most of the formal schemes being in evidence in their thinking. Reinforcement of these thinking skills, however, is still appropriate.

Following are more detailed descriptions of the reasoning skills tested for as described in the ATFR test manual:

Test Content- The items selected for the ATFR closely parallel the description of tasks employed by Inhelder and Piaget (1958) to clinically assess an individual’s ability to use eight specific concepts associated with the stage of formal operations. These eight concepts are called the ‘eight

> formal operational schemata’. They are defined by Inhelder and Piaget as: ‘…the concepts which the subject potentially can organize from the beginning of the formal level when faced with certain kinds of data, but which are not manifest outside these conditions…’ (1958, p. 308)

Further:

> The eight formal concepts by name are (1) multiplicative compensations; (2) correlations; (3) probability; (4) combinations; (5) proportions; (6) forms of conservation beyond direct verification; (7) mechanical equilibrium; and (8) the coordination of two or more systems of reference. …It is these eight concepts which underpin many of the tasks which are presented to Middle and High School students in their literature, social studies, arts, math, and science classes. They are presented as well in home economics and shop classes, and in business and media classes.

The detailed descriptions of each of the eight formal schemes/concepts will now be presented, as put forth on the ATFR test manual (Arlin, 1984), with each followed by a consideration of that scheme’s possible application to understanding flight and aerodynamic lift:

> MULTIPLICATIVE COMPENSATIONS (VOLUME) is the concept which supports the understanding that when there are two or more dimensions to be considered in a problem, gains or losses in one dimension are made up for by gains or losses in the other dimensions. An example of this is the concept of the conservation of volume. Since volume problems involve three dimensions (length, height, width) the correct solution to a conservation of volume problem requires compensation in terms of these three dimensions. In addition to volume problems, the concept of Multiplicative Compensations is required for students to understand density problems in general science…

Certainly, Multiplicative Compensations is applicable to understanding how wings generate lift as such understanding requires comprehension of the changes in air density, and thus pressure, of air flowing over and under a wing shape.

> CORRELATIONS (CORREL) is a concept that implies the ability of a student to conclude that there is or is not a causal relationship, whether negative or positive, and to explain the minority cases by inference of chance variables. Correlational reasoning leads to the conclusion that two events, variables, etc., are or are not related and in more sophisticated situations, to determine the strength of that relationship. Students use the concept of correlations when they consider whether or not there is a relationship between amount of sunlight and plant growth…

Some of the questions comprising the interview have to do with the role that various parts of an airplane have with its ability to fly. Based on the earlier interview mentioned in the introduction, it is clear that the participants may not necessarily make the connection (i.e. causal relationship) between the airplane's wings and the ability to fly. Also, another interview question asked if an airplane parked on the ground would "attempt" to fly if it faced directly into a strong wind. The participants may or may not make the connection that wings generate lift when air flows over them, whether due to the wing being moved through the air by engine power, or due to wind moving across a stationary wing.

> PROBABILITY (PROBAB) is a concept that supports the ability to develop a relationship between the conforming and the possible cases. Students use this concept whenever they figure the odds in games of chance… They are using this concept whenever they ask themselves the question 'What is the possibility that…?' or 'what's the likelihood that…?'

It is not believed that the concept of probability will be applicable to the understanding of how airplanes fly. However, an open mind will be kept in regard to this concept during the analysis of participants' answers.

> COMBINATIONAL REASONING (COMBIN) involves the concept of generating all possible combinations of a given number of variables, choices, events, scenarios when a problem's solution requires that all possibilities be accounted for. Combinational thinking supports student reasoning about colors in art, problems in genetics … and qualitative analysis problems in chemistry. Students use this concept when they ask the question: 'what are all the possible combinations (arrangements, permutations) of…?'

The concept of Combinational Reasoning may play a part in understanding how airplanes fly in that as the orientation of the wing to oncoming air (attack angle) changes, the lift produced by the wing varies.

> PROPORTIONAL REASONING (PROPOR) is the fifth formal scheme. It is defined as a mathematical concept which involves the ability to discover the equality of two ratios which form a proportion. Map drawing skills, making drawings (Feldman, 1981) and models to scale presuppose proportional reasoning…

While proportional reasoning is used by pilots when they plan flights with aeronautical charts, it is not clear that this concept is necessary for understanding how airplanes fly or wings generate lift.

> FORMS OF CONSERVATION BEYOND DIRECT VERIFICATION (MOMENT) and the seventh scheme, Mechanical Equilibrium, are more narrowly defined in terms of scientific concepts but they too have implications for other subjects in the curriculum. Forms of conservation

> beyond direct verification involves the ability to deduce and verify certain conservations by observing their effects and thus inferring their existence. When one plays billiards or pool, one such conservation concept is readily observed. If the cue ball makes a direct hit on another ball there is a perfect transfer of momentum. The cue ball stops and the ball which has been hit moves at the same speed as that with which the cue ball originally moved. No one has seen momentum, we only infer its existence from examples such as those observed on the pool table. There are many phenomena which we cannot observe directly.

Clearly, this concept is directly applicable to understanding how wings generate lift. One cannot “see” airflow over and under a wing, or the changes in pressure caused by an airfoil shape; one must infer these from observing how a wing acts. In addition, the Newtonian action-reaction of air bouncing off a wing, or a hand held out a car window, falls under this concept.

> MECHANICAL EQUILIBRIUM (MECHAN) requires the ability to simultaneously make the distinction and the coordination of two complementary forms of reversibility- reciprocity and inversion. The idea of equilibrium suggests a system of trade-offs of multiple compensations… This concept represents the coordination of many different sets of compensations so that a balance or equilibrium is maintained. Hydraulics, piston and many similar types of problems in science require this thinking.

Again, this concept is applicable to understanding how an airplane flies as there is a balance between the lifting force generated by a wing and the force of gravity pulling down on the airplane. Pilots also use this concept when determining the weight and balance of an airplane’s loading; if weight (passengers, luggage, etc.) is not properly distributed in an airplane, the airplane may not be able to get into the air, or worse, crash once airborne.

> THE COORDINATION OF TWO OR MORE SYSTEMS OR FRAMES OF REFERENCE (FRAMES) is one of the most complex schemes, and yet its applications are wide-ranging. It may well be the scheme which acts as a bridging concept between formal and any type of post-formal thinking (Arlin 1983b). The Coordination of Two or more Systems or Frames of Reference is the concept which requires the ability to coordinate two systems, each involving a direct and an inverse operation, but with one of the systems in a relation of compensation or symmetry in terms of the other. It represents a type of relativity of thought. A common experience for persons flying in airplanes is to hear the pilot comment that their airspeed is 540 miles per hour but that their groundspeed is 470 miles per hour. The two frames of reference for speed in this example are the work of the engine in the air and the progress that the plane is making relative to the ground being covered.

This concept is also applicable to understanding how airplanes fly and wings generate lift as lift is determined by the speed of the aircraft, as well as the attack angle of the wing. To go even further, the lift of a wing can be altered by adjusting the various control surfaces, such as ailerons, flaps, and elevators. An airplane moves on all three axes, so clearly this final, complex concept is at work.

Methodology

1. Participants

There were three participants- a high school student who had taken physics, a high school physics teacher, and a pre-service science teacher. The student and high school teacher were from an upstate NY school district in which the author lives; the high school principal helped greatly in obtaining these participants. The pre-service teacher was from a teaching program at St. John Fisher College, and was selected with the assistance of the author’s advisor.

2. Protocol

The data sources collected/developed were the Arlin Test of Formal Reasoning scores, interview recordings/transcriptions, participants’ drawings, and field notes as detailed below.

Arlin Test of Formal Reasoning

The interviews with the participants were preceded by the administration of the Arlin Test of Formal Reasoning to gauge the participants’ level of cognitive development. The five levels of cognitive development tested for, from concrete through high formal, were described in the literature review. Following are selected additional items from the ATFR test manual (Arlin, 1984) describing the test:

> The ATFR consists of 32 items organized into 8 subtests. Each of the subtests represents one the eight formal schemes. All items are presented in a four-response multiple-choice format and the answers are recorded by the subjects on a standard answer sheet. The test booklet is made up of a front page, a general instructions page…, and 14 pages of test items. A portion of each test page is allocated to a line drawing that represents to problem in graphic form. This is followed by the multiple choice items which relate to that drawing. Each item is followed by 4 possible answers. Wherever applicable a basic problem is posed in the first item, an answer is elicited and then the second item requires the selection of a category of explanations that the subject most closely associates with the answer. This procedure of a problem posed followed by a rationale for the answer

chosen is analogous to the use of the clinical method in the use of individual interviews to assess formal reasoning.

A time allowance of 45 minutes was planned for each participant to complete the ATFR, and it was scored after the interview using the answer sheets included in the ATFR test kit. These scores include the overall cognitive level, as well as specific scores for each of the eight subtests representing the eight formal schemes.

Interview recordings/transcriptions

As previously mentioned, this study grew out of an earlier paper in which an interview was conducted to probe an individual's misconceptions about how airplanes fly (although the cognitive development aspect was not included in that paper). That interview brought to light several practical problems in the recording of the interview. A basic Sony M-427 micro cassette recorder with a built-in microphone was used to tape the interview, and the most significant problem was that the voices were drowned out when a fan was turned on (as described below) and the conversation was completely unintelligible when playing the tape back for transcription.

For this study's interviews, two Sky SDM-788 wireless lapel microphones were used, which it was hoped would assure a clear recording of the conversations. The recording device was a Sony TC-FX600 stereo cassette deck using standard cassette tapes. This was also used to play the tapes back for transcription. In addition, the previously mentioned micro-cassette recorder was used as a back-up, and the interviews were video taped using a Sony CCD-TR81 Hi-8 camcorder. The value of having redundant recording devices cannot be overstated- the Sony tape deck failed during the final interview, and the transcription was made from both the micro-cassette recorder and the video camera.

Additional equipment included several sheets of paper, a standard electric fan, a paper airplane, a Styrofoam model wing that had curvature similar to actual airplane wings, a piece of corrugated cardboard cut to a similar shape as the Styrofoam model wing (in plan view, not in cross-section), a small carpenter's line level, and a sketch pad and writing/drawing utensils. The small carpenter's line level was included so that the participants could gauge the levelness of both the cardboard and Styrofoam wing models and make comparisons between the two.

The participants manipulated materials, verbalized explanations, and drew their ideas. Questioning began by asking the participants what their experience with airplanes was- whether they ever flew on one, knew anyone who's a pilot, had a toy airplane, glider, radio control model, etc. Questions were then asked about what they thought made the airplane get up into and stay in the air. Questions concentrated on issues surrounding airplane wings. After establishing what their general understanding was, manipulatives were brought into play, such as blowing over a piece of paper held in the hands at one end, and allowed to bend down, the blowing causing it to rise; blowing between two pieces of paper causing them to come together; and holding airplane and wing models in front of a fan to feel what the reaction was. The subject verbalized what they perceived to be happening as well as drew it.

Following is the interview 'script' that was followed for all three participants; there were specific questions tailored for each participant also, which are included at the beginning of the analysis for each participant:

General Interview questions:

- Have you ever flown on an airplane?
- Do you have any ideas about what makes an airplane fly and go up into the air?
- when you've flown on an airplane, describe to me what happens when the airplane takes off
- Are there any other parts of the airplane that you think are very important to the airplane being able to get up into the air?
- Is there any particular part of the airplane that you would think of as being very critical to being able to get up into the air?
- What does "Lift" mean to you?
- Is there a part of the airplane that has more to do with lift than another?
- Aerodynamics, what does that mean to you?

- Have you ever held your flattened hand out of a car window while the car is going down the road?
- If an airplane is parked on the ground, and there’s a really strong wind blowing right into the front of it, would that airplane try to fly?

Move into wing models

- Tell me what you notice as far as similarities and differences between those two models, and could you describe them?
- Do you have any ideas on why that curve is in that wing, and why that looks more a real airplane wing? Would that make a difference over the cardboard in anything?

Turn on fan, begin with cardboard wing with line level, describe sensations felt as “wing” is pivoted slightly up and down. Then Styrofoam wing, same thing. Describe what is happening.

Move to paper with cardboard attached. Predict what will happen when cardboard is raised into the air stream. Try with blowing over it with breath, don’t use fan. Have piece of paper without cardboard strip too.

- Describe what is happening if no air is blowing under the paper; how is paper rising?

Now 2 pieces of paper held vertically, to blow between. Make prediction of what will happen. Blow between them and describe what actually happens.

Move to drawing of wing shape. What does it look like?

- pretend that this wing is a plane flying through the air, and what's going to happen, this is the front edge here, and what do you think is going to happen to the air at that front edge?
- Can you draw what you mean with those colored pencils there? Use whatever color you want…
- let's pretend that this is going through the air, that there's two particles of air, two little bits of air, one's right above the other, and that wing shape comes along, one goes over and one goes under, can you somehow, using different colored pencils, describe for me what you think is going to, how are those two going to move? are they going to be the same, are they going to be different as one goes over and one goes under?
- ok if you took the regular wings off of an airplane, and just put a couple sheets of plywood on there, do you think the airplane would fly?

Move to paper airplane

- What is this?
- Throw it, what happens?
- Is it flying?
- Why or why not?

Complete interview, jot down field notes.

Participants' drawings

The participants were provided with a prepared drawing of a typical wing section, showing more curvature on the top and less curvature on the bottom. They were asked to verbalize and draw what they thought would happen to a parcel of air that is split at the wing's leading edge, and how one "piece" of that parcel would travel over the top of the wing compared with the “piece” that travels underneath. This method worked well in the previous interview. The high school physics teacher and pre-service science teacher also made additional drawings to describe certain ideas they were verbalizing. See figures 10 through 14.

Administering the ATFR and conducting each interview took about 2 hours for the high school science teacher and the pre-service teacher; the ATFR and interview with the high school student went much faster, taking about an hour total.

Field notes

On completion of each interview, field notes were taken to record anything of significance relating to the administration of the ATFR and conduction of the interview. These notes were scanned into an electronic format and are included at the end of this paper as figures 23 and 24 (John interview), figures 25 and 26 (Jane interview), and 27 and 28 (Joan interview).

Analysis

Each of the three interviews was analyzed individually, and results on the Arlin Test of Formal Reasoning were considered in relation to the participant's responses during the interview. The three interviews were considered all together, and similarities and differences were examined; this is presented in the discussion. The names of individuals have been changed to protect their privacy.

John

The first interview was conducted with John, the physics and earth science teacher at Bloomfield high school in upstate New York. The author happens to live in the Bloomfield School District, and knows the high school principal, Mark, from several years ago when the author taught technology education at another local district, where at the time Mark was middle/high school assistant principle. Mark was very helpful in arranging the interview with John.

The interview was conducted after school on the afternoon of Thursday, January 16, 2003, in John's classroom. The first thing was to read a prepared introductory statement that had a general paragraph regarding the overall expectations of the session, followed by a paragraph specific to the Arlin Test of Formal Reasoning, which led directly into the ATFR instructions. Once the participant was engaged in taking the ATFR, the recording equipment was set up, including stereo cassette tape deck, wireless lapel microphones, micro-cassette recorder, and 8mm video camera on tripod. Also, other equipment was set up including a table-top fan, and all necessary manipulatives and drawing utensils. Set-up took about 15 minutes, and John took about 23 minutes on the ATFR. Results of the ATFR will be presented after the discussion of the interview.

Each interview began with a brief introduction: "As I have explained, this is helping me out with a project for my graduate program. I'm going to ask you some questions, it is not a test, there are no right or wrong answers, the whole purpose of this is to help me understand what your understandings and beliefs are about the subject I'm going to ask you about." Then, preliminary questions specific to each participant were asked, in order to get some feel of their background and potential knowledge of airplanes and flight. In the case of John, these were:

- How long have you been teaching?
- Did you do anything else before becoming a teacher?
- How long have you been with this district?
- What subjects do you teach?
- What is your favorite subject to teach?

References to specific lines in the transcriptions will be in the following format: Ty, Lx, in which y is the specific transcription (1 for John, 2 for Jane, and 3 for Joan) and x is the specific line number(s) referenced in that transcription.

John has been teaching since January of 1997, all of it at the same district (T1, L13-14) and he did quite a variety of other things, after gaining his degree in Industrial engineering/marketing at Clarkson in 1986 (T1, L 34 & 26):

> "Uh, well, let's see, if we just go back to when I got out of college, I was a uh sales engineer for a small firm in Rochester that looked like it was about to go out of business at any point because they were doing all kinds of dumb things, so I left there and I uh, was a uh quality control supervisor at a canning factory for awhile and I uh sold reverse osmosis water systems door to door for awhile and the main thing I did between uh when I went back to college uh, I graduated actually in college from Clarkson in '86, and went back to Oswego in like '88 to take education courses and student teach, and uh, I worked at ARC which is uh, basically working with people with disabilities from like 1989 until '97, y'know starting out as a uh, y'know basically a counselor at one of the houses and being vocational evaluator and uh, rehab counselor and things like that at the clinic they had over here in Canandaigua. And I came from there to here so… I've done a few other things." (T1, L21-32).

John enrolled in SUNY Oswego to pursue his teaching certification in physics "because that's where most of the, uh, coursework was relevant that I'd already taken, it was the shortest path." (T1, L 36-37) He is currently working on Earth Science certification (T1-L39), and he has taught a variety of subjects: "I, uh, taught a bunch of different things, right now I uh teach AP physics, regents physics, uh, sort of a self-contained earth science that's at the regents level but it's got a special ed teacher in here to help keep the kids organized and make sure they follow through on stuff and then I've got one section of uh regents earth science and some labs that go with those." (T1, L 43-47). He teaches 9th through 12th grades (T1, L49) and his favorite subject to teach is "earth science I really enjoy more, it's maybe more to do with the kids than with the uh, the subject, the 9th grade kids are more enthusiastic, the seniors tend to get senioritis by now… and they sort of lose their enthusiasm for the subject" (T1, L51-55)

The interview then focused in on John's experience with and understanding of airplanes and flight, beginning with asking if he had ever flown on an airplane (T1, L57) which he answered in the affirmative (T1, L58). We then moved into his general ideas about flight: "what are your ideas about what makes an airplane fly and go up into the air?" (T1, L59) to which he answered at length:

> "well, it depends upon first of all y'know what kind of airplane, if we're talking about propeller driven versus jet airplane, uh, you need some method of getting the uh the plane moving forward relative to the air mass that it's in so that you have a flow of air over the wing surfaces, because the wing surfaces are flat on the bottom and curved on top you have a faster flow of air above the wing than below it because of Bernoulli's Principle that fast, uh, flow in a fluid is a place where there's a lower pressure, you have a lower pressure above the wing than below and therefore the net force is upwards y'know based upon the relative speed and the surface area of the wing and things like that and that if you can get going forward fast enough that your lifting force is greater than the weight of the airplane it should take off, so that's sort of what I think and y'know you have the jet engine pushing action reaction forces or the propeller kind of turning its way through the air that would uh y'know tend to pull it forward" (T1, L60-71).

It was interesting that he mentioned Bernoulli's Principle right off the bat, and he also mentioned action-reaction forces (Newton's third law) but he never mentioned Newton by name. In fact, it will be seen later in this analysis that despite several more references by John to action-reaction forces, he never once mentions anything about Newton or Newton's laws. As mentioned in the literature review, both Bernoulli's Principle and Newton's Third Law play a part in the generation of lift on a wing, with some differing opinions on their relative contribution to lift.

A question was then posed to have him expand on action-reaction forces, to which he responded:

> "well you have a situation in a jet engine for example you have the fuel being burned and ejected out of the back of the engine at a high speed every particle that's being ejected out is pushed on by the airplane and it pushes back so you have y'know equal and opposite forces going on there between the jet engine and the particles being thrown out of it. Um the same thing with the propeller I suppose it's turning through the air it's pushing on the air and the air pushes back and the net force then is forward" (T1, L73-78).

He mentions 'equal and opposite forces' but all in regards to a jet engine or propeller pulling or pushing an airplane through the air.

He was then asked to describe what happens when an airplane takes off (T1, L79-80) and he discusses various issues such as taking off into the wind (T1, L82-85) as well as increasing the speed until the lifting force is greater than the weight (T1, L87-88), and the use of wing control surfaces (T1, L89-90). He finishes by explaining that the landing gear are retracted to reduce friction (T1, L90-91) and he is asked to expand on that (T1, L94-96). His response is: "wind resistance, y'know the more things you have sticking down into the airflow y'know the more force it's going to take to push the airplane forward y'know once you get up off the ground you want to fold the landing gear up out of the way so that you have a more streamlined laminar flow of air around the fuselage and less turbulence around the landing gear and things that are down below" (T1, L97-101).

His mention of 'laminar flow' piqued the author's interest: "okay, I heard you mention the word laminar, explain that" (T1, L102) and John's response was:

> "well uh to explain it it would be sort of like when you have a flow of air um, [draws example of laminar flow on blank sheet of paper] as it goes around an object y'know say the surface of a wing if it remains in sort of a uh coherent streamlined pattern like that without any turbulence that's what we call laminar or streamlined flow the way you'd see that in engineering would be to put the object into a wind tunnel and either have ribbons attached to it or let dust or smoke blow past it and you would observe that now if you have an object that's got a lot of

> turbulence because of its shape you'd see these eddy currents kind of forming around behind and that would y'know that kind of flow is a non streamlined flow where you get a lot of friction because of that and that will tend to happen more as you go faster and faster that you get that kind of thing" (T1, L103-112). (See figure 11 for his drawing).

The preceding questions and answers showed that John had a solid understanding of the traditional physics explanations of flight, i.e. that Bernoulli's Principle describes the lower pressure in a fast moving fluid (gas or liquid) versus a higher pressure in a slow moving fluid; also that the wing shape, being curved on top and "flat on the bottom" causes air to move faster over the top causing the lowering of pressure above resulting in lift. Additionally, John knew that the air flow around a wing had to be smooth, or laminar, to produce lift; eddies and turbulent air flow destroy lift and cause friction, or drag. However, his statement that "the wing surfaces are flat on the bottom and curved on top" did indicate that he was not aware that wings are not necessarily flat on the bottom. Also, he did not as yet give any indication that Newtonian forces played a role in the generation of lift.

The subsequent questions and answers (T1, L113-147) expanded on the previous questions, by asking John more about the parts of an airplane critical to flight (the wings again, as well as propulsion sources and control surfaces), and about the meaning of the words lift and aerodynamics. One particular sentence in his explanation of lift caught the author's attention, as it showed the common, and mistaken, belief by the vast majority of people that air flowing over and under a wing must meet back up at the trailing edge of the wing; as explained in the literature review, the air flowing over the top reaches the trailing edge *well before* the air flowing underneath, and they never meet up again. John stated: "that's basically the idea that if you have two air molecules meeting at the leading edge of the wing they want to meet again at the back and if they want to do [fingers of left hand demonstrate air movement around wing top and bottom] that the one on top has to go farther because it's a curved wing and therefore they have to go faster to reach the back at the same time" (T1, L136-140).

The interview then shifted gears a bit, by asking if John had ever done the common practice of holding one's hand out the window of a car as it goes down the road

(T1, L148-149). Also, the idea of holding a flat board out of the window is considered, and the responses are quite revealing-John discusses the action-reaction forces of the air pushing his hand, or a board, up and down depending on the angle it is held at, but he does not make a connection between that and Newtonian physics, instead attempting to explain this in terms of aerodynamics and Bernoulli lifting forces:

> well I mean you can actually as you hold uh your hand out of the window [demonstrates with right hand extended with arm moving up and down, and hand changing "attack angle"] if you have a slight upward incline on the front edge of your hand you can feel the air trying to pull your hand up and if you tilt your hand that way [tilts hand down] you can feel it pulling down so you can kinda get a sense that air can provide a lifting or pushing down type force depending upon the angle of attack that your hand has as you get into it… and the other thing that we noticed is the faster you go the more noticeable that is (T1, L155-163).

Based on the previous discussion, John's answer begged a question to clarify his understanding of the forces at work here: "okay, is that due to an aerodynamic lifting force?**"** (T1, L164) and John's answer: "[pauses and thinks] yeah I'd say so". (T1, L165) The following passages in the transcription (lines 166-186) are copied here as they provide a good insight into John's fixation on aerodynamic forces (i.e. Bernoulli's Principle) causing the lifting of a flat hand or board being held in a wind flow, although John describes Newtonian action-reaction forces yet never mentions Newton (underlines are added for emphasis):

> **P1-** y'know because the more you cup your hand [demonstrates with right hand] the more you have a shape that's like an airplane wing and the more noticeable it would be yeah I would say so
>
> **I-** okay, how about if you kept your hand perfectly flat?
>
> **P1-** like that you mean like somehow I had just a flat sheet [demonstrates with hand]
>
> **I-** yeah
>
> **P1-** well then you would still yeah because you'd still have an aerodynamic effect but not because of the same reason I think cause it's kind of slicing through the air

> and [pause] yeah but I'd still say there would be a lifting force... because of the angle
>
> **I-** ok, uh because of the angle?
>
> **P1-** yeah, well y'know even if you took a flat board and hold it out the window y'know you would notice when you point it down that there's that the air is striking more directly on that surface and it's going to push it down and if you hold it up y'know it's going to push it up because the air is hitting one surface a lot more than the other
>
> **I-** and that's an aerodynamic lifting force?
>
> **P1-** I don't know… if I it's not the same reason I don't think now that you mention that it's definitely due to the interaction of the air molecules and the surfaces but it's not for the same reason that a wing would have lift I don't think [pause] I don't know

The author found it fascinating that a certified physics teacher with 6 or more years of teaching experience, and an undergraduate degree in engineering, would be so fixated on the concept of aerodynamic lift for a flat board rather than action-reaction forces, despite the fact that he was actually *describing* action-reaction forces. It goes to show how ingrained our society is in believing that Bernoulli's Principle is the sole explanation for a wing's generation of lift, rather than a combination of Bernoulli and Newton (and that's just for those people who have some grasp of the physics of flight, which most people don't have at all.) Indeed, until researching this project, the author held exactly the same beliefs despite earning his private pilot's license in 1985.

The interview then switched to considering whether an airplane parked on the ground would try to fly if a strong wind was blowing directly into the front of it (T1, L187-203) and John states that if the airplane is not tied down, it would probably just blow tumbling away, but if it was held by a rope it would act like a kite and indeed rise into the air. He drew his thoughts on this as well (figure 11).

The next phase of the interview involved the use of manipulatives- specifically a Styrofoam wing from a Styrofoam model airplane, which had a curvature to the top like a real wing; and a cardboard wing flat on top and bottom, but cut out to match the plan shape and size of the Styrofoam wing. First John is asked to describe similarities and differences between the two (T1, L204-206):

> well, the, the length of the cardboard wing and the [holds wings together] Styrofoam wing is just about the same and these are y'know front top yeah they're oriented the same which would mean that the amount of surface area on the bottom of the wing would be about the same… [picks up cardboard wing] this one's the same thickness all the way through when you look at it from the end there's no curvature or anything else to it it's just a flat uh basically flat piece of cardboard and y'know there's a slight downward turn but that may well have been from y'know transporting it or something like that so that's pretty flat… this one [picks up Styrofoam wing] as we look at it uh well this section here is flat [end of wing model that gets inserted into model airplane body] but I suspect that may be the piece that gets stuck into the airplane body… the rest of it here it's flat on the bottom curved over the top which would mean y'know <u>like I talked about a few minutes ago that a piece of air if it went over the top of the wing versus over the bottom it would have to go faster over the top to get to the back edge at the same time that its partner went y'know along the bottom they gotta go a bigger distance in the same amount of time</u> it's going to be going faster and therefore less pressure above the wing so I'd say this one would generate more lifting force out of the two if we were to put them into some kind of thing and, and try them at different angles and things like that [holds both wing models in opposite hands in front of himself, moving them in the same ways to demonstrate various attack angles] y'know had some way to measure the forces… and this one has imprints of y'know simulated control surfaces on it I suppose, this one is a lot less dense [referring to Styrofoam wing] I would say like if you were to look at the weight versus area (T1, L207-232).

In the above passages a pertinent section was underlined to again emphasize John's being stuck on air flowing over and under a wing meeting back up at the trailing edge. John then proceeds with some unexpected (but not unsurprising as he is a physics teacher) experimentation on the wing models involving determining relative mass by weighing them in his hands, and determining relative centers of gravity by balancing the model wings lengthwise on a pencil. They both balance at about the same point, which surprises him as he expected the larger mass at the end of the Styrofoam wing model, where it inserts into the model plane body, to cause a different center of gravity from the cardboard wing (T1, L234-242).

The author then asks John if the curvature on the Styrofoam wing would make any difference over the flat cardboard wing (T1, L243-245), and John's response is:

> yeah, I, I think y'know in terms of what I've talked about already in terms of Bernoulli's Principle that if you wanta have uh faster airflow over the top of the wing than the bottom you have to have the curved shape but if you go to an extreme with that say that you had something that was basically like a half circle y'know perfectly round on top [holds Styrofoam wing in left hand and describes a semi-circle over it with right hand] and flat on the bottom that wouldn't work out very well as a wing even though the air going over the top would have to go a lot faster you would have no longer have the streamlined aerodynamic flow you would have turbulence so you wouldn't get your lifting force so… (T1, L246-254)

In the above passage John explains that there is a limit to the amount of curvature that a wing can have; too much curvature, approaching a semi-circle, would destroy the aerodynamic airflow. The next step was to have John manipulate each wing model, in turn, in front of a standard table-top fan and describe what he was feeling as he did so. A simple carpenter's line level was provided to be held on a flat potion of each wing, so relative levelness and pivot angle could be gauged while manipulating each wing model. John's responses while manipulating the cardboard wing were:

> **P1-** well when you tilt it up you feel like it's trying to push up on the thing… and when it's pivoted so the front edge is down it feels like it wants to push it down… and when it's level it doesn't feel like it's doing much of anything… it kind of oscillates a bit, you can feel it vibrating up and down in a way
>
> **I-** ok, at what point in pivoting it up or down do you start to notice a ah, some kind of force on it?
>
> **P1-** well the more that you've tilted it, y'know, the more force is pushing back, but… it doesn't take too much, [pivots model wing slightly] the force seems to

> get bigger the more surface area's being exposed, but that's not surprising I guess… and it feels about equal up or down… it feels about equal either way [pivots wing model up and down several times] (T1, L277-294)

John is then asked to switch to the Styrofoam wing and describe what he feels with that one (**I** refers to author's responses):

> **P1-** all right, with it level you can feel this end of the wing [points to outer end and then demonstrates upward force with finger pushing end up] trying to pick itself up a little bit, notice the vibrations in it… some of that more, that really doesn't matter, well there's more force as you tip the leading edge up than there was for the cardboard I think, and when you tip the leading edge down boy, it really doesn't feel like it's pulling down as much. Let me try that, can I try it against the other one again?
>
> **I-** oh, definitely
>
> **P1-** [pivots Styrofoam wing up and down a few times in front of fan, then picks up cardboard wing and does the same, then picks up Styrofoam wing again and repeats with that] well, it's definitely different… it's almost like there's not as much surface area for the wind to push on, on the curved wing than there was on the flat one… and y'know when you have it angled up a little bit you don't have to hardly hold on to it at all, woops, if you don't drop it you can almost balance it
>
> **I-** [laughs] anything else that you notice, or…
>
> **P1-** the outer edge of the wing feels more like it wants to pick up, like it wants to rotate, like there's a torque on it… maybe if I hold it level the other way too [lengthwise] it would be better though [puts down Styrofoam wing and picks up cardboard wing again]
>
> **I-** go ahead and describe what you're feeling
>
> **P1-** well what I'm doing right now is I'm tilting, the wing's pretty flat to the fan but I'm tipping the outer edge up [outer end of the wing]… when I do it with this one it doesn't feel any different than it did when it was level… I guess it doesn't really feel much different with this one either [does same movement with Styrofoam wing], but it just feels like this one wants to pick up and go [Styrofoam wing], the other one really doesn't [alarm on I's palm pilot goes off] yeah, well it

> feels about the same amount of force. So I'd say that the Styrofoam wing feels like it could do a better job of flying an airplane than the cardboard one (T1, L296-330)

John did describe feeling some differences between the cardboard and Styrofoam wing, particularly that when held level, the Styrofoam wing did produce a sensation of lift, while the cardboard wing did not. Also, as the leading edge was tilted up, the Styrofoam wing seems to have produced a greater lifting force; however, as the leading edges were tipped down, he did not describe as much 'pushing down' force on the Styrofoam wing as on the cardboard wing. He also describes vibrations in the tip of the Styrofoam wing when held in front of the fan.

The next section of the interview involved two common 'tricks' often done in childhood- blowing over a piece of paper, and in between two pieces of paper held parallel and hanging down, which causes the first to lift up, and in the second case the two sheets to move together rather than apart. For someone unfamiliar with the ideas behind Bernoulli's Principle, these movements are contrary to expectations, and are a simple means of introducing the concept that as a fluid increases velocity, its relative pressure decreases.

ed was asked to perform both of these, each time predicting what would happen before hand. In each case he correctly described what would happen, and the theoretical basis for it, so the author will not go into detailed analysis of his responses here; the responses are in line with his previous descriptions of lift and Bernoulli's Principle. The reader is referred to T1, L333-382, for examination of this portion of the interview.

Then, a pre-made drawing showing a cross section of a wing was presented (see figure 10);John was asked to describe what it looked like to him: "well, I'd say it looks like a view looking in towards the body of an airplane from the outer edge of the wing, y'know, looking at the cross section of a wing I guess would be the best way to say it" (T1, L386-388). He was then asked to draw, using various colored pencils, the relative motion of air under and over the wing, as well as the various forces acting on the wing:

> **I-** pretend that the wing is on a plane that's flying through the air
>
> **P1-** all right

I- and, tell what you think is going to happen, with, this is the front edge or leading edge

P1- ok

I- what do you think is going to happen to the air at that front edge?

P1- what…

I- you can draw, sketch, with different colors if you want

P1- well ok

I- whatever you want to do

P1- let's say that we had two air molecules that were close to each other… and let's pretend for the sake of argument that maybe there's no wind that day, the only movement is because of the airplane… so the wing's moving forward and being as these two things are in a fluid uh, they're kind of fixed in relation to each other, and so as we go, time lapse, here goes this one and the wing's moving past it, and if this other one is going to keep up so that they can meet again at the back [sketching] they uh, have to take the same amount of time to go past the edge of the uh, the edge of the wing… if we had some way of measuring the path that they had to take, y'know with a string or something like that and actually measured these two distances y'know, we would see that the distance is larger on the top of the wing… than it is on the bottom and if we think about then, the velocity is distance over time, if they have to take the same amount of time there has to be a uh, above the wing, all right, so there has to be a higher velocity above the wing… uh, at least that's what I think will happen in terms of the air molecules as they move past the wing… is that what you asked me?

I- yeah, yeah what, um, can you sketch maybe with a different color what the relative forces are going to be, that that wing experiences, you had talked about some lifting forces…

P1- mm hmm, do you want all the forces acting on the wing or…

I- sure!

P1- ok, well the first thing that we'd have is that at the center of mass there'd be a uh, there'd be a force due to gravity which would be equal to mass, y'know this would be for the whole plane times the acceleration due to gravity so we've got a weight pulling it down, we have uh, a force equal to the pressure divided by the area of the wing up here and we'd have a [pencil breaks] oops sorry about that

I- that's ok, not a problem, that's my fault for sharpening them really…

P1- and there's your force equal to the pressure divided by the area down here and I've tried to draw these sort of like in relation to each other… so if the plane was just in level flight the two downward forces would be equal to the upward force and you would have a balance of forces there just keeping it at one level… uh, when I say pressure divide by area I'm saying that the pressure up here is less than it is down here because of the difference in the flow rates…

I- and graphically you're showing that by vectors

P1- by vectors yeah

I- ok, ok, all right

P1- and then the other thing we'd want to think about is uh, you'd have a uh, let's see, the plane's moving this way so there's a balance of forces between the uh, the force of the uh, propeller, or whatever it is that's driving the plane, minus the force of uh, friction we could call it I suppose which would be the uh, which would be y'know the uh air resistance I guess and, and these, if the plane's at a constant speed I have drawn them to exactly the same length to show that they were balanced y'know by the vector idea again [see drawing, figure 12]… uh, that's all the forces I can think of right now… if it was accelerating the propeller force would be higher than the friction force and so on… (T1, L389-456)

As can be seen in figure 12,John was drawing not only arrows representing vectors to describe the airflow around the wing, but also was writing down various formulas that related to the forces that would be on the wing and airplane. He definitely had a handle on the opposing forces on an airplane- lift vs. weight, and thrust vs. drag, although he didn't use all the terminology (friction instead of drag, propeller force instead of thrust). He also continued to state that the air flowing over the wing had to speed up so that it would reach the back edge at the same time as the air flowing under the wing.

The interview then moved into probing John's responses to some rather off-the-wall questions having to do with replacing the wings of a plane with flat sheets of plywood, and whether there was any way that airplane could then fly with plywood as wings, if they were tilted and so on. This proved interesting, as he continued to state that there would probably be some sort of aerodynamic effect but continued to miss the Newton 3rd law concept. In fact, although he at first stated that a plane with plywood wings would not fly, as the questioning continued he did start to believe that maybe if the plywood was tilted correctly, maybe it could indeed fly. The following are selected excerpts from this stage of the interview:

> **I-** ok ok if you took the regular wings off an airplane and stuck on a couple sheets of plywood instead, would the airplane be able to fly?
>
> **P1-** there are some airplanes that look pretty close to that but uh, let's see, just flat, so in other words it's the same top and bottom?
>
> **I-** mm hmm, just a sheet of plywood, go down to Chase Pitkin, buy a couple 4x8 sheets stick 'em on the sides...
>
> **P1-** no, I'd say I'd say not
>
> **I -** yeah?
>
> **P1-** I'd say not
>
> **I-** what if they were tilted some way?
>
> **P1-** [P1 pauses and thinks] I don't know, like you fly a regular paper airplane that you just fold up, there really isn't any curvature there but, uh… if it did fly it wouldn't be something I'd want to fly in [I laughs] I think because you get to any sort of speed the turbulence would build up pretty quickly and it wouldn't be a very pleasant thing to fly. I don't know, I'm going to stay with, even if you tilt it it's not going to work … **I don't think**… **although I couldn't really give you a detailed answer as to why.**
>
> **I-** ok, let's see, let's think about this as being attached to a real airplane again
>
> **P1-** all right
>
> **I-** if this wing, let's say is perfectly level with the ground, as the airplane is sitting on the runway
>
> **P1-** all right
>
> **I-** and then let's consider another scenario where as the airplane is sitting on the runway, this is tilted up a little bit
>
> **P1-** mm hmm

I- so that the leading edge is higher than the trailing edge back here… what are your thoughts about what the differences would be and how that wing would act?

P1- I think…

I- Let's say that we had two exact same planes next to each other going down the runway

P1- yeah

I- or uh, parallel runways

P1- yeah

I- and one had a flat wing, one had a tilted wing, the wing shapes themselves were exactly the same, the only thing changed between the airplanes was the angle that the wings were at

P1- so here's one airplane like that then the other one has the wing kind of tilted? [draws]… in relation to the body?

I- yeah

P1- now if you're looking at it from the front are both of the wings kind of straight across like that or is there

I- they would be, the only difference would be the

P1- angle of attack?

I- the angle of attack

P1- all right

I- tell me what angle of attack means to you

P1- well I would say that's the angle at which the wing is entering the surface, y'know, the fluid, be it air, or if you're talking about boats y'know, water or whatever, I think that if we looked at this situation here [draws], it would be that this airplane could take off at a lower speed… because…

I- that's the one with the greater angle

P1- **<u>yeah, the one with the greater angle, I think that that one would be able to take off at a lower speed, but I think if you were to look at the, the top speed would be less in that case because you're going to get the turbulent airflow happening at a lower airspeed because of that angle of the wing,,, if you go too extreme with that, like if you, it might make it easier to take off</u>**

> **<u>but you're not going to be able to go as fast once you get in the air…</u>** is what I think (T1, L457-518)

So here is a situation in which a certified physics teacher, with a degree in engineering, begins to allow that maybe an airplane with plywood sheets for wings just might be able to fly. This comment in no way is meant to belittle John; on the contrary it is a comment on our society that someone who really does understand Bernoulli's Principle and Newtonian physics can get caught up in connecting the simple Newtonian action-reaction effect of sticking one's hand out a moving car's window with the complex, combined effects of both Bernoulli's and Newton's theories that allow huge airplanes weighing thousands upon thousands of pounds to defy gravity, break bonds with the earth's surface, and soar into the skies. This will be addressed further in the discussion/conclusion.

The interview continued with consideration of paper airplanes and whether they actually fly or not. John mentions that he had his students do a lab on paper airplanes in physics, but the goal of the lesson was not about aerodynamics; rather, it was about design trade-offs in that you could make a paper airplane that stayed in the air for a 'long' time, or one that can fly a long distance, but not both. John begins by tossing a paper airplane provided by the author, and some discussion centers around the paper airplane stalling (T1, L537-545), and some various attributes of the plane such as size and positioning of the wings as well as the paper clip added for balance (T1, L546-579), and gets the provided paper airplane 'flying' fairly well. John then briefly describes how he was able to get it to 'fly' better: "I think that before when the paper clip was too far back it allowed it to rotate around the center of mass upwards [demonstrates with paper airplane in hand], that slowed it down, when it slowed down beyond, y'know, the stall speed the speed at which the lifting force wasn't sufficient it kinda just kinda fluttered down this has got it balanced more so the wing can kinda stay more level in the air" (T1, L581-585). The author pursued John's mention of lift in connection with the paper airplane:

> **I-** ok, now you mentioned the lifting force, tell me about that on this paper airplane.

P1- I don't know that this thing has much of a lifting force, I guess I'd like to see what it does in a wind tunnel

I- oh yeah! You just gotta push that in, there you go [P1 turns on fan and holds paper airplane in front of it]

P1- like it's really… unless you get sort of an angle at it, it doesn't feel like there's much lifting force at all

I- what keeps it up in the air then when you throw it, why doesn't it just drop down to the ground?

P1- well I think that the reason it doesn't just drop down on the ground is the same reason that doesn't just drop down on the ground [drops piece of paper flat, or parallel to the ground] that um, it is dropping down it's basically dropping at a slower rate than the acceleration due to gravity because you've got a wind resistance force slowing its acceleration down hey Ally [student comes into classroom selling something for a fundraiser, minor interruption] I think that this is more like a projectile than an airplane… and it's one that doesn't fall like a rock... I mean, there could be a little bit of lifting force but, but not as much as you would see if you built a different sort of airplane that had a y'know curvature to the wing like you would see there… if we had y'know another airplane with the same sized wings that we could somehow build out of something that would have that sort of wing shape I think you'd be able to measure a bigger lifting force whereas I think this just doesn't fall that quickly because for the same reason that this doesn't fall that quickly it's got surface area relative to its weight… **like I dunno** (T1, L588-616)

John's definitely on the right track by saying the paper airplane is more like a dart than an airplane, and the reason it doesn't just fall to the ground is the air resistance slowing it down, but he still allows the possibility that there may be aerodynamic lifting force somehow involved, and as the last line shows, he still isn't sure.

The planned interview ended at this point, but some previous comments John made caused the author to pursue additional questioning, specifically about the paper airplanes John had his students make for a physics lab. Most of the conversation here (T1, L617-699) is not directly related to the purposes of the interview, though it does make interesting reading in the transcription; John builds a paper airplane along the lines of one that his students made and tosses that several times, adjusting the wings and getting it to fly pretty well.

The author then asks whether aerodynamics was covered in John's physics classes, which they did to some extent: "well, yeah, we just did fluid dynamics in the AP physics which involves Bernoulli's Principle" (T1, L701-702).John then gets several things out of one of his cabinets, various model airplanes that he uses as teaching aids, which he demonstrates (T1, L 702-720). At this point John focuses on a model wing that was used to explore the shape of wings, and he realizes that it is not flat on the bottom, as he previously described wings as being:

> **P1-** [picks up AirHog wing] and we looked at the shape of the wing on this, it was the best thing I had, I have one of those Styrofoam jet gliders at home that has probably a better one but I didn't think to bring it in, <u>this actually has got [concave] curvature to the bottom surface too</u>
>
> **I-** <u>and what does that do to…</u>
>
> **P1-** **<u>well y'know I don't know</u>**
>
> **I-** <u>you were talking about flat bottom wings before so…</u>
>
> **P1-** <u>I think still if you were to measure the linear distance, bottom versus top, it's still gotta go farther over the top so I think the same principle is applying</u>, whereas this one really is more along the idea of what we were talking about [picks up package with another flying model airplane] with the uh, flat bottom, this one has some dihedral to it, which is the tilting in, towards the center [shows with hands in a "V" shape]
>
> **I-** ok, is that similar to what you were mentioning [I picks up paper airplane and flexes wings up a bit] here?
>
> **P1-** yeah, y'know, with the folding of those, I think it has to do with control, of the airplane, I'm not really sure… I just remember when I was a kid my dad was into model airplanes when he was a kid and so we used to build the ones out of balsa wood with the framework and all that stuff… and then we'd fly them two or three times and they'd break, and I remember he had these blocks that he made to get the right, sort of angle there [uses right hand to demonstrate angle of wings

> coming up from body of plane] when he was making the balsa gliders and stuff, so I know that sort of idea is important to the flight characteristics… I think more in terms of stability than actually the, lifting (T1, L721-745)

As can be seen, John also mentions the dihedral angle of the wing, which is an upward angle from the body of the plane out to the end of the wing, which helps provide stability. However, while John does believe that this angle provides stability more than lifting force, his experience with this is making model airplanes with his dad when John was a kid.

At this point the author has another line of questioning pop into his mind, and he wonders why he didn't think of it before:

> **I-** have you ever been to an air show? [this question was asked "off the cuff"]
>
> **P1-** oh yeah, yeah I love airplanes
>
> **I-** yeah?
>
> **P1-** yup
>
> **I-** yeah, I've been to air shows too, and um, one thing that's always amazed me is those airplanes that fly upside down, how the heck do they do that?
>
> **P1-** [thinks for several moments] yeah, because what we're looking at here is we've got the, uh, different lifting forces, I think that if you're looking at one flying upside down, [picks up Air Hog wing again] normally this would be flying in this sort of attitude, [flips wing upside down and holds it with more of an up angle] I think if they're upside down they have to kind of angle the nose, well from their perspective down, but from the ground kind of up, to give the different angle of attack of the wing surface through the air… you can't do it forever I don't think, like I don't think they could keep flying upside down for a really long time, maybe I'm wrong, but they'd have to have that angled in such a way like this so that you did have an upward, upward force
>
> **I-** mm hmm, what if I told you that as long as the fuel could still get to the engine they could fly upside down forever?
>
> **P1-** yeah I think that you're right now that you say that, I believe you
>
> **I-** how, how would you explain that?

P1- well, basically, at whatever speed they're doing it, that angle must provide enough lifting force to keep the airplane flying at that height, because if they were constantly coming down [demonstrates with hand] they wouldn't let them do that any where near the ground and they usually do a near-ground pass like that so it must be that they can hold it level, not only hold it level but actually steer it up like that… yeah, I believe you…

I- what would be the aerodynamic lift, provided, in that case?

P1- [pauses and thinks for a moment]

I- or would there be aerodynamic lift?

P1- well yeah, obviously there would have to be but… it has more to do with the angle [holding model Styrofoam wing] effect than it has to do with the curved surfaces effect I think at that point…

I- now you mentioned the angle effect before, can you explain that a little bit more…

P1- well like when you have your hand out of a window, when you angle your hand upward, it lifts it up, when you angle it down, it pushes it down… [demonstrates with hand]

I- ok, that's not, are you saying that that's not Bernoulli's Principle, or is it?

P1- [pauses to think] Bernoulli's has just to do with a different velocity… of the fluid on one side of the surface from the other…[thinks for several moments] **it may well still be, but for a different reason, I think**… like if you have a bigger angle like that the air that's hitting here [points to underside of his hand] may be getting slowed down a lot cause it's kind of like hitting a wall, and the air up here isn't, **so it could still be a lifting force, and if that's the case then maybe my answer about the plywood, flat wing could be wrong** (T1, L746-790)

As can be seen in these passages, John struggles with the concept of airplanes flying upside down. He continues to attribute flying in attitudes other than normal, upright flight as being due to something other than Bernoulli's Principle, or at least "some other" explanation of Bernoulli's Principle. He believes it has more to do with the angle, as when holding one's hand out the window of a moving car (i.e. pure Newtonian physics). As he thinks through the (incorrect) possibility that lift may be provided just by air bouncing off the underside of a wing, he begins to question if his statement about an airplane with plywood wings not being able to fly was actually true!

As the interview winds down, John mentions that there are certain types of planes he has always been fascinated with, including the French Mirage and the Harrier Jump-Jet. However, he confuses the Harrier's vertical take-off and landing abilities (due to the pilot's ability to direct the jet engine exhaust into a vertical direction) with lift: "they can basically, their lifting force can be supplied just by an engine pushing down" (T1, L802) When in fact, the 'engine pushing down' is used just for take-offs and landings; when the Harrier is in the air, the pilot rotates the engine exhaust cowlings to create forward thrust, at which point the wings generate lift and the Harrier is like any other fighter jet.

The author and John then engage in a general discussion of the general knowledge and understanding kids get about various parts of our society, as well as constraints on classroom time that prevent kids from really applying and internalizing what they learn in school, before having to absorb even more information. The final conversation of the interview was interesting enough that it is included in its entirety here:

> **P1-** I think that probably kids don't really have an idea at all of why airplanes fly
>
> **I-** why do you think that is?
>
> **P1-** they are never taught it, really, like unless, I don't know how much they do with it in technology but not everybody takes technology… when we talked about the Bernoulli thing, I think that was a lot, a lot of them that was the first time they knew that there was a pressure difference if you had a difference in the fluid flow rate, that they hadn't really thought of as air being a fluid, um, that they just figured it was probably the angle, because that's what they felt when they stuck their hand out of the car, I don't know that a lot of kids have flown, or seen air shows or things like that,
>
> **I-** but airplanes are pretty commonplace in our society
>
> **P1-** yeah, you see them, you see them but uh, I don't know if they ever really think about what it takes to make one fly… it's too bad in a way, that they know, another thing, Doc, the chemistry teacher, was appalled today he was talking to me after school that how few kids know the voltage that's in the wall, so they don't know if it's a hundred and ten or whatever, or a hundred and fifteen volts,

they just like say whatever… they don't have any sense of how things around them work…

I- do you think that's a bad thing?

P1- well, yeah, y'know I think that a well-rounded person oughta know enough, well of course now there are so many things to know, but, uh, enough about all the different parts of their society that they could explain it pretty fully to anybody that was foreign to that society and I think our kids lack a lot of the fundamentals about how very basic things work, like water magically comes out of the faucet when you turn it on, y'know, those sorts of things

I- meat comes from Wegman's

P1- yeah

I- I agree, I know exactly what you're saying… well I think that I, uh, unless you have some more uh, anything else that you want to mention, or anything, that pretty much, uh, covers it for actual questions that I have

P1- yeah, all right, that's good, one thing we did think about doing a few years ago we were going to have high school teachers take their advanced kids, let them go down to the earlier grades and do demonstrations on stuff like this and I was going to always have them do a unit on flight and we even have a little resource book here somewhere on principles, basics of flight and things like that, but we never really had time to do it… it gets into the Regents time and then there's all these state tests, in fourth grade and eighth grade, and all these other things now, so there's never any time to let kids go and apply what they know, and sometimes having them teach it, they learn more about it than if you just told them,

I- well, you and I as teachers know that that's true, if you have to explain it to someone else, it tends to bring a lot more clarity for your own mind

P1- yeah, yeah, I guess that's about it, then

The interview ends here, after nearly an hour. The author expected it to take perhaps thirty to forty-five minutes, but was very pleased that additional information was given and tangents were taken by the participant. One cannot go into an interview like this expecting it to be predictable! While there was (and should be) a general script of questions, unexpected things pop up, and additional questions come to the interviewer's mind. The field notes made after this interview may be seen in figures 23 and 24.

Jane

The second interview was conducted with Jane, a pre-service science teacher who is working on her teaching certification at St. John Fisher College. The interview was conducted in the late morning of Thursday, January 30, 2003, in Jane's home in Victor, NY. As with John's interview, the first thing was to read a prepared introductory statement that had a general paragraph regarding the overall expectations of the session, followed by a paragraph specific to the Arlin Test of Formal Reasoning, which led directly into the ATFR instructions. Once the participant was engaged in taking the ATFR, the recording equipment was set up, as in the first interview. Set-up took about 15 minutes, and Jane took about 40 minutes on the ATFR. Results of the ATFR will be presented after the discussion of the interview.

As before, the interview began with a brief introduction, followed by preliminary questions specific to the participant were asked; in the case of Jane, these were:

- Why are you becoming a science teacher?
- Did you do anything else before becoming a teacher?
- How long have you been with this district?
- What subjects do you plan to teach?
- What would be your favorite subject to teach?
- What is your age?

Jane definitely has an interesting background. Currently in her mid thirties, she has arrived at the doorstep of teaching via a circuitous path. The first four pages of the interview transcription focus on her experience, and selected excerpts that illustrate pertinent aspects and answers to the above questions are presented here (note that in most cases where the author's response consists of 'ok' or 'mm hmm', these are not included here):

I- ok, well, uh, why are you becoming a science teacher?

P2- um, my main goal actually would be going into earth science to teach natural resource conservation and, uh, biological preservation, so that's sort of my focus in the long run… and, um, my degree was in wildlife biology, so I'm sort of staying on that avenue…

I- cool, so I take it you did some other things before you decided to become a teacher

P2- oh yes, yeah, I um actually was able to work for the uh, conservation of natural resources, um, for the natural resource conservation service, but that was back in Iowa… um, loved it, did habitat restoration with them, and then I uh, budget cuts came through, and I wasn't really anxious to go back to school at that time, so I ended up actually getting a certification in radiography… and was a CAT scan tech in a hospital, loved it, absolutely loved it, it was an incredible job, but when I moved out here, I wasn't real pleased with the health care system, and, ah, so I uh, got married, right away, and my husband and I decided to start a family, so, I quit my job to be a stay-at-home mom and I'm back in school! I always wanted to be a teacher it's just that now the opportunity's actually finally come up

I- why did you always want to be a teacher?

P2- I always wanted, I just felt that um, if you're a productive teacher you can touch more people and gain better, more results than what I could do, do for myself… you know, influence more people and hopefully have, make a positive change

I- so, how come you didn't become a teacher earlier? What is the impetus at this point?

P2- Uh, y'know I was um, getting ready, I had, and it took six years to get my bachelor's degree

I- that's nothing, it took me eleven

P2- [P2 & I laugh] and it was just a point you reach and, I'm like my gosh, I'm 26 years old, you know, I need to graduate, actually I lived overseas for a year, I went to New Zealand for a year, and actually worked on, uh, took some master's courses over there, in marine science, and that just sort of kind of lengthened my period of education, I just wanted to be done, and I went to Iowa State University and if I wanted to go into education, I would have to be in school for another two years and I just wanted to get out into the work force and take a break from things for a while.

I- I totally understand!

P2- oh yes [laughs] be a productive citizen

I- yeah, ok, so you've already kind of touched on this but what grade levels and subjects do you plan to teach?

P2- ah, well secondary, ah, earth science, environmental stud… actually some schools are instituting environmental studies programs, so I really hope to be able to go in that aspect, and biology, and hopefully one day I'd like to go up into administration

I- yeah?

P2- yeah, definitely, maybe even teach at a college level

I- oh, that'd be great

P2- so… yeah!

I- cool, and I think um, that the next question is what would be your favorite subject to teach? And I think you kind of alluded to that already

P2- oh yeah environmental science, environmental studies, definitely

I- ok are there any districts that you would prefer to work with, or…

P2- no, I don't think so, ah… I think, from students that I've talked to, I have nieces and nephews, well my husband's nieces and nephews that are, y'know in all grade ranges an um, as far as school districts, I'd almost like to teach in the inner city, almost

I- yeah?

P2- uh, I think that there's a lot of messed up communities there for them to understand, um, the world around them, and the environment around them, and it just seems that when people are able to connect outside of their immediate environment it really enriches them as a person and sort of raises them to a higher level of thinking, that, more privileged kids already have access to, and they do take it for granted, but, um, I just want to get kids out of that destructive nature, to have them more conducive to them being a more productive citizen, so…

I- very laudable goal!

P2- yeah, and I know I've got a lot of obstacles! [laughs]

I- yeah, it takes people who want to try and overcome them or there's no hope at all so…

P2- yeah, because I've been there, I moved a lot as a kid, and I've lived in inner city school districts to very prominent, well-to-do school districts, so I've had an opportunity to study in all of that, so it's kinda, I'm not going into this blindly

I- mm hmm

P2- well, I can say that and until I'm actually in it [laughs]

I- how soon is it going to be until you get your, so now you're in your initial, undergraduate teaching…

P2- yes

I- certification courses?

P2- exactly, I've only had three courses, and, uh, with my other baby on the way I'm not going to be, ah, I'm not real pressed for time to finish… my goal is to be done, or to almost to be done by the time they reach pre-school

I- mm hmm, oh ok

P2- so that, in about 3 to 4 years I'd like to be done, and get into the work force

I- at least to get your provisional certification?

P2- exactly, exactly (T2, L17-104)

Jane certainly has an interesting background with a strong interest in environmental studies and resource conservation, as well as an admirable goal of teaching these subjects to less privileged inner-city kids. She also has a definite plan, with her first priority being raising her own children and working on her teaching certification over several years until they are ready for pre-school, at which time she plans to enter the teaching work force.

The interview now moved into specifics about Jane's experience with flying:

I- … have you ever flown on an airplane?

P2- yes I have

I- ok, what kind of airplanes have you flown on?

P2- ahhhh, I've flown on 747s, 767, once, I've flown in little two-seater Cessnas… I've flown on, um, let's see, old, um, I forget the name, planes built back in the 50s, I've flown on a C47, um, let's see what else, basically kind of every make and model, yeah

I- cool, how old were you when you first flew on an airplane?

P2- that I can remember how old I was, I was, I can remember back to 2, I've been flying since then

I- yeah, with your parents and…

P2- yeah, flying with my parents, I didn't actually fly by myself until I was, um, how old what grade was I in, fourth grade

She has quite a bit of experience flying, from an early age. It was now time to probe her understandings of how airplanes fly:

I- ok, so do you have any ideas about what makes an airplane fly, and how it gets up into the air?

P2- I do, I do

I- tell me about those… what do you think?

P2- um, actually, it's uh, I think the real basic part of it [minor distraction from her son] was the design of the wing… and the shape of the wing, how it's curved on top and concave on the bottom, it's not actually flat on the bottom, so, what it does, the physics of air, as air rushes over the wing, the pressure is less on top and greater on the bottom and that provides lift

I- ok, so the pressure is less on top and greater on the bottom, can you elaborate on that?

P2- ah, as airflow, let's see, as air flows over the top it slows down, decreasing the air pressure, on the top of the wing, and as it flows underneath the wing it's faster, increasing the pressure, and the difference in the pressure provides the lift for the airplane

I- ok, ok, so I heard you mention the word lift, what does, uh, tell me more about what you think about lift

P2- what I think about lift… ah, as in like definition of lift?

I- sure, yeah, whatever

P2- oh, ok, ah, lift is um, the ability, I guess what it is is it's the force that raises a… raises an object off the plane, off the immediate plane… umm… and lift can be controlled, lift will vary depending on again the atmospheric pressure umm… airflow, the mediums you're going through… so… on a same principle, would be in a submarine, underneath the water, as to airplanes in the air (T2, L144-173)

This provides a fascinating insight into Jane's beliefs about airplane flight as compared with John's. Jane picked right up on the wing being the major factor providing lifting force, and she was aware that the curvature of the wing provides this, but she also stated that the wing was concave on the bottom, not flat. She did make the connection that these curved wing surfaces create a lower pressure on top compared with below the wing, but she states that air is moving slower across the top and faster under the bottom. As will be seen, this misconception continues throughout the interview until near the end, when she realizes her error.

As with the first interview, the next step was to ask the participant to describe what happens when an airplane takes off: "um, it increases, let's see, well you're increasing your, your speed, with the engine, and, um, as you pick up speed, um, again, you, you, get the physics of lift, on the plane, and when, I know when you reach a certain speed, you have generated enough lift or pressure differential on the wing to lift the mass of the plane up off the ground… so it's all y'know speed and uh, yeah, airspeed that um, that is influential, y'know, obviously you have to be going fast enough… to create the lift, for the pressure difference needed" (T2, L174-184) This was very straightforward, as she knew that in order to generate lift, a pressure differential had to be created by differing air speeds over and under the wing (even though at this point she thinks that air flows slower over the top and faster underneath) and that the airplane has to reach a certain speed in order for the lifting force to become great enough to take off.

After that came a question regarding Jane's thoughts about parts other than the wings, which would be important for an airplane to fly: "um, body shape, the streamline of the uh, of the, the engine, or of the plane itself… um, materials it's made out of 'cause you want to minimize your drag, which helps, um, let's see, you want to maximize the amount of lift that you can create, and I know that's why there are little winglets on the end of the uh, wings [P2 momentarily distracted by her son and gets up] um let's see, ah, I know that, or I don't *know* but I understand that the tail is mostly just for maintaining direction and stability of the plane in flight, so, I suppose the things would be the style of the fuselage, or the plane, and the parts it's made out of and weight, obviously you want to minimize your weight" (T2, L187-195). She understands that body shape and materials contribute to how much drag, or friction, is created. However, she then mentions winglets, which are in fact on some airplanes, and she mentions these again later in the interview and elaborates more on them. She also mentions the tail as maintaining direction and stability, which is largely true, although the direction of the plane is primarily controlled by banking the wings with the ailerons; the tail rudder helps to maintain the plane's body in a straight, or tangent, path around the direction of flight, and the horizontal stabilizer and elevators control level, up, and down direction.

Following a very brief consideration of gliders, which really did not provide any useful insights (T2, L196-208), the author pursued a line questioning to probe where Jane got her understanding about airplanes and flight from. When we first spoke on the phone to arrange the interview, she mentioned that her father worked in air traffic control, so we began with that:

> **I-** all righty, as I recall, when we first talked on the phone the other day… you mentioned that your father worked in air traffic control? …is that correct?
>
> **P2-** yup
>
> **I-** ok, tell me about that and what you learned about airplanes and flying as a result of that.
>
> **P2-** um, ever since I was little dad always to me up to, um, the airports, and we just hung around airplanes all the time… unfortunately, being an air traffic controller, I mean, he, he knows about planes and flight and the whole nine yards but he's not a real, um, he's not a real mechanical person, he's not a real hands-on person when it comes to airplanes so it was more of this is that type of airplane and this is that type of plane and here's the differences between them but not why they fly… so I never really learned anything about why they fly from him… just landing and taking off and all that kind of thing but it really just gave me an interest in it, especially the difference between um, um, propellers and jet engines

> what the differences were [phone rings, P2 answers it, momentary distraction] so that was it and then, um, I ended up dating a couple helicopter pilots and airline pilots and they're the ones who sort of explained the physics of flight… and I'm sure I learned something in high school but… that sort of runs right over your head, you actually see it and you see the drawings of the airplanes and they sort of explain a little bit of the principle to you… that was real interesting
>
> **I-** all right, so you kind of learned about, not so much in school, but from
>
> **P2-** yeah, just from people sort of explaining a few things to me and, ah, I know that ah, you know initially people wanted to mimic the flight of birds and instead of actually following the physics of ah, the structure of bird wings… and gliding… and, and um, so y'know obviously when everything relates back to nature I take a little bit more of an interest to it… and um… so y'know just a little bit of reading, asking questions and just trying to store little bits of information in the back of your mind (T2, L209-253)

So Jane's interest in planes started at an early age by being regularly exposed to them at airports with her father, and the fact that mankind's interest in flight and development of airplanes came from watching birds appealed to her interest in nature. However, she never really had any formal training in the physics of flight (that she could recall from high school); her understandings about flight came from having it explained by helicopter and airline pilots she dated later in life.

The next part of the interview was somewhat repetitious in that it continued to probe whether there were other parts of the airplane that had more to do with lift than other parts, and Jane repeated wings and rudders, but she also began to talk about friction and drag:

> **P2-** definitely, yup, and y'know you have your, your, rudders that are part of the wing that can increase or decrease drag or promote lift… slow the plane down speed the plane up, that type of thing, so…
>
> **I-** you mentioned the word drag, what does that mean?
>
> **P2-** ah, an increase in friction, an increase, yeah an increase in friction you're increasing your air pressure and you're increasing the friction which slows the

> plane down… so… and I know that using it to slow the plane down in itself is used in itself to increase or decrease the height of the plane (T2, L260-269)

Her explanation of friction having to do with increasing air pressure is unclear, but not totally incorrect in that higher air pressure indicates higher air density which would certainly increase friction and drag. However, the rudder does not really affect drag; drag generally is caused by things sticking out from the body of an airplane that disturb the smooth, laminar flow of air, such as antennae, struts, landing gear, etc. It can be argued that when the rudder is moved to one side or the other, it is disturbing the airflow off the tail section and hence contributing to drag, but many other parts of the airplane are as well; in straight-ahead flight, the rudder is usually in a neutral position, and thus is not contributing to drag.

The author wanted to discover what her understandings were regarding the term aerodynamics, and whether she was familiar with Bernoulli's Principle:

> **I-** ok, there's a word aerodynamics, are you familiar with that word?
>
> **P2-** yes I am
>
> **I-** ok, and what does that mean?
>
> **P2-** ah… aerodynamics, I know it has… they use it to describe the shape, like if something is aerodynamically… um… is conducive to, to air, to flow through the air… um, if something is shaped to be, hopefully to be maximized for speed… and less drag, less force of friction, so…
>
> **I-** mm hmm, when you were talking about <u>the differing speeds of air going over and under a wing, is there any… word, to describe that effect?</u>
>
> **P2-** you mean as in aerodynamics? [laughs]… or do you mean a word like to describe , umm… oh, that describes the air going over or under the wing?
>
> **I-** well… <u>is there something in science that is a term, that explains why that difference in pressure happens?</u>
>
> **P2-** I'm sure there is… um… hmmm… um… I know that there is, it's just not coming to me… the only thing I can think of is air pressure, but I know that that's not right, but, so I just kind of dance around it (T2, L270-297)

She certainly seems to have a general understanding of aerodynamics, but lacks the terminology to describe it fully; she also seems to be aware of a term (Bernoulli's

Principle) that explains differences in air pressure due to differing speeds, but does not have the term memorized.

We now moved into the questioning regarding holding one's hand, or a flat board, out of a car window as it goes down the road:

> **I-** um, have you ever held your flattened hand out of a car window while the car's going down the road?
>
> **P2-** oh yes
>
> **I-** ok tell me what happens there
>
> **P2-** oh yeah, well, y'know, obviously, when you increase the surface, when you increase the plane of surface to the direction of the air um, it blows your hand back and as long as you keep it level to the air, um, you can maintain, y'know, by doing this y'know, [demonstrates with hand] up and down, if you angle the, theJohnge downward um, the air will force your hand down, and if you angle it up, it will create lift… or y'know will blow your hand back, as long as you keep it level you can maintain a level through the air [continues to demonstrate with hand]
>
> **I-** ok, so you say, now we're talking about a flat hand here… which, um, maybe we can even think of it as, uh, because we can curve our hand, too… now, let's say we were holding say a board, just a flat piece of 1 x 12 or something like that, or plywood out the window… um, and I heard you mention lift, tell me what's happening there
>
> **P2-** with the board, or with your hand…
>
> **I-** well, a flat object…
>
> **P2-** ok, a flat object, as long as you um, keep it level with the airflow, then the pressure of the air will be equal above and below the board… which will maintain stable, along the same plane of flight… but when you, um, for instance if you tilt it upward, you are increasing the air pressure below, decreasing above, that's going to lift the board up… and if you tilt it downward, then the air pressure's greater above than below and it's going to force the board down… or your hand down (T2, L300-333)

Jane’s explanation is quite similar to John’s, in that she knew that by keeping one’s hand level, it would slice through the air easily, while by angling it up or down the force of the air would push the hand or board back and up or back and down. Yet as with John, she seems to relate the higher pressure on the bottom of the hand, due to Newton’s 3rd law, with the increase in pressure on the bottom of an aerodynamic wing caused by Bernoulli’s Principle.

The next step was to consider an airplane parked on the ground, with a strong wind blowing into the front of it:

> **I-** so if an airplane was parked there on an airport, tied down or not, if there is a really strong wind blowing directly into the front of that airplane, what’s going to happen, is it going to try and fly, or, what’s going to happen?
>
> **P2-** if, if it’s blowing directly into, the plane’s just stable and all, that if a strong wind is blowing, it’s going to try and lift the plane up, the front end will try and lift up a bit,
>
> **I-** mm hmm, and what’s going on there?
>
> **P2-** um, as I said, the under part of the wing is not actually flat, it’s a bit, a bit concave… and the top part’s curved so if you get airflow coming right at, because the way the front of the wing is designed it’s rounded… and, um, when you have airflow straight underneath you’re still going to create, airflow underneath, you’re going to have a pressure greater below, than above, and it’s going to try to lift the front of that plane up… ‘cause that’s just the nature, that’s just the way the plane is built um, **that’s why you have flaps on the back, to stabilize that when you’re in the air, because the plane actually doesn’t fly straight through the air, it flies at more of an angle, like, this [demonstrates with hand]… I know that when you fly, just due to the structure of the wings, and the plane…**
>
> **I-** can you tell me more about that angle, why would that have an angle…
>
> **P2- why it flies through like that? Um, the weight of the plane, number one, there’s a lot of weight in the back of the plane, which throws it a little bit off balance, and two, um, when a plane actually flies** [minor distraction from P2’s son investigating the video camera tripod] **when a plane actually, when it’s flying at an angle like this, what you’re actually doing is you’re equalizing**

> **the pressure above and below, on that wing, which is helping it maintain a stable flight if you were to have to fly through this way you create pressure difference which, um, in the lift of the wing which is going to try to lift it up this way** anyway so… [demonstrates with hand]… flying through (T2, L340-373)

Jane seems to start out on the right track here, as she appears to be saying that as long as there is airflow around the wing, lift will be generated, whether the air flow is due to the plane moving through the air, or the air moving past the plane. However, she goes off on a tangent (underlined and bolded text above) with flaps providing stability, and the airplane flying at an angle due to more weight in the back of the plane (planes should be carefully balanced around an imaginary axis running from end of wing to end of wing, otherwise the plane will likely crash). So the author is not sure at all where she was going with the plane flying at an angle and so forth; it definitely points to a significant misconception about how airplanes fly.

During John's interview, the author came on the idea of asking about air shows, and planes flying upside down, toward the end. After that, the author incorporated this question into the early stages of the interviews. Jane's answers to how airplanes can fly upside-down were somewhat confusing, and primarily focused on flaps and the rudder, as well as pressure differences on different sides of the wings. The reader is referred to the transcription, T2, L374-400, to read her explanation, if desired. The author did notice her continuing to talk about the rudder and flaps, while not mentioning the proper terms for other movable control surfaces such as ailerons and elevators. So, questions were directed toward probing her understanding of these:

> **I-** what are flaps and what do they do?
>
> **P2-** flaps, flaps um, they add um, they add a flexibility or availability to… to monitor or differentiate your lift patterns because the wing is fixed, you can't change that, so what the flaps will do is they either increase drag or they decrease drag or they change the momentum of the airplane
>
> **I-** mm hmm, where are flaps located?
>
> **P2-** flaps are located, you have them on the back, on the tail, and then you also have them on the very back of the wing

I- ok where on the back of the wing itself are they located in relation to the body, where the wing attaches to the…

P2- they're closest

I- closest

P2- they're closest to the body

I- ok are there any other surfaces that move on a wing?

P2- ah, other than the flaps, um… hmmm… not that I can think of... no, that's, that's the flaps, and there's different kinds, I mean you have some that go up and some that go down so I mean, you've got different sets of flaps… that do different things

I- So there's more flaps, there's more than one flap on a wing…

P2- I think there's more than one yeah I'm trying to think when I looked outside the plane the last time I looked did it go up or down… yeah I have seen actually some that go down and you have a smaller, you have a larger set here and you've got a smaller over there and so actually I've seen some go down and some flip up this way so, y'know, depending on the design of the plane

I- Now you said you've flown in a two-seat Cessna like a 152

P2- yeah, yeah

I- what um, do you remember anything about those wings and the flaps or whatever on them as compared to maybe like a 747 or a 767

P2- um, if I remember right they were bigger and they took up more of the wing

I- in which…?

P2- in the smaller plane

I- in the smaller plane…

P2- is that right? No… I was spotting wolves and I wasn't paying too much attention to the flying, it was so small, it kind of freaked me out a little at first [laughs] um, and actually it was, actually they were smaller, I believe the flaps were smaller… it was actually sort of like a biplane with wings on top and then a smaller set on the bottom (T2, L401-440)

This was interesting in that Jane, despite learning about airplanes and flight from her father at an early age, and from dating pilots, did not seem to understand about the various control surfaces. She seems to be equating every control surface other than the rudder with flaps- including the ailerons (one of these is on the back, outer edge of each wing, and they move in opposite directions, causing the airplane to roll, or bank, left or right), and the elevators (the movable horizontal surfaces on either side of the rudder, which move in the same direction to control the pitch of the plane, causing it to climb or descend). Flaps are extendable surfaces on the back, inner edges of the wings which are usually kept in the ‘closed’ position during flight; they are extended during landing to provide a steeper approach to the runway, and are used for take-off sometimes on short runways, and some small planes do not even have flaps.

Except for the fact that the author expected Jane to have more understanding of airplane control surfaces, given her background, it is not at all surprising that flaps would be considered by most people to be any horizontal surface that moves on an airplane. This is because most people who have flown at all, have flown in large commercial jet liners; a passenger looking at one of those wings on landing sees a whole range of surfaces moving up and down. Of course, many of these are air spoilers which are needed on huge, heavy aircraft to slow it down on landing; but someone unfamiliar with small aircraft wings might assume that these multiple moving surfaces are present on all wings, and flaps is an easier term to commit to memory than ailerons!

At this point the interview turned to the cardboard and Styrofoam model airplane wing manipulatives. As with John, Jane was asked to first describe similarities and differences between the two:

> **P2-** ok, the similarities are um, that the shapes are pretty much the same, but the Styrofoam piece has a curved surface more like a plane... than the flat piece here
>
> **I-** so the shape you’re talking about looking down on the
>
> **P2-** the shape looking down is the same, the size is approximately the same, uh, it’s just the uh, oh thickness, y’know, is different, the thickness is different and the actual curvature… is a little different
>
> **I-** ok, and do you have any idea why the curve is on that wing, can you tell me a little bit more about the curve of that Styrofoam wing?
>
> **P2-** sure, the curves of the Styrofoam wing here, when the air flows over this way, over the top, uh, it slows the air down, decreasing pressure, while you’ve got

underneath where airflow goes faster, increasing pressure, and that will provide lift to the plane… at the correct speed it will overcome the mass of the plane

I- and so that would make a difference over that cardboard

P2- uh, sure, because even if it's controlled strictly by tilting… you'd have to rotate this to get lift up and down whereas this ah, you don't have to, it can remain fixed (T2, L455-476)

Jane notices the differences between the flat cardboard wing and the curved Styrofoam wing, but continues along her earlier line if thought that air slows down going over a wing and speeds up going under. She also allows that a flat wing could produce lift if it was tilted or rotated; a curved wing could remain fixed to produce lift.

We then move into holding the two wing models in front of a fan, with Jane describing what she fells as she tilts/pivots the models up and down:

P2- oh sure, so if we're holding it level [hold cardboard wing model], it's, it's, you're feeling a little bit of vibration but, but y'know, I'm feeling a neutral, I'm not feeling any kind of a… push or pull, or pressure on it so…

I- ok, and as you tilt it slightly one way or the other describe what you're feeling

P2- as I tilt it slightly up I feel um, the pressure moving it, wants to push the wing back towards me… the paper back towards me… and if I feel, uh, and up, back and up, and if I tilt it downward, I feel like it wants to push it down and back

I- ok, and maybe tilt it even a little more

P2- yeah, there we go… oh yeah, I mean like you can feel like it, y'know, just wants to go back and up, and back, so… [pivots cardboard wing model up and down and end to end]… and depending on how I curve it this way and that way then the direction it wants to go

I- ok, let's try the same thing with the Styrofoam wing, you just want to put the level right on that flat part

P2- ok there we go ummm…. I guess again, a little vibration but not much um, not much pressure, y'know I feel like it, yeah not much, I mean I feel like maybe a little bit more pressure on it but nothing much

I- pressure in which way?

P2- uh, up, like it wants to just lift up

I- so when it's level…

P2- like it just wants to lift up… this way

I- and did you feel that with the cardboard?

P2- no

I- when it was level

P2- no I didn't, no, but I definitely, y'know, again when I, when I tilt it back towards me um, it just wants to go up and back, and then down, it wants to go down, down and back

I- ok

P2- but um, when I hold it level it… it feels like it wants to go up a just little bit (T2, L497-538)

As with John's manipulation of the wings and description of the sensations he was feeling, Jane too felt the vibration in the Styrofoam wing when it was held level, and noticed that while level, the Styrofoam wing felt as though it was pulling up. The cardboard wing still just gave the sensation of being pushed back and down or back and up when it was tilted down or up in front of the fan.

The interview then moved to using the papers to blow over and between, and there was a great deal of broken discussion here, sentences started then broken off, so only the relevant passages are presented here, the reader is referred to the transcription for the full dialogue (T2, L543-636):

I- I'm going to ask you to raise it up till it's just under your mouth and blow over it, and first off, I'd like you to predict what you think will happen when you do that, so the air is just going over the top of it and no air is going underneath

P2- not underneath, just on top, ah, that the, [holds piece of paper] this would want to push down, the piece would want to push down… and the paper, actually might lift up a little bit

I- and why would the paper lift up?

P2- <u>I'm not sure, it's just a feeling I have</u>… ok, but um… I'm thinking the air would flow down this way would push down here… and the, it'd want to kind of do this, I don't know I'm just thinking [demonstrates with hand]

I- what do you think is happening there?

P2- I'm trying to think of speed… I'm just trying to think, I know that as air goes, as air goes here, hmmm, cause I know it's bringing the paper…. [continues to blow] now it's bringing the paper up just a little bit… so somehow I know that the pressure is decreasing, or inc… decreasing up here and increasing down here [lifts paper with hand]

I- ok, how about the speed of the air?

P2- the speed of the air has increased up here, [momentary distraction from P2's son] is increasing down here and uh, or the speed is, is increasing up here and decreasing down here

P2- it was contrary to all my, what I was thinking because… well no… well yeah because it was normally… slow… well… it's kind of like having a wing upside down, the pressure being… [P2's son starts making cooing sounds] yeah that's what I'm thinking too [laughs] exactly! You read my mind son… cause we're increasing pressure here, or increasing wind speed here,

I- mm hmm

P2- which is decreasing pressure, lifting up the paper, so if it's slower down here… is that making sense? mm hmm…. I think I, I'm still having a hard time, I guess I'd have to see like a formula or, or have it explained to me in the physics, because

I- all right now, have you ever, I wonder if you've ever done this little trick, where you take two pieces of paper, and you hold them, they're supposed to both hang down so they're pretty much parallel, and then you blow in between 'em, and I'd like you to do that but first, I'd like you to predict what you think will happen when you blow in between those two pieces of paper, are they going to… move apart?

P2- I think that they're going to move together…

I- and why is that?

P2- yeah… well I know when I do part of this, air is going to go out the sides, and out the bottom, it's going to go out in all directions,

I- mm hmm

P2- cause airflow isn't just, in one direction… ummm… well again we're increasing air flow, which would be decreasing pressure, which would be, increasing the airflow which is decreasing the pressure on the inside, which allows the air pressure on the outside to be greater, forcing the papers together (T2, L545-634)

Jane is now beginning to make a connection between faster airflow causing lower pressure, but she isn't quite getting the whole picture yet, and is trying to reconcile what she was previously thinking with what she's actually observing. The next step is to bring out the drawing of the wing section (see figure 13), which results in a remarkable outcome:

I- ok, I've got here, a drawing, and um, what does that look like to you?

P2- ah, it looks like a cross section of a wing

I- ok, now let's say that this cross section of a wing is actually the edge of a wing, flying through the air, this would be the front… and um, what do you think is going to happen to the air, at that front edge?

P2- it's going to split

I- ok, so let's say we have one little parcel of air that gets split in two… we've got half of it going over the top and half of it going under the bottom, how are those going to move, uh, as one goes over the top, one goes under the bottom?

P2- ok, how's it going to move?

I- you talked about air having different speeds, depending on where it is…

P2- ahh, you know, now it just hit me, because the airflow, it's not going to slow down as it comes here, it actually has to speed up, it actually has to speed up as it comes over this part, because, and it'll slow down as it comes through here because it's going to meet, it's, it's like a volume of water, it's going to, I mean these two points are going to keep up with each other, one's not going to slow down, one's not going to speed up, so what happens actually is the airflow… goes faster over here, slower underneath here,

I- mm hmm

P2- to maintain the same point, of movement… so, as it goes faster up on top here, um, right, so air flow increases… which decreases your pressure, here,

<u>decreases, and of course it's the opposite here, airflow, decreases, which increases air pressure, here…</u>

I- ok

P2- **<u>there you go, and that's how you get your lift</u>**

I- ok…

P2- **<u>that's, ah, that's, that's, that was, so, everything opposite, and, and it finally just hit me [laughs]</u>**

I- that's fine!

P2- duh! [laughs] duh! Yeah, I'm thinking, well wait a minute, because, cause yeah because airflow is not, yeah, it's not going to split off and move in, um… like one, like one parcel's not going to slow down while the other one speeds up, they're going to want to maintain, ah, the same, I want to say the same distance, of flow across the wing, so… (T2, L639-682)

Jane has something of a revelation, and gets very excited when she realizes that her thinking was backwards and that airflow actually increases in speed over the wing while staying relatively slower under the wing, thus decreasing pressure above the wing, causing lift. However, she also is of the common belief that the air flowing over and the air flowing under have to meet back up at the trailing edge of the wing.

To further probe her understandings of what happens when the air gets to the back of the wing, questions were focused on this area:

I- …so what's going to happen when these two parcels of air get to the back, of the wing?

P2- well what's going to happen is as they mix you're going to end up with actually, it's kind of a tornado effect, and they're going to start spiral, spiraling around, ah, one… cause what's going to happen is this part ,um, yeah airflow, as airflow increases and this is slower, yeah you're actually getting sort of a funnel effect, and the air is going to spiral around each other until some where back at this point, um, it will become, it will become the same, it'll become the same speed or the same, ah, or same pressure again… cause you're having two differences in pressure, and so you actually do get sort of a, um, a spiral effect off the back of the wing

I- ok, so if you’re saying that… if I understand you correctly, that these, this parcel that’s been split in half, those two halves… how are they going to move, to that back edge of the wing?

P2- as the wing moves through it they eventually, yeah, eventually they merge, they come together, and eventually will stabilize and just… go, they’ll go back to an equilibrium, they’ll go back to either stable, or say you had five miles per hour they’ll go back to being five miles per hour(T2, L694-720)

As mentioned, Jane became very excited at figuring out that the airflow over the wing is faster than under it. Her responses became very rapid and somewhat disorganized; the author found it more difficult to keep the line of questioning on track. After a few minutes she began to state that the airflow wasn’t just from the front to the back of the wing:

P2- cause I also, the thing is the airflow not only goes this way and this way it also comes off, this way and it also goes back toward the plane…

I- ok, tell me more, tell me more about that

P2- um, I guess if you’re, if you’re looking down on the wing, there’s my beautiful wing drawing… you’ve got airflow, and you’re in, the airplane’s moving this way, ok, you’ve got airflow coming down that way, uh, which goes over and under [draws], you also have the airflow moving *this* way, and you’ve got airflow moving off the end of the plane, that way, it doesn’t just, it doesn’t just move in one direction actually, it wants to move off in all directions um, I know that’s why they have the winglets here, is to maintain, um, cause you lose like a third of your lift… by the air moving off this way, that’s why they have a little winglet, which keeps the air flow over the wing itself (T2, L730-742)

She seems to believe that the air is moving in all directions, and that the small vertical projections found on the ends of some wings on large aircraft save a great deal of lift:

I- does every wing have a winglet on it?

P2- not every wing does, no, no, but your bigger airlines will, and they’re not very big, they’re very small, uh, actually, and they’re just these little pieces that

> sort of jut up and that is actually, I think it’s like they lose like a third of your lift, without the winglet (T2, L743-746)

Actually, winglets on large, heavy planes are not so much to prevent loss of lift, but to help stop air that is trying to slide out from under the wing tips to equalize pressure between the relatively high pressure air under the wing and the lower pressure air above. Jane’s statement that air spirals off the back of the wing is in fact fairly accurate, although it actually spirals off the wing tips. This phenomenon with large heavy aircraft is called wake turbulence, and is most pronounced during take-off and landing when the airplane is at a high angle of attack. This is an extreme hazard to small, general aviation aircraft, and wake turbulence avoidance training when following large aircraft landing and taking off is a critical part of private pilot instruction. Jane’s further statements confirm that this is the line of thinking she is actually taking:

> **P2-** um, the pressure of the air is different, coming off, and when they do come back together, ah, they don’t just, y’know, they *will* converge this way, y’know they *will* come together, and as I mentioned they spiral around and eventually come off… and um, I, the only reason that I can even explain it that way is because I know this is why you have to maintain a certain distance between takeoffs… between airplanes (T2, L758-765)

The interview now turned to the question of whether plywood sheets would make an acceptable substitute for regular wings:

> **I-** ok, if you took the wings off of an airplane, and stuck sheets of plywood on there… do you think the airplane would fly?
>
> **P2-** yes, it would have the ability to fly, however it would take, ah, a greater amount of speed… it take a greater, a uh, a tremendous more amount of force, cause you’re now taking all the physics of, of uh, lift and airflow, I mean you’re, you, you, are no longer taking advantage of natural forces around it, but I think it could fly, I do believe it could fly, if, um, back in the old days that’s kind of how they did it, that’s why they weren’t very successful with it… I was thinking more of a glider, I mean, how the plywood would work, ah, you’d have to have some way… to… you’d have to have some way to… to tilt the plane up, either a flap or something, um, you’ve got your straight wing here, you’d have something off the

back, uh, to control up or down, y'know to get sort of a, ah, to create lift… you know, or you'd have to have something pulling the front of that plane up, or pulling that wing down [distraction from son]

I- if you had that same parcel of air that got split, one going over the top and one under the bottom, how would that move, in that case?

P2- if you didn't have anything, if you, if you didn't have anything to, to change the dimension, if it was just a plain flat board, you wouldn't, unless you changed the angle of the airflow, by somehow, like maybe dropping off a cliff or something like that, the thing would just keep going straight

I- ok, so it would stay up in the air?

P2- ahhh… would it stay up in the air? …. I think like a um, I guess like a glider… but then we're talking something that isn't flexible or doesn't, ah… I think that eventually it would have to come down, eventually… it's not going to maintain a uh, well I guess, in a, if, you were in an ideal world and there was no change in wind, if the wind's just coming straight on, and you're not changing the wings, um, and you have a constant force, of moving it through… theoretically I guess it could stay aloft (T2, L788-825)

Jane's answer, which considers the angle effect of air hitting the underside of the wing, or plywood, (Newtonian action-reaction) is almost identical to John's answer about the plywood. There is the same connection between the greater force caused by 'air hitting a wall' and the pressure differential due to Bernoulli's Principle.

The remainder of the interview focused on the paper airplane, and this only lasted a couple of minutes. Pertinent passages from this part of the interview, after Jane threw the paper airplane and observed its behavior, are:

I- ok, was it flying?

P2- ahhh, yeah, gliding…

I- all right, and um, how is it doing that?

P2- [laughs] um, let's see, gliding through, well you had some airflow, y'know, by throwing it, by throwing the plane, uh, it has some, you created some airflow, through, underneath… which sort of helps sort of create a lift in the plane, it just kind of glided through until its speed decreased, y'know, natural thing, uh, friction, air friction, decreases your speed, as you decrease your speed you decrease the air flow and it eventually just goes right down on the ground.

I- ok, how would air flow around these wings as compared to say, a wing like this, like on a Cessna or 747?

P2- ahhh… let's see, ah, the, I would say it's not as aerodynamic… it's not going to, ah, make full use of a principle of, um… I guess if you were flying something like this, [pointing to drawing of wing shape] compared to something like that, this would go a bit further [wing shape]… ah, just because, in addition to just natural, pressures, you're also creating a variation in the airflow… where this you're not [paper airplane]… so this one [wing shape] will maintain a longer lift, yeah this would fly a little bit longer than that [paper airplane]

Jane's interview ends at this point, also after nearly an hour.

Joan

The third interview was conducted with Joan, a senior at Bloomfield high school who took Regents physics during her junior year. The interview was conducted after school on Wednesday, February 26, 2003, in John's classroom. John was instrumental in recruiting a student to participate in the research project; the author's goal was to have an average student, as opposed to an advanced student, but as will be seen Joan is an exceptionally bright student at the top of her class. During the initial discussions about selecting a student to interview, the author and John agreed that convincing a high school student to stay after school for up to an hour and a half or more would probably require an incentive. John suggested that he could give some extra credit, and the author decided to get two $10 gift certificates, one for movie tickets and one for pizza. As fate would have it, Joan worked at the local pizza restaurant where the author got the certificate, so she gave that to a friend.

As with John's and Jane' interviews, the first thing was to read a prepared introductory statement that had a general paragraph regarding the overall expectations of the session, followed by a paragraph specific to the Arlin Test of Formal Reasoning, which led directly into the ATFR instructions. Once the participant was engaged in taking the ATFR, the recording equipment was set up, as in the first interview. Set-up took about 15 minutes, and Joan took about 30 minutes on the ATFR. Results of the ATFR will be presented after the discussion of the interview.

As before, the interview began with a brief introduction, followed by preliminary questions specific to the participant were asked; in the case of Joan, these were:

- Have you gone to Bloomfield Schools all your life?
- What do your parents do?
- Have your parents ever been involved in anything having to do with airplanes or aviation?
- I understand that you're a senior now, and that you took physics last year, when you were a junior. If I'm not mistaken, most students who take physics take it in their senior year. Why did you choose to take it last year when you were a junior?
- Is physics a mandatory class or an elective? If an elective, why did you take it?
- Did you like the class? How well did you do in it?
- What part(s) of physics did or do you most enjoy?
- What do you plan to do after graduating high school?

This final interview started off with a problem- the stereo cassette deck that had been successfully used to record the first two interviews failed at the start of this one. When 'record' was pressed, the tape deck started for about two seconds, then stopped. This flustered the author a bit, but 'the show went on' as there was also the video camera to record the interview, as well as the micro-cassette recorder for back-up. John did go get another tape deck from the school, but it did not have the stereo inputs required by the wireless microphone receivers. The only thing that really happened was the author forgot to start the interview off with another brief spiel about the interview not being a test, no wrong answers, etc.

This interview had a decidedly different atmosphere than the first two, as Joan was fairly quiet and did not elaborate on her answers as John and Jane did. She did relax somewhat as the interview went on and begin to offer more in-depth explanations of her thoughts, but overall this interview went much faster, being completed in less than half the time as the first two.

The interview began with the preliminary questions specific to this participant:

I- Ok Joan, have you gone to Bloomfield Schools all your life?

P3- yes

I- ok, um, what do your parents do?

P3- my mom used to be an accountant but she quit to take care of the kids, and my dad used to be an electrician but he’s retired

I- ok, um, have your parents ever been involved in anything having to do with airplanes or aviation?

P3- no

I- ok, all right, ok I understand that you’re a senior now, and that you took physics last year

P3- yes

I- ok, and you were a junior obviously last year, and if I’m not mistaken, most students who take physics take it in their senior year?

P3- yeah

I- ok, how come you chose to take it last year when you were a junior?

P3- Because I had taken chemistry and biology the year before and I didn’t want to take it when I was a senior when I was taking AP biology

I- ok, cool, now is physics a mandatory class or is it an elective?

P3- it’s an elective

I- ok, and how come you took it?

P3- cause I’m majoring in science

I- oh, ok

P3- and I’m planning on becoming a veterinarian sometime…

I- oh cool, excellent! Now as far as taking physics, did you like the class?

P3- I liked the class, but not the extra stuff we did

I- oh, yeah?

P3- like the teachers [interruption by PA announcement]

I- I’m sorry, interrupted by the intercom, so you were, so you didn’t like the activities, or the labs, or what?

P3- it’s just that I didn’t find it very interesting

I- oh really? Ok, that’s fine… how well did you do in it?

P3- pretty well…

I- pretty well?

P3- yes, I was at the top of the class

I- were you? So, you did really well in it, but it was just kind of boring for you…

P3- Yeah (T3, L5-42)

Joan went on to say she had been accepted to RIT (Rochester Institute of Technology) and waiting on replies from several others. Then we moved right into the meat of the interview:

I- ok, so we're going to kind of move into the general questions, have you ever flown on an airplane?

P3- once

I- once, and how old were you?

P3- fourteen

I- ok, so not too long ago then, like three or four years?

P3- four

I- four years? Ok, and what kind of plane was it? Like was it a big passenger jet liner…

P3- yeah

I- as opposed to a little two or four seat plane?

P3- [nods head yes]

I- do you know anyone who is a pilot, like flies small planes or anything?

P3- um, I have some cousins, my dad's friends, who I don't know… so I don't really know anyone personally… my cousins I don't see, they're in college

I- oh, ok, so it's not like they told you about flying or anything like that, ok… so do you have any ideas about what makes an airplane fly and go up into the air?

P3- I remember talking about it in physics once

I- yeah? What do you remember, I mean I, again, this is not a test or anything, I mean I'm just trying to see where your understandings are, so… just if you have any, bits of memory from when you took the class, and talking about it

P3- just drawing a cross section of a wing on the board and showing where the air flows… that's about it (T3, L62-87)

It was quickly established that Joan was a very intelligent student, and that she had some limited experience with flying, but her only exposure to the theories of flight was during physics class the year before. It should be mentioned here that after the interview, John (who had been sitting at his desk throughout the interview) mentioned that the Regents physics class Joan had taken did not cover fluid dynamics and Bernoulli's Principle, it only covered balance of forces and as far as flight was concerned they only looked briefly at airflow around a wing. Bernoulli's Principle was covered in AP physics, which was taught during the current year, and when asked why it wasn't taught for Regents physics, John stated that there was nothing on the state test about it, although there used to be.

When asked to describe what happens when an airplane takes off, Joan's response was brief: "well it felt a little bit like, if you're in a car, they just start, start going really fast, then it took off, and you didn't feel anything" (T3, L90-91). Moving into questions about parts of an airplane critical to flight, Joan's answers began to take on more depth:

> **I-** is there any particular part of the airplane that you think of as being very critical to the airplane being able to get up into the air?
>
> **P3-** the engines
>
> **I-** the engines? ok
>
> **P3-** pretty much
>
> **I-** ok, any other parts that you think are important
>
> **P3-** <u>the wings</u>
>
> **I-** ok, and can you tell me a little bit more about the engines and the wings and how it works, how the plane can get up, I mean it's pretty amazing that something that huge can get up into the air
>
> **P3-** well the engines give it like momentum, the wings can catch the air cause it's moving that fast cause the engines catch the air and go up [starts moving hands more to express her ideas]… the wings catch the air, the engines move the wings that fast… I guess
>
> **I-** Oh, there's no right or wrong, don't try to second-guess yourself or anything, just tell me what comes to mind, that's all I'm looking for… when you say that

the wings catch the air, what do you mean by that? Can you describe that a little more, or…

P3- like the top's bent, and the bottom's more flat, so the air goes either slower or faster over the top, and that makes it push up, the air on the bottom pushes up (T3, L92-114)

Joan is showing that she does indeed have an understanding that a difference in airflow around a curved wing has something to do with an airplane's ability to take flight. The next questions were concerned with determining her understanding of the term 'lift':

I- ok, all right, have you ever heard of the word lift?

P3- yeah

I- as applied to flying and airplanes, ok, what is that word mean to you, in that context?

P3- it's um, air pushing on the bottom of the wing, keeping the wings up…

I- ok, is there a part of the plane that has more to do with lift than another?

P3- the wings… I'm kind of stuck on those (T3, L115-122)

She definitely knows that somehow air is 'pushing up' on the underside of the wing, in order to lift an airplane into the air. The next several questions had to do with gliders, and the fact that they fly with out engines, but Joan took 'gliders' to mean hang gliders launching off cliffs, not the gliders with long, thin wings the author had in mind. This line of questioning was not deemed important for the current participant so the interview moved on to defining the word 'aerodynamics':

I- ok, here's another word, aerodynamics, have you heard of that?

P3- yeah

I- and what does that mean to you? Can you tell me in your own words what that might mean?

P3- I've heard it more applied to cars, and stuff, just more streamlined, doesn't slow it down, doesn't catch the front air as much as possible, so it's not so… (T3, L139-145)

Joan has an understanding that aerodynamics has something to do with smooth airflow, but has apparently never encountered the term in the context of aviation. The scenario of holding one's hand out of a car window was now raised:

> **I-** have you ever when you've been driving in a car, or being driven in a car, have you ever held your flattened hand, y'know, like this out of the car window while the car's going down the road?
>
> **P3-** sure
>
> **I-** ok, can you tell me what happens when you do that?
>
> **P3-** you can feel the wind, air resistance
>
> **I-** ok, if you're holding it, totally flat, what kind of sensation do you recall, or what do you think would happen even if you don't recall
>
> **P3-** not much
>
> **I-** not much? And as you start to tilt it one way or the other what do you think, what would happen?
>
> **P3-** if you tilted it, it would be like wind was hitting it, your hand would move (T3, L146-157)

Had this been the first interview, the author would have pursued these answers further, to get more depth. However, it was apparent that Joan was more comfortable giving fairly short answers, and not elaborating on them as John and Jane had freely done. It was also possible to take Joan's answers and 'read between the lines', putting them into the context of the answers given by John and Jane. In other words, Joan's above explanation of 'wind was hitting it, your hand would move' is reliably interpreted as the action-reaction answers given in the first two interviews.

The answer to the next question was more enlightening:

> **I-** if you've got an airplane that's parked on the ground, at an airport, and there's a really strong wind blowing right into the front of it, would that airplane try to fly? Do you think somehow it would try to get up into the air?
>
> **P3-** sure
>
> **I-** yeah? And why would it do that?
>
> **P3-** cause it's the same thing as if it was moving, it's still having the wind coming… (T3, L158-163)

This clearly showed that Joan understood that it did not matter whether the airplane was flying, causing air to flow over the wings, or if the airplane was parked and wind was causing the airflow. She correctly saw that it is the relative motion of the wing and the air that produces lift, or the ability to fly.

As in the first two interviews, the next line of questioning had to do with air shows and how certain airplanes can fly upside-down. She simply stated that she had “no idea” how an airplane could fly upside-down, so we moved on to the manipulatives, starting as before with the participant describing similarities and differences between the cardboard and Styrofoam wing models:

P3- well, one’s cardboard and one’s Styrofoam… they’re the same size, [picks up both wing models] both have flattened bottoms, one has a flat top, the other has a curved top

I- ok, do you think, or can you, uh, do you have any ideas on why that curve is in the Styrofoam wing, and why it looks more like a real airplane wing? …and would that make a difference over the cardboard wing model in any way

P3- yes, the cardboard doesn’t have a curve, this one is like the drawing that you showed me, right there [points to end of Styrofoam wing]… so the air would go over it, and maybe slow down or something like that, and the air would push up here, [points to underside of wing model] cause it was going faster… I’m not sure exactly

I- oh, that’s fine, that’s not a problem, but you’re telling me about the wing, or the air, somehow is different, for the air that goes over the top of the wing, as opposed to the air that goes under the wing?

P3- yeah

I- ok, and if you could just tell me a little bit more about what you’re thinking about that?

P3- that I think I’m remembering that there’s a difference…

I- that there is a difference in the speed

P3- yeah…

I- that there is a difference, and that has something to do with… you were starting to say…

P3- oh, it has to do with how it’s able to get up

I- with the lift?

P3- yeah (T3, L171-202)

Joan seems to be thinking along the same lines as Jane did- she knows that there is a difference in airflow above and below the wing that causes lift, but she is thinking that because the air beneath the wing 'pushes up', it must be going faster than the air flowing over the top, like the air hitting the bottom of one's hand sticking out the window of a moving car. Again, there is more familiarity with the action-reaction forces of wind, in everyday life, than there is with 'higher fluid velocity causing lower pressure'.

Joan was given instruction in how to hold the wing models and the line level, the fan was turned on, and she started with the cardboard wing model:

P3- [stands in front of fan] it's just vibrating a little

I- vibrating a little, ok, now if you want to start tilting it up or down a little bit, and tell me what you feel

P3- a lot more resistance

I- a lot more resistance? ok

P3- like it's being pushed down…

I- pushed down when you tilt the front edge down, and… up, when you tilt it up

P3- yeah

I- ok, anything else, or is that it?

P3- that's pretty much it (T3, L220-229)

There was nothing surprising in her descriptions here; they were almost identical to John's and Jane's, with the cardboard wing being pushed down or up when tilted down or up. Joan then switched to the Styrofoam wing:

I- ok, why don't you switch to the Styrofoam wing… try to start out with it level, if you can, ok, what are you feeling?

P3- well it's shaking a lot more

I- shaking a lot more? Ok, do you feel anything other than the shaking? Y'know, as far as any differences between that wing and the uh, cardboard wing?

P3- no, it's just shaking

I- ok, start tilting it one way or the other and

P3- [tilts wing model up a bit] it goes up a lot more than the other one did, it goes up a lot more

I- ok, do you have any ideas on why that might be?

P3- well it should probably try to go up even when its level, but…

I- uh huh, and why do you say that? That it should probably be trying to go up when it's level…

P3- because we learned… because it's not like when it's on the runway, the airplane, it's starting like this, it works up to that

I- starting like what?

P3- like, on the runway, it starts flat, it doesn't start like that, [demonstrates with wing model that the plane starts on the runway with wings level, not already tilted] then when it gets going it slowly goes up (T3, L230-248)

Again, Joan's answers and descriptions closely parallel John's and Jane's, with the Styrofoam wing having a greater lifting effect, and vibrating more. However, Joan did not seem to notice any appreciable feeling of lift when the Styrofoam wing was held level in front of the fan, as John and Jane did. She did state that it should have some sort of lift when it was level, but she went on to state that an airplane on a runway starts with the wings level, then as it gets going it tilts up; apparently she felt that in flight the wings are necessarily tilted up, to get the 'hand out the car window' action-reaction effect, and that's what causes lift.

The interview then moved, as before, to blowing over a sheet of paper and in between two sheets:

I- I've just got a plain piece of 8 ½ by 11 copy paper here, and I want you to blow as hard as you can right over the top of it, first I want to ask you what you think will happen when you do that?

P3- um, maybe the paper will go up?

I- maybe the paper will go up? And why…

P3- I don't know I've never done this before

I- no? and why, are you just taking a guess, or do you …

P3- yeah, it's just a guess

I- ok, so go ahead, and give it a shot, and see what happens

P3- [blows over paper, which rises quite a bit]

I- and, I guess your predication was correct

P3- yeah

I- now, it’s interesting… that went up, but no air was going underneath it…

P3- true

I- what do you think

P3- [shakes her head, thinks a moment] um, it was moving faster, that’s what I said, I don’t know

I- which air was moving faster

P3- this one [moves left hand over top of paper]

I- going over the top

P3- yeah

I- I’m going to show you how I would like you to hold, these pieces of paper parallel so they’re hanging down, [demonstrates] and then I’m going to ask you to blow right in between them, and before you do that I’m also going to ask you what you think will happen

P3- they’ll go together

I- they’ll go together? And why is that?

P3- because in the last one it moved in the direction of where the faster air was

I- ok, you want to give that a shot?

P3- [blows in between] I didn’t do it right [blows again] did anything happen?

I- yeah it did, they did go together, I know it’s kind of hard to see when your head is right over it, now I’m going to ask you, cause you were talking about air… having differences in the way it goes over and under a wing, after you’ve done these two little things here does that give you any more… uh, how do I want to say this, things to think about as far as that wing shape, with the curve?

P3- uh, **maybe the curve makes the air move faster over the top**

I- do you recall learning anything about if air moves faster, what might happen to some of the other properties of the air?

P3- no (T3, L249-296)

This was extremely interesting because Joan was making accurate predications based first on a guess, and then on her observation that the paper moved in the direction of where the faster air was. She then drew the conclusion that air must move faster over the top of a wing, because the wing moves up.

We now moved on to the wing cross section drawing (see figure 14):

I- now we're going to move to this drawing, what does that look like to you?

P3- it looks kind of like an airplane wing, kind of

I- kind of an airplane wing? You mentioned something before about (your teacher) putting up a drawing on the board, is it anything like that?

P3- yes, kind of,

I- if I give you this back [hands back Styrofoam model wing], can you kind of point out on here, what that might sorta kinda look like…

P3- this part, right there [points to end of wing]

I- ok, so it's like you're looking in at the end of the wing

P3- yeah

I- like a cross section, ok, all right, I want you to pretend that that is a real wing, flying through the air… and on the front edge here, which corresponds to this edge, what do you think is going to happen to the air at this front edge of the wing?

P3- <u>it's going to get divided</u>

I- it's going to get divided? Ok, I've got some colored pencils here, and, if um, if you could draw what you mean by divided, and what may be happening with, you mentioned air having differences going over and under, if you could draw with y'know, one or more of the colored pencils what you uh… are talking about

P3- [draws]

I- ok, ok you're saying that it goes faster here over the top than the bottom?

P3- yes,

I- ok, so let's see, let's pretend that we've got a packet of air, that comes right into the front edge of the wing here, [points to front edge of wing in drawing] we'll be trying to get a little more detailed here, and that packet is split in two, can you draw, above or below, a relative motion of those two?

P3- what do you mean?

I- well you're saying that there's a difference in speed, of the air flowing over and under the wing,

P3- ok

I- and can you somehow draw with another color or whatever, like, two packets of air, one moving under the wing and one moving over the wing, and say at different points in time, how those are going to be moving, in relationship to each other?

P3- [draws]

I- and if you can tell me, I see you're drawing arrows of different lengths and such

P3- mm hmm, more arrows, it seems to my knowledge, I don't know, it just seems that this air has further to go, so it just takes longer, to get from here…

I- ok, so you're saying that, if I'm understanding you correctly, that the piece of air that's flying, the piece of air that's moving underneath the wing, is moving faster, or slower, than the piece of air that's moving over the top?

P3- well, I was thinking like it was going the same speed but this one has to go further

I- it has to go further but they're going the same speed…ok, what's going to happen at the back edge of the wing, are they going to get to the backJohnge at the same time, or are they going to get there at different times, or…

P3- I don't know…

I- well I'm just asking because you're saying that they're moving at the same speed, but this one has farther to go over the top

P3- **this is why I'm not into airplanes, I keep thinking I'm wrong**, it seems like this will reach, before this one…

I- ok, so the one going underneath would get to the back edge before the one going over the top,

P3- I guess… (T3, L297-348)

Joan correctly states that the air gets divided at the front edge of a wing, but gets confused about whether the air moves faster or slower over the top than the bottom, or the same speed. This is interesting as she just came to the correct conclusion that air moves faster over the top of the wing while blowing over and between the pieces of paper. Her statement that “this is why I’m not into airplanes, I keep thinking I’m wrong” is quite telling, as she seems to keep second-guessing herself, even when she’s right the first time. This is also reflected in several answers on the ATFR that she changed; in three cases her first answers were correct, and she changed them to incorrect answers.

The remainder of the interview went very quickly, for Joan’s answers were extremely brief- when asked if an airplane could still fly if its wings were replaced with big sheets of plywood, she answered “probably not” and “it might go up, it might break” (T3, L349-356). The only significant comment to come out of throwing the paper airplane and being asked if paper airplanes really flew was:

P3- yes
I- yeah?
P3- sure, sure
I- and, why do you think so or not?
P3- because they were up in the air, they hadn’t crashed yet (T3, L375-379)

This completed the interview with Joan, about ½ hour in length.

Arlin Test of Formal Reasoning Results

This portion of the research project posed the most uncertainty for the author. The original goal was to analyze the participants’ responses in the interviews, and see if any comparisons of any kind could be made to their level of cognitive development (a la Jean Piaget) as determined by the Arlin Test of Formal Reasoning. The thought was, thinking about airflow around wings and the physics of Bernoulli’s Principle are very abstract endeavors. The ATFR is designed to determine, first of all, overall cognitive level: concrete, high concrete, transitional, low formal, or high formal. Secondly, the eight subtests within the ATFR are designed to create a profile of the individual’s formal reasoning performance, indicating potential areas of strength and weakness.

So, can any type of meaningful connection be made between the participants’ interview responses and their score on the ATFR? The author is hesitant to draw any conclusions; although he had a general psychology course in undergraduate school, a course in adolescent psychology while obtaining his NY state provisional teaching certification, and was introduced to the theories of Jean Piaget and Lev Vygotsky in a teaching methods course and several courses in the SJFC master’s program, he has no real formal training in psychology. So, the following will be fairly brief, and the author begs forgiveness from any psychologist reading this!

All of the participants displayed what the author believes are pretty strong abstract reasoning abilities, even though certain participants had stronger vocabulary in aeronautical and physics terminology. Some of the answers to various parts of the interview were surprisingly similar among all three participants. The participants were given the ability to express their thoughts in a variety of ways- verbally, with manipulatives, and by drawing, and this gave them equal opportunities to express abstract concepts in ways that best suited them individually.

Before presenting the individual results, the cognitive levels derived from the total score are (out of a total possible of 32 points):

Concrete— 0 to 7 points
High Concrete-- 8 to 14 points
Transitional-- 15 to 17 points

Low Formal--	18 to 24 points
High Formal--	25 to 32 points

The eight subtests are the following (refer to the literature review for full descriptions) and each has a possible total of 4 points:

(S1) multiplicative compensations; (S2) correlations; (S3) probability; (S4) combinations; (S5) proportions; (S6) forms of conservation beyond direct verification; (S7) mechanical equilibrium; and (S8) the coordination of two or more systems of reference

John's overall score was 28 (see figure 15) indicating high formal reasoning. His scores on the subtests were: S1- 4, S2- 2, S3- 4, S4- 3, S5- 4, S6- 4, S7- 3, S8- 4.

Jane's overall score was 23 (see figure 19) indicating low formal reasoning. Her scores on the subtests were: S1- 4, S2- 4, S3- 4, S4- 2, S5- 4, S6- 2, S7- 2, S8- 1.

Joan's overall score was 22 (see figure 21) indicating low formal reasoning. Her scores on the subtests were: S1- 4, S2- 4, S3- 4, S4- 1, S5- 4, S6- 1, S7- 0, S8- 4. It must be noted that Joan changed two answers that she originally had incorrect to correct answers, and three answers that she originally had correct to incorrect answers. Had she left those three correct answers alone, she would have scored 25, just into the high formal reasoning range, and for S7 she would have scored a 3.

All three participants got perfect scores of 4 on three subtests- S1- multiplicative compensations, S3- probability, and S5- proportions. As discussed in the literature review, multiplicative compensations is applicable to understanding how wings generate lift as such understanding requires comprehension of the changes in air density, and thus pressure, of air flowing over and under a wing shape. Each participant did indeed show an ability to think abstractly about air being split and flowing above and beneath a wing, and to visualize this in their mind. Probability does not seem to be applicable to understanding how airplanes fly, as is the case with proportions.

The scores on S2- correlations show an unexpected pattern- Jane and Joan both got perfect scores of 4, but John only got a 2, indicating that he does not use this formal scheme much in his thinking. As stated in the literature review, correlational reasoning leads to the conclusion that two events, variables, etc., are or are not related and in more sophisticated situations, to determine the strength of that relationship. It seems unusual for a teacher of hard science to not have this concept well developed. But it does possibly provide insight into why John never mentioned Newton during his interview, yet made several references to action-reaction forces. It may also explain why he didn't appear to allow that both Bernoulli's Principle and action-reaction forces could be at work on a wing simultaneously. This is an interesting anomaly in that John got the highest overall ATFR score of all, by far. It shows that one can be a high formal thinker, yet still not have all eight formal schema fully developed.

John's, Jane's, and Joan's score on S4- combinations, were 3, 2, 1, respectively. This schema involves the concept of generating all possible combinations of a given number of variables, choices, events, scenarios when a problem's solution requires that all possibilities be accounted for. People use this concept when they ask the question: 'what are all the possible combinations (arrangements, permutations) of…?' The concept of Combinational Reasoning may play a part in understanding how airplanes fly in that as the orientation of the wing to oncoming air (attack angle) changes, the lift produced by the wing varies. John apparently has a good grasp of this (score of 3 and 4 on the subtests generally indicate a grasp of the given schema), and he demonstrated this by trying various arrangements of the manipulatives, such as balancing the wing models on a pencil. Jane and especially Joan did not demonstrate this schema; this may be the underlying reason for Joan's comment that she wasn't into airplanes, because she kept thinking she was wrong.

Scores on S6- forms of conservation beyond direct verification were 4, 2, and 1 for John, Jane and Joan, respectively. This scheme is more narrowly defined in terms of scientific concepts but they too have implications for other subjects in the curriculum. Forms of conservation beyond direct verification involves the ability to deduce and verify certain conservations by observing their effects and thus inferring their existence. When one plays billiards or pool, one such conservation concept is readily observed. If the cue ball makes a direct hit on another ball there is a perfect transfer of momentum. The cue ball stops and the ball which has been hit moves at the same speed as that with which the cue ball originally moved. No one has seen momentum, we only infer its existence from examples such as those observed on the pool table. There are many phenomena which we cannot observe directly.

Clearly, this concept is directly applicable to understanding how wings generate lift. One cannot “see” airflow over and under a wing, or the changes in pressure caused by an airfoil shape; one must infer these from observing how a wing acts. In addition, the Newtonian action-reaction of air bouncing off a wing, or a hand held out a car window, falls under this concept.

ed has a firm grasp of this, while Jane’s and Joan’s scores are the same as for S4, combinations. Both Jane and Joan knew that differences in air flow above and beneath a wing causes lift, yet Jane at first was stating that air slows down over the top of the wing. In the case of Joan, this may further explain her comment about always thinking she’s wrong about airplanes; plus, she was never taught about Bernoulli’s Principle in physics, only that there was a difference in the airflow around a wing that resulted in a balance of forces. This may also help explain why Joan did not expand on her answers as John and Jane did, or, that could simply have been shyness. It’s really difficult to say.

Scores on S7- mechanical equilibrium, were 3, 2, and 0 for John, Jane, and Joan. However, as mentioned previously, Joan initially got three answers correct on this sub test, then went back and changed them to incorrect answers.

This schema requires the ability to simultaneously make the distinction and the coordination of two complementary forms of reversibility- reciprocity and inversion. The idea of equilibrium suggests a system of trade-offs of multiple compensations… This concept represents the coordination of many different sets of compensations so that a balance or equilibrium is maintained. Hydraulics, piston and many similar types of problems in science require this thinking.

Again, this concept is applicable to understanding how an airplane flies as there is a balance between the lifting force generated by a wing and the force of gravity pulling down on the airplane. Pilots also use this concept when determining the weight and balance of an airplane’s loading; if weight (passengers, luggage, etc.) is not properly distributed in an airplane, the airplane may not be able to get into the air, or worse, crash once airborne.

Again, John had a good grasp of this schema, while Jane did not. In fact, Jane’s comment about an airplane being heavier at the back, throwing it off-balance a little, dovetails well with her score on this subtest. The author is hesitant to draw and conclusions about Joan's score here, as it is not accurate; she would have scored evenly with John if she had not changed her answers on the three questions.

Scores on S8- The coordination of two or more systems of reference were 4, 1, and 4 respectively for John, Jane, and Joan. This is one of the most complex schemes, and yet its applications are wide-ranging. It may well be the scheme which acts as a bridging concept between formal and any type of post-formal thinking (Arlin 1983b). The Coordination of Two or more Systems or Frames of Reference is the concept which requires the ability to coordinate two systems, each involving a direct and an inverse operation, but with one of the systems in a relation of compensation or symmetry in terms of the other. It represents a type of relativity of thought. A common experience for persons flying in airplanes is to hear the pilot comment that their airspeed is 540 miles per hour but that their groundspeed is 470 miles per hour. The two frames of reference for speed in this example are the work of the engine in the air and the progress that the plane is making relative to the ground being covered.

This concept is also applicable to understanding how airplanes fly and wings generate lift as lift is determined by the speed of the aircraft, as well as the attack angle of the wing. To go even further, the lift of a wing can be altered by adjusting the various control surfaces, such as ailerons, flaps, and elevators. An airplane moves on all three axes, so clearly this final, complex concept is at work.

ed and Joan both had perfect scores on this schema, while Jane scored a 1. This would appear to be reflected in her comments regarding the control surfaces on airplanes- ailerons, elevators, and flaps. She refers to all of them as flaps, and doesn't really explain what they do except that they alter the momentum of the plane, increase or decrease drag, and so on, which is not accurate. It does not seem reasonable to the author that between Jane's father, and the pilots she dated, she never had all the control surfaces explained to her; they're basic to all airplanes.

If the author was a trained psychologist, he could no doubt get much deeper into the analysis of the ATFR results and the participants' answers during the interviews. However, the consideration of the ATFR will end here, and perhaps the reader can consider the data and come to additional conclusions.

Discussion

The concept of aerodynamic lift is not an easy one to understand. The Newtonian, action-reaction component of lift has a much smaller role in the overall production of lift than the Bernoulli's Principle component, yet the action-reaction idea is much easier to understand. People experience this every day in easily comprehended ways: throw a ball against a wall, it bounces back; hold your flattened hand out of a moving car's window and the force of the air pushes your hand back. I believe that it makes a lot of sense that people who have not learned about Bernoulli's Principle would attribute the ability of an airplane to fly to engines and air bouncing off the wings.

However, Bernoulli's Principle is a very abstract concept. One cannot visualize it as one can an action-reaction concept. One can see action-reaction effects; one cannot see Bernoulli's Principle at work (at least in normal, every-day life.)

All of the participants were willing to allow, to one degree or another that flat sheets of plywood could serve as wings and provide some degree of lift. This was based on the action-reaction forces of air flow bouncing off an object. However, even John, the physics teacher, did not mention Newton and in fact tried to reconcile this "lifting force" with something to do with Bernoulli's Principle.

In addition, all of the participants had similar observations about the cardboard and Styrofoam wing models, from the size and shape to the reactions in the fan's airflow. They all felt that the curved Styrofoam wing was trying to lift up while held level in front of the fan, and that it vibrated toward the outer edge.

The author sees two primary impacts on teaching about flight and lift as a result of these interviews. First, experiences need to be created that allow students to begin to question the role of various parts of an airplane in causing it to fly. Playing with and studying toy airplanes and gliders, as well as considering full-size gliders, would presumably provide opportunity for this. The goal of this stage would be to help students begin to see the role of the wing in flight; the wing is the part that really 'flies', everything else is just along for the ride, and would fall out of the sky like rocks if it weren't for the wing.

Once there was a focus on the wing as being the one part that is truly critical to flight, there would need to be investigation into exactly what it is about wings that cause them to act as they do in moving air. Holding pieces of cardboard in front of fans reinforces the Newtonian aspect of lift, but this is a minor part of the overall lift equation, and there would need to be a way to help students create their own understandings of the importance of air flow over a curved surface. A teacher can stand in front of a class all day reciting Bernoulli's Principle (basically, that as the velocity of a fluid increases, its relative pressure decreases), but how are students supposed to internalize that? The author thinks it can only be done through hands-on, visually clear and stimulating activities. It is believed that having the participants hold the model wings in front of the fan was a step in the right direction, but the scale was too small for really feeling the forces at work. Something larger would be necessary.

The trickiest aspect would be providing a means for the students to see how air flows over a wing. The best way to do this is with a wind tunnel, but that is not something that every school has. Somehow providing a non-toxic smoke stream or streams (with or without wind tunnel) that the students could experiment with moving models in would be ideal. The bottom line is that there needs to be a way to see how the air is moving and reacting to a wing shape. Students also would need to be able to somehow feel the forces imparted on the wing, in perhaps somewhat more sophisticated ways than I provided.

I am not aware of any computer programs that might allow students to explore these topics virtually, but a well-designed software package of this type would most likely contribute to the visual-learning aspect for students, as well as allow them to perform experiments and calculations. I think it is safe to say that more schools have computer resources than have wind tunnels. There would certainly need to be means to compare air velocity with relative pressure.

The abstract aspect of lift needs to be removed as much as possible from the instruction about lift, and replaced by well-designed visual and kinesthetic experiences that deeply involve students in fully comprehending how a wing can fly. The author thinks most everyone is fascinated by the fact that flight is even possible, and by bringing the laws of nature that allows it into easy grasp of students, so that they can construct their own knowledge about it, true, deep understanding is much more likely.

John’s comments about students not having any real idea how things work in our society really rings true. While it is impossible for one person to know everything about how our technologically, socially and politically complex society works, citizens should have a basic, accurate understanding about the fundamental principles of how things work. Wings produce lift due to both Bernoulli’s Principle and Newtonian Mechanics; electricity comes from generation plants through electric lines into our homes and businesses where most outlets provide 110 volts (also, it is the amperage, or flow, of electricity that can kill, not voltage), and so on.

The author learned an immense amount through the implementation of this project, much more than how to word questions and conduct interviews. Having attempted to teach about flight and lift to 7th and 9th graders, he now sees how difficult it is to understand the abstract concepts involved. It is important to eliminate the abstractions as much as possible, and use real, comprehensible methods to help students, both children and adults, to really understand about flight.

Were I to do this interview again, I would add some questions as to what would happen if an airplane’s engine(s) stopped while in flight. My guess is the answer would be that the airplane would fall out of the sky, when in fact the airplane can still glide, with the wings continuing to develop lift as the airplane descends to a (hopefully) controlled and safe landing. Such maneuvers are, in fact, a critical part of private pilot training, in which the flight instructor will suddenly pull the engine throttle back to idle, and the student has to properly control the airplane to achieve the correct glide rate and identify potential emergency landing areas.

If a project along these lines were to be conducted again, I believe it would be enlightening to perform the interview on children and adults not only who score in the formal ranges, but also who score lower on the ATFR, into the concrete and transitional range, to see what, if any, conceptual differences there are on this subject between the two groups. Perhaps the ATFR could be used as a screening process to identify these individuals.

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Appendix A

John Interview Transcription

(In transcription, **I** refers to interviewer, and **P1** refers to John)

ed Interview Transcription (T1)
Interview date: January 16, 2003. Place: John's science classroom at Bloomfield (NY) high school.

I- John, as I've explained this is helping me out with a project for my graduate program, I am going to ask you some questions, it is not a test, there are no right or wrong answers, the purpose of this is to help me understand what your understandings [school announcement over loudspeaker] and beliefs are about the subject that I'm going to be asking you about. First I'm going to ask you some general questions about being a science teacher,
P1- Alright
I- How long have you been teaching?
P1- Well, since January of '97, I've been here, I came in the middle of the year and I've been here since
I- Okay
P1- And I'd only subbed before that and that had been like, y'know, ten years before so
I- Oh, okay, okay, so I guess my next question is relevant, did you do anything else before you became a teacher?
P1- Oh, yeah
I- What did you do?
P1- Uh, well, let's see, if we just go back to when I got out of college, I was a uh sales engineer for a small firm in Rochester that looked like it was about to go out of business at any point because they were doing all kinds of dumb things, so I left there and I uh, was a uh quality control supervisor at a canning factory for awhile and I uh sold reverse osmosis water systems door to door for awhile and the main thing I did between uh when I went back to college uh, I graduated actually in college from Clarkson in '86, and went back to Oswego in like '88 to take education courses and student teach, and uh, I worked at ARC which is uh, basically working with people with disabilities from like 1989 until '97, y'know starting out as a uh, y'know basically a counselor at one of the houses and being vocational evaluator and uh, rehab counselor and things like that at the clinic they

had over here in Canandaigua. And I came from there to here so… I've done a few other things.

I- yeah, what's your undergraduate degree in?

P1- Uh, Industrial engineering/marketing at Clarkson

I- Okay, and then you went back to Oswego to get your degree in…

P1- Yeah, basically I picked physics y'know, because that's where most of the, uh, coursework was relevant that I'd already taken, it was the shortest path.

I- right

P1- I'm working on earth science certification right now, so…

I- very cool, so you've probably been teaching about, well, you got into teaching about the same year that I did, and I taught for three years in technology education, um, what subjects do you teach?

P1- I, uh, taught a bunch of different things, right now I uh teach AP physics, regents physics, uh, sort of a self-contained earth science that's at the regents level but it's got a special ed teacher in here to help keep the kids organized and make sure they follow through on stuff and then I've got one section of uh regents earth science and some labs that go with those.

I- okay, generally what's the level of the students who you teach, what grade level?

P1- uh 9th through 12th

I- 9th through 12th? Okay. What's your favorite subject to teach?

P1- hmm, well, like if I was starting out from scratch, like earth science I really enjoy more, it's maybe more to do with the kids than with the uh, the subject, the 9th grade kids are more enthusiastic, the seniors tend to get senioritis by now

I- [laughs]

P1- and they sort of lose their enthusiasm for the subject

I- [laughs again] I understand, okay, well very cool, alright, moving into some general questions, have you ever flown on an airplane?

P1- yep

I- okay, what are your ideas about what makes an airplane fly and go up into the air?

P1- well, it depends upon first of all y'know what kind of airplane, if we're talking about propeller driven versus jet airplane, uh, you need some method of getting the uh the plane moving forward relative to the air mass that it’s in so that you have a flow of air over the wing surfaces, because the wing surfaces are flat on the bottom and curved on top you have a faster flow of air above the wing than below it because of Bernoulli’s Principle that fast, uh, flow in a fluid is a place where there’s a lower pressure, you have a lower pressure above the wing than below and therefore the net force is upwards y’know based upon the relative speed and the surface area of the wing and things like that and that if you can get going forward fast enough that your lifting force is greater than the weight of the airplane it should take off, so that’s sort of what I think and y’know you have the jet engine pushing action reaction forces or the propeller kind of turning its way through the air that would uh y’know tend to pull it forward

I- okay, action reaction forces tell me a little bit more about those

P1- well you have a situation in a jet engine for example you have the fuel being burned and ejected out of the back of the engine at a high speed every particle that’s being ejected out is pushed on by the airplane and it pushes back so you have y’know equal and opposite forces going on there between the jet engine and the particles being thrown out of it. Um the same thing with the propeller I suppose it’s turning through the air it’s pushing on the air and the air pushes back and the net force then is forward

I- okay, when you’ve flown on an airplane describe to me what happens when the airplane takes off

P1- like on a jet, I guess I’ve flown on small planes and big planes but like y’know you basically get in the airplane go to the end of the runway and they decide which way the wind’s blowing cause you want to take off into the wind uh because then you don’t have to get up as high of a speed relative to the ground as you would if you’re trying to go with the wind because it’s the speed between the airplane and the air that makes a difference and then you uh they hit the gas and cause the forces to increase and increase and accelerate down the runway until you get up to a speed where the lifting force is greater than the weight and at that point the plane will begin to come up off the ground y’know they control the rate at which it comes up with the control surfaces on the back of the wings y’know once they get up off of the ground and are safely up they’ll pick the landing gear up and reduce friction so that they can climb even more rapidly and then they'll continue on upward until they get to their cruising altitude and then kind of level off

I- okay, alright, you mentioned friction there,

P1- yeah

I- what is…

P1- wind resistance, y'know the more things you have sticking down into the airflow y'know the more force it's going to take to push the airplane forward y'know once you get up off the ground you want to fold the landing gear up out of the way so that you have a more streamlined laminar flow of air around the fuselage and less turbulence around the landing gear and things that are down below

I- okay, I heard you mention the word laminar, explain that

P1- well uh to explain it, it would be sort of like when you have a flow of air um, [draws example of laminar flow on blank sheet of paper] as it goes around an object y'know say the surface of a wing if it remains in sort of a uh coherent streamlined pattern like that without any turbulence that's what we call laminar or streamlined flow the way you'd see that in engineering would be to put the object into a wind tunnel and either have ribbons attached to it or let dust or smoke blow past it and you would observe that now if you have an object that's got a lot of turbulence because of its shape you'd see these eddy currents kind of forming around behind and that would y'know that kind of flow is a non streamlined flow where you get a lot of friction because of that and that will tend to happen more as you go faster and faster that you get that kind of thing

I- okay

P1- and these eddy currents are the turbulence that I was talking about

I- okay let's see is there any particular part of the airplane that you would think of as being very critical to being able to get up into the air?

P1- any just one part?

I- yeah a particular part

P1- okay I guess the uh the wing in terms of being able to take off because even if you didn't have an engine if you had a place where it was windy enough you could have your wing tied to the ground and balance on it and take off [uses hands to emphasize this idea] even without an engine so I would say the wing

I- okay okay are there any other parts of the airplane you think are very important to for the airplane to get up into the air?

P1- well if you're talking about something you can fly around in you'd need some sort of engine or propelling device that would allow you to get off of the ground

I- okay

P1- and then once you're up into the air you want to be able to steer so those parts become important at that point I suppose the tail and the control surfaces and things

I- okay you've kind of explained this anyway but I'm going to go ahead and ask it- what does lift mean to you?

P1- well it's the forces acting upon the wing of the airplane the idea that uh you have a pressure difference between the top and the bottom of the wing and if there's more pressure which is force per unit of area below the wing than above there's going to be an overall leftover force you'd call a net force pushing up and that would be what we call the lifting force and that's basically the idea that if you have two air molecules meeting at the leading edge of the wing they want to meet again at the back and if they want to do [fingers of left hand demonstrate air movement around wing top and bottom] that the one on top has to go farther because it's a curved wing and therefore they have to go faster to reach the back at the same time

I- okay um let's see what does the word aerodynamics mean to you?

P1- uh aerodynamics would be the study of the flow of air around an object looking at the effect of the shape of the object maybe in terms of wind tunnel testing do you have a streamlined or laminar flow of air around it the aerodynamics would also be like the overall flight characteristics of the airplane based upon the shape and the size the engine type and the engineered top speed and things like that that you were trying to get out of it so there's a couple different meanings depending on what you're talking about I guess

I- okay fine have you ever held your flattened hand out of a car window while the car is going down the road?

P1- well my mom always told me not to because you could hit a mail box and break your arm off

I- [laughs]

P1- but I have of course yes

I- and describe to me what happened when you did that

P1- well I mean you can actually as you hold uh your hand out of the window [demonstrates with right hand extended with arm moving up and down, and hand changing “attack angle”] if you have a slight upward incline on the front edge of your hand you can feel the air trying to pull your hand up and if you tilt your hand that way [tilts hand down] you can feel it pulling down so you can kinda get a sense that air can provide a lifting or pushing down type force depending upon the angle of attack that your hand has as you get into it

I- okay

P1- and the other thing that we noticed is the faster you go the more noticeable that is

I- okay, is that due to an aerodynamic lifting force?

P1- [pauses and thinks] yeah I’d say so

I- yeah?

P1- y’know because the more you cup your hand [demonstrates with right hand] the more you have a shape that’s like an airplane wing and the more noticeable it would be yeah I would say so

I- okay, how about if you kept your hand perfectly flat?

P1- like that you mean like somehow I had just a flat sheet [demonstrates with hand]

I- yeah

P1- well then you would still yeah because you’d still have an aerodynamic effect but not because of the same reason I think cause it’s kind of slicing through the air and [pause] yeah but I’d still say there would be a lifting force

I- okay alright

P1- because of the angle

I- ok, uh because of the angle?

P1- yeah, well y’know even if you took a flat board and hold it out the window y’know you would notice when you point it down that there’s that the air is striking more directly on that surface and it’s going to push it down and if you hold it up y’know it’s going to push it up because the air is hitting one surface a lot more than the other

I- and that’s an aerodynamic lifting force?

P1- I don't know… if I it's not the same reason I don't think now that you mention that it's definitely due to the interaction of the air molecules and the surfaces but it's not for the same reason that a wing would have lift I don't think [pause] I don't know

I- okay you've already kind of mentioned this as well just kind of your own free will in a way but uh if an airplane is parked on the ground and there's a really strong wind blowing right into the front of it would that airplane try to fly?

P1- well I know that they anchor the airplanes to the ground so that they wouldn't get blown over I think in order for it to fly you'd almost have to have a kite type situation where you'd have like some sort of rope attached to the ground to hold it in place because if the airplane was just loose it would just get blown away like a piece of debris

I- mm hmm

P1- versus if you have it being held y'know like here's your airplane [draws rough sketch of his idea on bottom of sheet he previously drew laminar flow example on] and if you've got a rope tied to the ground or something like that then the wind can pick it up because if you just have it loose it's just going to get blown along with the wind it's the same if you're flying a kite and you let go of the kite it'll fall y'know or why you can't like be picked up and carried away by a kite even a great big one

I- okay

P1- so I would say that the wind can definitely blow the airplane away but it wouldn't take off and fly on it's own without being held forward by something

I- okay all righty, I've got a couple of wing models over here I'd like you to take a look at these two and tell me what you notice as far as similarities and differences and if you can describe those similarities and differences

P1- well, the, the length of the cardboard wing and the [holds wings together] Styrofoam wing is just about the same and these are y'know front top yeah they're oriented the same which would mean that the amount of surface area on the bottom of the wing would be about the same

I- okay

P1- [picks up cardboard wing] this one's the same thickness all the way through when you look at it from the end there's no curvature or anything else to it it's just a flat uh basically flat piece of cardboard and y’know there’s a slight downward turn but that may well have been from y’know transporting it or something like that so that’s pretty flat

I- okay

P1- this one [picks up Styrofoam wing] as we look at it uh well this section here is flat [end of wing model that gets inserted into model airplane body] but I suspect that may be the piece that gets stuck into the airplane body

I- that’s correct

P1- the rest of it here it’s flat on the bottom curved over the top which would mean y’know like I talked about a few minutes ago that a piece of air if it went over the top of the wing versus over the bottom it would have to go faster over the top to get to the back edge at the same time that its partner went y’know along the bottom they gotta go a bigger distance in the same amount of time it’s going to be going faster and therefore less pressure above the wing so I’d say this one would generate more lifting force out of the two if we were to put them into some kind of thing and, and try them at different angles and things like that [holds both wing models in opposite hands in front of himself, moving them in the same ways to demonstrate various attack angles] y’know had some way to measure the forces… and this one has imprints of y’know simulated control surfaces on it I suppose, this one is a lot less dense [referring to Styrofoam wing] I would say like if you were to look at the weight versus area

I- okay

P1- they’re about the same mass though I mean without really massing them I can’t tell but they feel similar

I- mm hmm, okay

P1- what else… [balances each lengthwise on a pencil to determine center of gravity] just a second…

I- now you’re balancing them

P1- well the balance points pretty similar I was surprised I thought this one [Styrofoam wing] would be closer to the edge because of the bigger mass of stuff that’s here [end of Styrofoam wing model that gets inserted in Styrofoam model body]

I- that's neat, I, I hadn't thought of that… um, okay I'll go ahead and ask this… do you have any ideas on why that curve is in that wing and why that looks more like a real airplane wing? Would that make a difference over the cardboard in any way?

P1- yeah, I, I think y'know in terms of what I've talked about already in terms of Bernoulli's Principle that if you wanta have uh faster airflow over the top of the wing than the bottom you have to have the curved shape but if you go to an extreme with that say that you had something that was basically like a half circle y'know perfectly round on top [holds Styrofoam wing in left hand and describes a semi-circle over it with right hand] and flat on the bottom that wouldn't work out very well as a wing even though the air going over the top would have to go a lot faster you would have no longer have the streamlined aerodynamic flow you would have turbulence so you wouldn't get your lifting force so..

I- okay

P1- that has to do with providing the lifting force or the aerodynamic lift,

I- okay

P1- I would say, that's why I would say it's curved

I- okay, okay what I'm going to do now is turn on that fan and in front of you

P1- all right

I- and the fan is going to provide airflow and… um… what we're going to do is start with the cardboard wing, I have this little carpenter's line level here [demonstrates how to hold wing with line level on end]

P1- mm hmm

I- and the purpose of that is so that you can gauge the relative

P1- angle?

I- levelness

P1- okay

I- of each, of each piece and I want you to hold it more or less like that [] fairly gently and what we're going to do is hold that in front of the

P1- try and keep it level in other words?

I- well at the beginning and then I'm going to ask you to move it in a couple different ways and um, let's see, I'm gonna… try and avoid having it blowing right on the microphone there we go.. okay if you hold it probably just about right at that level where the wires are bent on the frame, um, go ahead and slightly pivot it up and down and describe what kind of sensations you feel

P1- [stands in front of fan holding model cardboard wing] well when you tilt it up you feel like it's trying to push up on the thing

I- ok

P1- and when it's pivoted so the front edge is down it feels like it wants to push it down

I- ok

P1- and when it's level it doesn't feel like it's doing much of anything

I- ok

P1- it kind of oscillates a bit, you can feel it vibrating up and down in a way

I- ok, at what point in pivoting it up or down do you start to notice a ah, some kind of force on it?

P1- well the more that you've tilted it, y'know, the more force is pushing back, but

I- mm hmm

P1- it doesn't take too much, [pivots model wing slightly] the force seems to get bigger the more surface area's being exposed, but that's not surprising I guess

I- ok

P1- and it feels about equal up or down

I- ok

P1- it feels about equal either way [pivots wing model up and down several times]

I- ok, I'd like to try the same thing now with the Styrofoam wing

P1- all right, with it level you can feel this end of the wing [points to outer end and then demonstrates upward force with finger pushing end up] trying to pick itself up a little bit, notice the vibrations in it.

I- yeah, ok

P1- some of that more, that really doesn't matter, well there's more force as you tip the leading edge up than there was for the cardboard I think, and when you tip the leading edge down boy, it really doesn't feel like it's pulling down as much. Let me try that, can I try it against the other one again?

I- oh, definitely

P1- [pivots Styrofoam wing up and down a few times in front of fan, then picks up cardboard wing and does the same, then picks up Styrofoam wing again and repeats with that] well, it's definitely different

I- hmm

P1- it's almost like there's not as much surface area for the wind to push on, on the curved wing than there was on the flat one

I- huh

P1- and y'know when you have it angled up a little bit you don't have to hardly hold on to it at all, woops, if you don't drop it you can almost balance it

I- [laughs] anything else that you notice, or…

P1- the outer edge of the wing feels more like it wants to pick up, like it wants to rotate, like there's a torque on it

I- ok

P1- maybe if I hold it level the other way too [lengthwise] it would be better though [puts down Styrofoam wing and picks up cardboard wing again]

I- go ahead and describe what you're feeling

P1- well what I'm doing right now is I'm tilting, the wing's pretty flat to the fan but I'm tipping the outer edge up [outer end of the wing]

I- mm hmm

P1- when I do it with this one it doesn't feel any different than it did when it was level

I- ok

P1- I guess it doesn't really feel much different with this one either [does same movement with Styrofoam wing], but it just feels like this one wants to pick up and go [Styrofoam wing], the other one really doesn't [alarm on I's palm pilot goes off] yeah, well it feels about the same amount of force. So I'd say that the Styrofoam wing feels like it could do a better job of flying an airplane than the cardboard one

I- ok, great, all right, very good [P1 tries to turn fan off, but a knob must be pushed in, so I does it and comments that the fan control is poorly designed] ok, let's see what do I got here… woops [knocks over micro-cassette recorder reaching for paper] ok, what I'm going to ask you to do next is to hold this paper like this and just put your mouth, blow over the top of it

P1- mm hmm

I- first I'd like you to predict what will happen when you do that

P1- so I'm holding my mouth so I'm above it and blowing..

I- yes

P1- over the top of it, it's going to pick the paper up I think

I- ok, and why?

P1- well the same reason that we talked about a few minutes ago if I blow over the top of it so the air above it is moving and the air below it is not, and if you have a faster air velocity there's going to be less pressure there so the pressure below will be greater, it will pick it up

I- ok

P1- at least that's what I think

I- ok go ahead and give it a try

P1- [begins blowing over top, 4 blows] I guess it did it, didn't it? [P1 had a hard time seeing the paper where it was held below his eyes]

I- uh, yeah

P1- [blows again] there we go

I- yeah ok, so you said that blowing over the top of that, the air would be moving and the air underneath wasn't moving

P1- mm hmm

I- so what do you think about that?

P1- well it's the same reason that roofs will blow off of a house during a hurricane, the air in the attic is more or less still

I- mm hmm

P1- the air outside is moving pretty fast, and Bernoulli's principle relates the pressure versus velocity of a fluid, you've got low pressure outside the house high pressure inside the house it can actually pop the house right off and the same thing is going on here, because of the fast flow of air, there's less pressure above than below so the natural tendency is to have a net lifting force upward on the paper, in that case equal I suppose to the paper's weight when it's out there just flat [holds up end of paper with hand]

I- ok very good, um, let's see… all right, next thing, another common… trick, what I'd like you to do is to try and hold these two pieces of paper so that they're hanging [demonstrates holding paper] vertically and are parallel to one another and I'm going to ask you to blow in between them

P1- mm hmm

I- and I'm going to ask you first to predict what will happen when you do that

P1- well, I think that if I was to hold them apart like this and if I was to blow in between 'em that they're going to be pushed in towards the center, for the same reason, that air flowing through the middle is going to give a low pressure zone because of the movement of air and the air on the outside not moving is going to be pushing inwards with more pressure than there is on the outside and it'll force 'em together.

I- ok, why don't you give it a shot?

P1- [holds papers, one in each hand, and blows between them] yup

I- certainly looks… you weren't doing that with your hands or anything were you?

P1- oh no [blows again] I…

I- I was just kidding…

P1- oh, okay [I laughs]

I- ok, all right, now, get this out of the way, ok, now what we're going to do is take a look at this drawing that we've been looking at here of, what does this drawing look like to you?

P1- well, I'd say it looks like a view looking in towards the body of an airplane from the outer edge of the wing, y'know, looking at the cross section of a wing I guess would be the best way to say it

I- ok, ok, all right, pretend that the wing is on a plane that's flying through the air

P1- all right

I- and, tell what you think is going to happen, with, this is the front edge or leading edge

P1- ok

I- what do you think is going to happen to the air at that front edge?

P1- what…

I- you can draw, sketch, with different colors if you want

P1- well ok

I- whatever you want to do

P1- let's say that we had two air molecules that were close to each other

I- ok

P1- and let's pretend for the sake of argument that maybe there's no wind that day, the only movement is because of the airplane

I- ok

P1- so the wing's moving forward and being as these two things are in a fluid uh, they're kind of fixed in relation to each other, and so as we go, time lapse, here goes this one and the wing's moving past it, and if this other one is going to keep up so that they can meet again at the back [sketching] they uh, have to take the same amount of time to go past the edge of the uh, the edge of the wing.

I- ok

P1- if we had some way of measuring the path that they had to take, y'know with a string or something like that and actually measured these two distances y'know, we would see that the distance is larger on the top of the wing

I- mm hmm

P1- than it is on the bottom and if we think about then, the velocity is distance over time, if they have to take the same amount of time there has to be a uh, above the wing, all right, so there has to be a higher velocity above the wing

I- ok

P1- uh, at least that's what I think will happen in terms of the air molecules as they move past the wing

I- ok

P1- is that what you asked me?

I- yeah, yeah what, um, can you sketch maybe with a different color what the relative forces are going to be, that that wing experiences, you had talked about some lifting forces…

P1- mm hmm, do you want all the forces acting on the wing or…

I- sure!

P1- ok, well the first thing that we'd have is that at the center of mass there'd be a uh, there'd be a force due to gravity which would be equal to mass, y'know this would be for the whole plane times the acceleration due to gravity so we've got a weight pulling it down,

I- ok

P1- we have uh, a force equal to the pressure divided by the area of the wing up here and we'd have a [pencil breaks] oops sorry about that

I- that's ok, not a problem, that's my fault for sharpening them really…

P1- and there's your force equal to the pressure divided by the area down here and I've tried to draw these sort of like in relation to each other

I- ok

P1- so if the plane was just in level flight the two downward forces would be equal to the upward force and you would have a balance of forces there just keeping it at one level

I- ok

P1- uh, when I say pressure divide by area I'm saying that the pressure up here is less than it is down here because of the difference in the flow rates

I- and graphically you're showing that by vectors

P1- by vectors yeah

I- ok, ok, all right

P1- and then the other thing we'd want to think about is uh, you'd have a uh, let's see, the plane's moving this way so there's a balance of forces between the uh, the force of the uh, propeller, or whatever it is that's driving the plane, minus the force of uh, friction we could call it I suppose which would be the uh, which would be y'know the uh air resistance I guess and, and these, if the plane's at a constant speed I have drawn them to exactly the same length to show that they were balanced y'know by the vector idea again [see drawing]

I- mm hmm

P1- uh, that's all the forces I can think of right now

I- ok

P1- if it was accelerating the propeller force would be higher than the friction force and so on…

I- ok, ok if you took the regular wings off an airplane and stuck on a couple sheets of plywood instead, would the airplane be able to fly?

P1- there are some airplanes that look pretty close to that but uh, let’s see, just flat, so in other words it’s the same top and bottom?

I- mm hmm, just a sheet of plywood, go down to Chase Pitkin, buy a couple 4x8 sheets stick ‘em on the sides...

P1- no, I’d say I’d say not

I - yeah?

P1- I’d say not

I- what if they were tilted some way?

P1- [P1 pauses and thinks] I don’t know, like you fly a regular paper airplane that you just fold up, there really isn’t any curvature there but, uh… if it did fly it wouldn’t be something I’d want to fly in [I laughs] I think because you get to any sort of speed the turbulence would build up pretty quickly and it wouldn’t be a very pleasant thing to fly. I don’t know, I’m going to stay with, even if you tilt it it’s not going to work

I- ok

P1- I don’t think

I- ok

P1- although I couldn’t really give you a detailed answer as to why.

I- ok, let’s see, let’s think about this as being attached to a real airplane again

P1- all right

I- if this wing, let’s say is perfectly level with the ground, as the airplane is sitting on the runway

P1- all right

I- and then let’s consider another scenario where as the airplane is sitting on the runway, this is tilted up a little bit

P1- mm hmm

I- so that the leading edge is higher than the trailing edge back here… what are your thoughts about what the differences would be and how that wing would act?

P1- I think…

I- Let’s say that we had two exact same planes next to each other going down the runway

P1- yeah

I- or uh, parallel runways

P1- yeah

I- and one had a flat wing, one had a tilted wing, the wing shapes themselves were exactly the same, the only thing changed between the airplanes was the angle that the wings were at

P1- so here's one airplane like that then the other one has the wing kind of tilted? [draws]

I- yeah

P1- in relation to the body?

I- yeah

P1- now if you're looking at it from the front are both of the wings kind of straight across like that or is there

I- they would be, the only difference would be the

P1- angle of attack?

I- the angle of attack

P1- all right

I- tell me what angle of attack means to you

P1- well I would say that's the angle at which the wing is entering the surface, y'know, the fluid, be it air, or if you're talking about boats y'know, water or whatever, I think that if we looked at this situation here [draws], it would be that this airplane could take off at a lower speed… because…

I- that's the one with the greater angle

P1- yeah, the one with the greater angle, I think that that one would be able to take off at a lower speed, but I think if you were to look at the, the top speed would be less in that case because you're going to get the turbulent airflow happening at a lower airspeed because of that angle of the wing

I- mm hmm

P1- if you go too extreme with that, like if you, it might make it easier to take off but you're not going to be able to go as fast once you get in the air.

I- hmm

P1- is what I think

I- ok, ok, well this is moving along a lot quicker than I expected, which is good, ok what is this?

P1- well it looks as if it might be one of those so-called paper airplanes that kids sometimes make

I- yeah, they do that once in a while in class don’t they

P1- yup

I- all right…

P1- I’ve actually had them do a lab on it before in physics

I- oh have you?

P1- I have em try to go for flight time versus distance and to come up with a balance, what they usually find out is you can’t have both, you can either get one that stays up, well I think my record was like ten seconds

I- wow

P1- flight time, we’d go down to the gym and do it, or one that can go all the way across the gym and hit the other wall,

I- mm hmm

P1- but you can’t get both

I- cool, well go ahead and give it a toss, and tell me what happens.

P1- [P1 throws it] it looked like it stalled

I- before it stalled, was it flying?

P1- well, can I throw it again?

I- oh, absolutely! Throw it all you want

P1- actually that flew pretty well that time let me throw it in a way that isn’t going to hit anything

I- that doesn’t matter

P1- [throws again] well it definitely stalls I would say it was gliding fairly well before that happened

I- ok, tell me about the shape of the wings on that

P1- well, they’re basically, say, triangular I suppose if you’re looking at them from above or below, uh, the surface area of the wing is a lot greater than that of, I guess you could call it the body

I- ok

P1- they’re not really tilted up or down or anything, the back edge is a little bit, very, what I’d call streamlined, y’know, smaller in the front than the back, if you were to try to throw it this way, y’know it probably wouldn’t work too well [P1 throws it backwards, I laughs]

I- just goes right down doesn’t it?

P1- and because of the way that it’s folded the center of gravity is probably, well, if it wasn’t for the paper clip, fairly close to the front

I- ok

P1- there’s more mass of paper up in here [points to front of paper airplane], in a small place

I- tell me about the aerodynamic curvature of the wings

P1- well, that’s hard to say, like this wing, you can kind of see, because of the way the paper bulges up that it is a bit of a curvature to it there the other wing isn’t really like that, unless you do that to it, the other thing you could do I suppose would be to do this thing to it, throw it so they were kind of pointed up in a “Y” shape

I- ok, what would that do to change the flight characteristics of it?

P1- I think it would make it more stable, from rocking, if nothing else

I- ok, why don’t we test it?

P1- it went a little bit farther before it started doing stuff

I- yeah

P1- I think the paper clip is in the wrong place though

I- then move the paper clip

P1- I didn’t know if you had it there for a reason [moves paper clip and throws again] well that was a lot better,

I- yeah

P1- I think I might have gone a little bit too far forward [picks it up and throws again toward back of room]

I- well that’s cruising right along…

P1- not bad at all now, I’d say it’s flying better now

I- so why is that?

P1- I think that before when the paper clip was too far back it allowed it to rotate around the center of mass upwards [demonstrates with paper airplane in hand], that slowed it down, when it slowed down beyond, y'know, the stall speed the speed at which the lifting force wasn't sufficient it kinda just kinda fluttered down this has got it balanced more so the wing can kinda stay more level in the air

I- mm hmm

P1- I think that's why changing the paper clip made a difference

I- ok, now you mentioned the lifting force, tell me about that on this paper airplane.

P1- I don't know that this thing has much of a lifting force, I guess I'd like to see what it does in a wind tunnel

I- oh yeah! You just gotta push that in, there you go [P1 turns on fan and holds paper airplane in front of it]

P1- like it's really… unless you get sort of an angle at it it doesn't feel like there's much lifting force at all

I- what keeps it up in the air then when you throw it, why doesn't it just drop down to the ground?

P1- well I think that the reason it doesn't just drop down on the ground is the same reason that doesn't just drop down on the ground [drops piece of paper flat, or parallel to the ground] that um, it is dropping down it's basically dropping at a slower rate than the acceleration due to gravity because you've got a wind resistance force slowing its acceleration down hey Ally [student comes into classroom selling something for a fundraiser, minor interruption] I think that this is more like a projectile than an airplane

I- ok

P1- and it's one that doesn't fall like a rock

I- mm hmm

P1- I mean, there could be a little bit of lifting force but, but not as much as you would see if you built a different sort of airplane that had a y'know curvature to the wing like you would see there

I- mm hmm

P1- if we had y'know another airplane with the same sized wings that we could somehow build out of something that would have that sort of wing shape I think you'd be able to measure a bigger lifting force whereas I think this just doesn’t fall that quickly because for the same reason that this doesn’t fall that quickly it’s got surface area relative to its weight

I- mm hmm, ok

P1- like I dunno

I- [end of planned interview, about 40 minutes into interview] now I’m curious to ask you about the paper airplanes that you have your students build

P1- yeah

I- and you mentioned that there are differences in between the time in air and the uh, the speed, can you tell me some of the designs…

P1- well yeah, the ones that would stay in the air a long time [begins making a paper airplane] would be ones that would have a fairly large wing area relative to the overall size of the airplane there was one that… I can’t remember the exact design, it was one that they went on the internet and researched and found it was the world record holder for these and it had a sort of a design that was somewhat like this [P1 makes paper airplane] if I remember right, I’m never good at replicating these but, it was something, this is one that I’ve made, and then you had to do something else to it I think uh, there was more to it than what I’m doing but I think that this will work when it’s all said and done, let’s see, that piece gets ripped, I used to make airplanes in school too I know the shop class here, the technology class here used to get uh, like meat trays and make airplanes out of little Styrofoam meat trays

I- oh yeah?

P1- yeah

I- that’s interesting, I never thought of using Styrofoam meat trays to...

P1- I don’t know where they got ’em from, and then it seemed like there was something they did back here where they took some of this off by creasing it across then they would tear this off without ripping it which I probably won’t be able to do… let’s see, yeah, that went in there, it seemed like this was creased… like that… I don’t know if that’s going to stay though, I think that there was something, there was something else that they had that kind of kept things in place and it kinda, there were paper clips involved and things [completes paper airplane after about 2 minutes, and throws it]

I- right

P1- but it had a fairly big wing area, it had a fairly big wing area in relation to the size, it may be that you have to do some manipulation with this, or I don't know what but uh,

I- right, it almost looks like a stealth fighter

P1- yeah, and these are, the ones that looked sort of like this stayed up in the air [throws his paper airplane again] quite a long time when they threw them down there, they did a lot of loops and a lot of circling around and things like that

I- cool!

P1- but uh, it looks to me like it needs some weight on the front though… [takes paper clip off first paper airplane, brought in by I, and puts it on his airplane] and then the ones that went the farthest were basically really I guess you'd call them streamlined or pointy they were more like darts than airplanes and they just flew as a virtue of them being thrown as very fast projectiles [throws his paper airplane again]

I- that's pretty cool

P1- I don't know that's not very good but at any rate they made some that stayed up in the air for quite a long time that had big wings for their length

I- cool

P1- along those lines

I- cool

P1- and some of them got into the research on the internet and looked up a bunch of stuff about airplanes and model airplanes and things like that so…

I- cool

P1- I don't know, that's not very good though darn it

I- it looks pretty neat to me

P1- then some other designs they had that were pretty successful were taking a couple drinking straws and making a uh, tube body and then taking a couple of strips of paper and making them into rings and taping that on so you had a big ring on one end [does a quick demonstration with a full sheet of paper, curving it more or less into a circle] and a small one on the other and those flew pretty well

I- oh wow!

P1- and there was a bunch of different weird designs that they came up with

I- huh, cool

P1- so… maybe this one flew better without that, I don’t remember

I- so what was the um, the object of your lesson when you did that

P1- well basically to begin thinking about um, not so much airplanes, but trade-offs in design like you can’t make one thing that does everything well um, the airplanes are one way to look at that, um, they did make some conclusions, we did talk a little bit about what it takes for a wing to stay in the air, y’know the lifting force has to be bigger than the weight and things like that

I- mm hmm

P1- [P1 throws his airplane again] there we go

I- whoa!

P1- that was better

I- that was sweet! [laughs]

P1- I knew I did something right, I think, yeah, y’know what, the one that had the tail on it had a little bit different folding to it that

I- oh ok

P1- that’s better now

I- that’s pretty cool

P1- that’s better now, all right, um, yeah, at any rate it was just something where they, uh, it was a contest, the spirit of competition and things to, and some of them, we did two different periods, one period to kind of test some ideas and we went back for, y’know, the record

I- mm hmm

P1- and some of them really took it as being a contest and got into it and were like keeping track of how the other sections were doing and things like that so…

I- cool [45 minute audio tape runs out, remainder of transcription made from video tape of interview] what, um, do you get into any aerodynamics in your physics classes?

P1- well, yeah, we just did fluid dynamics in the AP physics which involves Bernoulli’s Principle, in fact I’ve got, in my cupboard here some stuff, a couple different things I’ve brought down to use as, sort of a visual, [P1 opens cabinet] I have a lot of toys that I use, I had this, I had my AirHog airplane, and I just basically used the wing from that, [gets some things out of cabinet] and I've got this thing too, which flies pretty good

I- oh, yeah, they sell these in Wal-Mart

P1- yeah, they fly really well

I- do they?

P1- better than any right that they have, for they price that they are, and all these things have the same idea, y'know this has the flat bottom and the rounded top [holds a model helicopter, pointing to rotor blade] and you've got the angle of attack thing going on here and basically the idea that a helicopter has its wing rotating through the air, and these [pulls string on launch mechanism sending model helicopter flying into the air, bounces off ceiling and crashes back to floor to the amusement of I & P1] fly pretty well

I- cool!

P1- [goes to pick up model helicopter] and uh, I bought these up at a store that was going out of business, I got three of them for like four dollars, or something like that, I'm always looking for the bargains [launches model helicopter again at more of an angle sending it farther]

I- that's pretty slick…

P1- [picks up AirHog wing] and we looked at the shape of the wing on this, it was the best thing I had, I have one of those Styrofoam jet gliders at home that has probably a better one but I didn't think to bring it in, this actually has got [concave] curvature to the bottom surface too

I- and what does that do to…

P1- well y'know I don't know

I- you were talking about flat bottom wings before so…

P1- I think still if you were to measure the linear distance, bottom versus top, it's still gotta go farther over the top so I think the same principle is applying, whereas this one really is more along the idea of what we were talking about [picks up package with another flying model airplane] with the uh, flat bottom, this one has some dihedral to it, which is the tilting in, towards the center [shows with hands in a "V" shape]

I- ok, is that similar to what you were mentioning [I picks up paper airplane and flexes wings up a bit] here?

P1- yeah, y’know, with the folding of those, I think it has to do with control, of the airplane, I’m not really sure… I just remember when I was a kid my dad was into model airplanes when he was a kid and so we used to build the ones out of balsa wood with the framework and all that stuff

I- mm hmm

P1- and then we’d fly them two or three times and they’d break, and I remember he had these blocks that he made to get the right, sort of angle there [uses right hand to demonstrate angle of wings coming up from body of plane] when he was making the balsa gliders and stuff, so I know that sort of idea is important to the flight characteristics

I- ok

P1- I think more in terms of stability than actually the, lifting

I- have you ever been to an air show? [this question was asked “off the cuff”]

P1- oh yeah, yeah I love airplanes

I- yeah?

P1- excuse me I’m getting the helicopter

I- not a problem

P1- yup

I- yeah, I’ve been to air shows too, and um, one thing that’s always amazed me is those airplanes that fly upside down, how the heck do they do that?

P1- [thinks for several moments] yeah, because what we’re looking at here is we’ve got the, uh, different lifting forces, I think that if you’re looking at one flying upside down, [picks up Air Hog wing again] normally this would be flying in this sort of attitude, [flips wing upside down and holds it with more of an up angle] I think if they’re upside down they have to kind of angle the nose, well from their perspective down, but from the ground kind of up, to give the different angle of attack of the wing surface through the air… you can’t do it forever I don’t think, like I don’t think they could keep flying upside down for a really long time, maybe I’m wrong, but they’d have to have that angled in such a way like this so that you did have an upward, upward force

I- mm hmm, what if I told you that as long as the fuel could still get to the engine they could fly upside down forever?

P1- yeah I think that you’re right now that you say that, I believe you

I- how, how would you explain that?

P1- well, basically, at whatever speed they're doing it, that angle must provide enough lifting force to keep the airplane flying at that height, because if they were constantly coming down [demonstrates with hand] they wouldn't let them do that any where near the ground and they usually do a near-ground pass like that so it must be that they can hold it level, not only hold it level but actually steer it up like that

I- mm hmm

P1- yeah, I believe you…

I- what would be the aerodynamic lift, provided, in that case?

P1- [pauses and thinks for a moment]

I- or would there be aerodynamic lift?

P1- well yeah, obviously there would have to be but… it has more to do with the angle [holding model Styrofoam wing] effect than it has to do with the curved surfaces effect I think at that point…

I- now you mentioned the angle effect before, can you explain that a little bit more…

P1- well like when you have your hand out of a window, when you angle your hand upward, it lifts it up, when you angle it down, it pushes it down… [demonstrates with hand]

I- ok, that's not, are you saying that that's not Bernoulli's Principle, or is it?

P1- [pauses to think] Bernoulli's has just to do with a different velocity… of the fluid on one side of the surface from the other…[thinks for several moments] it may well still be, but for a different reason, I think… like if you have a bigger angle like that the air that's hitting here [points to underside of his hand] may be getting slowed down a lot cause it's kind of like hitting a wall, and the air up here isn't, so it could still be a lifting force, and if that's the case then maybe my answer about the plywood, flat wing could be wrong

I- are there any other thoughts that you have?

P1- about airplanes or…?

I- about airplanes and flight, aerodynamics, lift, whatever

P1- the thing that always fascinated me were the French Mirage fighter jets that have the little tiny stubby wings, they look a lot like Chuck Yeager's X-1 there in terms of the overall shape of them, and they have to be flying incredibly fast even to get off the ground, I’ve always liked those for that reason just because it looks like the type of airplane that you have to really, really know what you’re doing in order to fly

I- mm hmm

P1- that and Harrier jump-jets, I always liked those for a different reason

I- those are cool, I like those too

P1- they can basically, their lifting force can be supplied just by an engine pushing down

I- mm hmm

P1- vertical take-off and landing sort of idea

I- yeah

P1- I think that probably kids don’t really have an idea at all of why airplanes fly

I- why do you think that is?

P1- they are never taught it, really, like unless, I don’t know how much they do with it in technology but not everybody takes technology

I- mm hmm

P1- when we talked about the Bernoulli thing, I think that was a lot, a lot of them that was the first time they knew that there was a pressure difference if you had a difference in the fluid flow rate, that they hadn’t really thought of as air being a fluid, um, that they just figured it was probably the angle, because that’s what they felt when they stuck their hand out of the car, I don’t know that a lot of kids have flown, or seen air shows or things like that,

I- but airplanes are pretty commonplace in our society

P1- yeah, you see them, you see them but uh, I don’t know if they ever really think about what it takes to make one fly… it’s too bad in a way, that they know, another thing, Doc, the chemistry teacher, was appalled today he was talking to me after school that how few kids know the voltage that’s in the wall, so they don’t know if it’s a hundred and ten or whatever, or a hundred and fifteen volts, they just like say whatever… they don’t have any sense of how things around them work…

I- do you think that’s a bad thing?

P1- well, yeah, y’know I think that a well-rounded person oughta know enough, well of course now there are so many things to know, but, uh, enough about all the different parts of their society that they could explain it pretty fully to anybody that was foreign to that society and I think our kids lack a lot of the fundamentals about how very basic things work, like water magically comes out of the faucet when you turn it on, y'know, those sorts of things

I- meat comes from Wegman's

P1- yeah

I- I agree, I know exactly what you're saying… well I think that I, uh, unless you have some more uh, anything else that you want to mention, or anything, that pretty much, uh, covers it for actual questions that I have

P1- yeah, all right, that's good, one thing we did think about doing a few years ago we were going to have high school teachers take their advanced kids, let them go down to the earlier grades and do demonstrations on stuff like this and I was going to always have them do a unit on flight and we even have a little resource book here somewhere on principles, basics of flight and things like that, but we never really had time to do it

I- mm hmm

P1- it gets into the Regents time and then there's all these state tests, in fourth grade and eighth grade, and all these other things now, so there's never any time to let kids go and apply what they know, and sometimes having them teach it, they learn more about it than if you just told them,

I- well, you and I as teachers know that that's true, if you have to explain it to someone else, it tends to bring a lot more clarity for your own mind

P1- yeah, yeah, I guess that's about it, then

I- well great! John, I really appreciate your taking the time, [shakes P1's hand]

P1- that's fine, I hope I was of some help

I- you were, a great deal of help… a great deal indeed

Appendix B

Jane Interview Transcription

(In transcription, **I** refers to interviewer, and **P2** refers to Jane)

Jane Interview Transcription (T2)

Interview date: January 30, 2003. Place: Jane's home in Victor, NY.

I- As I've explained this is helping me with a project for my graduate program, I'm going to ask you some questions, it's not a test, there are no right or wrong answers, the whole purpose of this is to help me understand what your understandings and beliefs are about the subject I'm going to ask you about.

P2- ok

I- I have some preliminary questions first

P2- mm hmm

I- um, now, you're becoming a science teacher?

P2- yes

I- is that true?

P2- well, uh, biology

I- biology? ok

P2- and hopefully science

I- ok, well, uh, why are you becoming a science teacher?

P2- um, my main goal actually would be going into earth science to teach natural resource conservation and, uh, biological preservation, so that's sort of my focus in the long run

I- ok

P2- and, um, my degree was in wildlife biology, so I'm sort of staying on that avenue

I- oh ok

P2- mm hmm

I- cool, so I take it you did some other things before you decided to become a teacher

P2- oh yes, yeah, I um actually was able to work for the uh, conservation of natural resources, um, for the natural resource conservation service, but that was back in Iowa

I- mm hmm

P2- um, loved it, did habitat restoration with them, and then I uh, budget cuts came through, and I wasn't really anxious to go back to school at that time, so I ended up actually getting a certification in radiography

I- oh, wow

P2- and was a CAT scan tech in a hospital, loved it, absolutely loved it, it was an incredible job, but when I moved out here, I wasn't real pleased with the health care system, and, ah, so I uh, got married, right away, and my husband and I decided to start a family, so, I quit my job to be a stay-at-home mom and I'm back in school! I always wanted to be a teacher it's just that now the opportunity's actually finally come up

I- oh yeah?

P2- yeah

I- why did you always want to be a teacher?

P2- I always wanted, I just felt that um, if you're a productive teacher you can touch more people and gain better, more results than what I could do, do for myself

I- mm hmm

P2- you know, influence more people and hopefully have, make a positive change

I- cool

P2- so…

I- so, how come you didn't become a teacher earlier? What is the impetus at this point?

P2- Uh, y'know I was um, getting ready, I had, and it took six years to get my bachelor's degree

I- that's nothing, it took me eleven

P2- [P2 & I laugh] and it was just a point you reach and, I'm like my gosh, I'm 26 years old, you know, I need to graduate, actually I lived overseas for a year, I went to New Zealand for a year, and actually worked on, uh, took some master's courses over there, in marine science, and that just sort of kind of lengthened my period of education, I just wanted to be done, and I went to Iowa State University and if I wanted to go into education, I would have to be in school for another two years and I just wanted to get out into the work force and take a break from things for a while.

I- I totally understand!

P2- oh yes [laughs] be a productive citizen

I- yeah, ok, so you've already kind of touched on this but what grade levels and subjects do you plan to teach?

P2- ah, well secondary, ah, earth science, environmental stud… actually some schools are instituting environmental studies programs, so I really hope to be able to go in that aspect, and biology, and hopefully one day I'd like to go up into administration

I- yeah?

P2- yeah, definitely, maybe even teach at a college level

I- oh, that'd be great

P2- so… yeah!

I- cool, and I think um, that the next question is what would be your favorite subject to teach? And I think you kind of alluded to that already

P2- oh yeah environmental science, environmental studies, definitely

I- mm hmm

P2- definitely, yeah

I- ok are there any districts that you would prefer to work with, or…

P2- no, I don't think so, ah… I think, from students that I've talked to, I have nieces and nephews, well my husband's nieces and nephews that are, y'know in all grade ranges an um, as far as school districts, I'd almost like to teach in the inner city, almost

I- yeah?

P2- uh, I think that there's a lot of messed up communities there for them to understand, um, the world around them, and the environment around them, and it just seems that when people are able to connect outside of their immediate environment it really enriches them as a person and sort of raises them to a higher level of thinking, that, more privileged kids already have access to, and they do take it for granted, but, um, I just want to get kids out of that destructive nature, to have them more conducive to them being a more productive citizen, so…

I- very laudable goal!

P2- yeah, and I know I've got a lot of obstacles! [laughs]

I- yeah, it takes people who want to try and overcome them or there's no hope at all so…

P2- yeah, because I've been there, I moved a lot as a kid, and I've lived in inner city school districts to very prominent, well-to-do school districts, so I've had an opportunity to study in all of that, so it's kinda, I'm not going into this blindly

I- mm hmm

P2- well, I can say that and until I'm actually in it [laughs]

I- how soon is it going to be until you get your, so now you're in your initial, undergraduate teaching…

P2- yes

I- certification courses?

P2- exactly, I've only had three courses, and, uh, with my other baby on the way I'm not going to be, ah, I'm not real pressed for time to finish… my goal is to be done, or to almost to be done by the time they reach pre-school

I- mm hmm, oh ok

P2- so that, in about 3 to 4 years I'd like to be done, and get into the work force

I- at least to get your provisional certification?

P2- exactly, exactly

I- and you're doing all your classwork at Fisher?

P2- yeah, yeah, doing it all at Fisher

I- cool

P2- there's a very positive influence, or atmosphere there

I- mm hmm

P2- I like it, ah, I've only had a couple of instructors but I see a lot of good changes going through with that and the thing is they're really the only school close that teaches the GMST program

I- mm hmm

P2- SUNY's just too far

I- yeah

P2- and even though it's a great school, I think, I was never really really big on private schools, um, even though my resources were kind of limited but I think in this case it's a really good program

I- yeah, and I like the master's program there

P2- oh, yeah, incredible

I- it's really good

P2- it really is yeah

I- ok, let's see, now I'll kind of move into the meat of things, have you ever flown on an airplane?

P2- yes I have

I- ok, what kind of airplanes have you flown on?

P2- ahhhh, I've flown on 747s, 767, once, I've flown in little two-seater Cessnas,

I- oh yeah?

P2- oh yeah, yeah, I've flown on, um, let's see, old, um, I forget the name, planes built back in the 50s, I've flown on a C47, um, let's see what else, basically kind of every make and model, yeah

I- cool, how old were you when you first flew on an airplane?

P2- that I can remember how old I was, I was, I can remember back to 2, I've been flying since then

I- yeah, with your parents and…

P2- yeah, flying with my parents, I didn't actually fly by myself until I was, um, how old what grade was I in, fourth grade

I- oh wow

P2- I actually flew by myself, so yeah

I- wow

P2- yup, so that was an interesting experience

I- cool

P2- yeah!

I- ok, so do you have any ideas about what makes an airplane fly, and how it gets up into the air?

P2- I do,

I- ok

P2- I do

I- tell me about those

P2- [laughs]

I- what do you think?

P2- um, actually, it's uh, I think the real basic part of it [minor distraction from her son] was the design of the wing

I- ok

P2- and the shape of the wing, how it's curved on top and concave on the bottom, it's not actually flat on the bottom, so, what it does, the physics of air, as air rushes over the wing, the pressure is less on top and greater on the bottom and that provides lift

I- ok, so the pressure is less on top and greater on the bottom, can you elaborate on that?

P2- ah, as airflow, let's see, as air flows over the top it slows down, decreasing the air pressure, on the top of the wing, and as it flows underneath the wing it's faster, increasing the pressure, and the difference in the pressure provides the lift for the airplane

I- ok, ok, so I heard you mention the word lift, what does, uh, tell me more about what you think about lift

P2- what I think about lift… ah, as in like definition of lift?

I- sure, yeah, whatever

P2- oh, ok, ah, lift is um, the ability, I guess what it is, is it's the force that raises a… raises an object off the plane, off the immediate plane

I- mm hmm

P2- umm… and lift can be controlled, lift will vary depending on again the atmospheric pressure umm… airflow, the mediums you're going through

I- mm hmm

P2- so… on a same principle, would be in a submarine, underneath the water, as to airplanes in the air

I- hmm, ok, all right, let's see, ok when you've flown on an airplane describe to me what happens when the airplane takes off

P2- um, it increases, let's see, well you're increasing your, your speed, with the engine, and, um, as you pick up speed, um, again, you, you, get the physics of lift, on the plane, and when, I know when you reach a certain speed, you have generated enough lift or pressure differential on the wing to lift the mass of the plane up off the ground.

I- ok

P2- so it's all y'know speed and uh, yeah, airspeed that um, that is influential, y'know, obviously you have to be going fast enough

I- mm hmm

P2- to create the lift, for the pressure difference needed

I- right ok, um, ok now you've mentioned wings, are there any other parts of the airplane you think are really important to the airplane to be able to get up into the air?

P2- um, body shape, the streamline of the uh, of the, the engine, or of the plane itself

I- mm hmm

P2- um, materials it's made out of 'cause you want to minimize your drag, which helps, um, let's see, you want to maximize the amount of lift that you can create, and I know that's why there are little winglets on the end of the uh, wings [P2 momentarily distracted by her son and gets up] um let's see, ah, I know that, or I don't *know* but I understand that the tail is mostly just for maintaining direction and stability of the plane in flight, so, I suppose the things would be the style of the fuselage, or the plane, and the parts it's made out of and weight, obviously you want to minimize your weight

I- how about gliders, are you familiar with those?

P2- yes I am

I- yeah?

P2- yeah, yup, gliders, yeah, gliders, uh, I know that their wings are, y'know the body is extremely small and the wings are extremely long

I- mm hmm

P2- and its principle is based or the gliders are based on um, airflow, or uh, from the ground, ah, yeah, differences in airflow patterns and it just takes advantage of, as heat rises, [demonstrates with hand] and, or as warm air rises and it picks up on that

I- mm hmm

P2- and that's how it can sustain its flight through, um, through the air.

I- ok

P2- yeah, yup

I- all righty, as I recall, when we first talked on the phone the other day

P2- mm hmm

I- you mentioned that your father worked in air traffic control?

P2- mm hmm,

I- is that correct?

P2- yup

I- ok, tell me about that and what you learned about airplanes and flying as a result of that.

P2- um, ever since I was little dad always to me up to, um, the airports, and we just hung around airplanes all the time

I- yeah

P2- unfortunately, being an air traffic controller, I mean, he, he knows about planes and flight and the whole nine yards but he’s not a real, um, he’s not a real mechanical person, he’s not a real hands-on person when it comes to airplanes so it was more of this is that type of airplane and this is that type of plane and here’s the differences between them but not why they fly

I- ok

P2- so I never really learned anything about why they fly from him

I- ok

P2- just landing and taking off and all that kind of thing but it really just gave me an interest in it, especially the difference between um, um, propellers and jet engines what the differences were [phone rings, P2 answers it, momentary distraction] so that was it and then, um, I ended up dating a couple helicopter pilots and airline pilots and they’re the ones who sort of explained the physics of flight

I- ok

P2- and I’m sure I learned something in high school but,

I- mm hmm

P2- that sort of runs right over your head, you actually see it and you see the drawings of the airplanes and they sort of explain a little bit of the principle to you

I- mm hmm

P2- that was real interesting

I- mm hmm

P2- yeah, yup

I- all right, so you kind of learned about, not so much in school, but from

P2- yeah, just from people sort of explaining a few things to me and, ah, I know that ah, you know initially people wanted to mimic the flight of birds and instead of actually following the physics of ah, the structure of bird wings

I- mm hmm

P2- and gliding

I- mm hmm

P2- and, and um, so y’know obviously when everything relates back to nature I take a little bit more of an interest to it.

I- mm hmm

P2- and um… so y’know just a little bit of reading, asking questions and just trying to store little bits of information in the back of your mind

I- gotcha, ok, um, some of these are a little bit repetitious but I’m going to throw them out anyway

P2- that’s fine

I- is there any part of an airplane that has more to do with lift than another part?

P2- well, wings, the wings are the primary principles for the lift of the plane

I- ok

P2- definitely, yup, and y’know you have your, your, rudders that are part of the wing that can increase or decrease drag or promote lift

I- mm hmm

P2- slow the plane down speed the plane up, that type of thing, so…

I- you mentioned the word drag, what does that mean?

P2- ah, an increase in friction, an increase, yeah an increase in friction you’re increasing your air pressure and you’re increasing the friction which slows the plane down

I- ok

P2- so… and I know that using it to slow the plane down in itself is used in itself to increase or decrease the height of the plane

I- ok, there’s a word aerodynamics, are you familiar with that word?

P2- yes I am

I- ok, and what does that mean?

P2- ah… aerodynamics, I know it has… they use it to describe the shape, like if something is aerodynamically… um… is conducive to, to air, to flow through the air

I- mm hmm

P2- um, if something is shaped to be, hopefully to be maximized for speed

I- mm hmm

P2- and less drag, less force of friction, so…

I- mm hmm, when you were talking about the differing speeds of air going over and under a wing, is there any… word, to describe that effect?

P2- you mean as in aerodynamics? [laughs]

I- well…

P2- or do you mean a word like to describe , umm… oh, that describes the air going over or under the wing?

I- well… is there something in science that is a term, that explains why that difference in pressure happens?

P2- I'm sure there is… um… hmmm… um… I know that there is, it's just not coming to me

I- ok, that's fine

P2- ok

I- that's ok

P2- ok, can I blame this on pregnancy? [laughs]

I- sure! [laughs]

P2- ok! I have a hard time remembering my own name every day!

I- not a problem…

P2- you know, the only thing I can think of is air pressure, but I know that that's not right, but, so I just kind of dance around it

I- not a problem, just kind of going off in different angles here… as we go on

P2- oh, that's ok

I- um, have you ever held your flattened hand out of a car window while the car's going down the road?

P2- oh yes

I- ok tell me what happens there

P2- oh yeah, well, y'know, obviously, when you increase the surface, when you increase the plane of surface to the direction of the air um, it blows your hand back and as long as you keep it level to the air, um, you can maintain, y'know, by doing this y'know, [demonstrates with hand] up and down, if you angle the, the edge downward um, the air will force your hand down, and if you angle it up, it will create lift

I- mm hmm

P2- or y’know will blow your hand back, as long as you keep it level you can maintain a level through the air[continues to demonstrate with hand]

I- ok, so you say, now we’re talking about a flat hand here,

P2- mm hmm, mm hmm

I- which, um, maybe we can even think of it as, uh, because we can curve our hand, too,

P2- mm hmm

I- now, let’s say we were holding say a board, just a flat piece of 1 x 12 or something like that, or plywood out the window

P2- mm hmm

I- um, and I heard you mention lift, tell me what’s happening there

P2- with the board, or with your hand…

I- well, a flat object…

P2- ok, a flat object, as long as you um, keep it level with the airflow, then the pressure of the air will be equal above and below the board

I- ok

P2- which will maintain stable, along the same plane of flight

I- ok

P2- but when you, um, for instance if you tilt it upward, you are increasing the air pressure below, decreasing above, that’s going to lift the board up

I- mm hmm

P2- and if you tilt it downward, then the air pressure’s greater above than below and it’s going to force the board down

I- ok

P2- or your hand down

I- can you make any comparisons between a flat, well… I’m going to hold off on that ‘cause we’ll be getting into that in a minute,

P2- ok

I- um… I'm sure that as you've mentioned, that your father showed you around airplanes at airports and such, and um, so obviously you know that they get tied down, I assume…

P2- yeah, oh yeah

I- so if an airplane was parked there on an airport, tied down or not, if there is a really strong wind blowing directly into the front of that airplane, what's going to happen, is it going to try and fly, or, what's going to happen?

P2- if, if it's blowing directly into, the plane's just stable and all, that if a strong wind is blowing, it's going to try and lift the plane up, the front end will try and lift up a bit,

I- mm hmm, and what's going on there?

P2- um, as I said, the under part of the wing is not actually flat, it's a bit, a bit concave

I- mm hmm

P2- and the top part's curved so if you get airflow coming right at, because the way the front of the wing is designed it's rounded

I- mm hmm

P2- and, um, when you have airflow straight underneath you're still going to create, airflow underneath, you're going to have a pressure greater below, than above, and it's going to try to lift the front of that plane up

I- mm hmm

P2- 'cause that's just the nature, that's just the way the plane is built um, that's why you have flaps on the back, to stabilize that when you're in the air, because the plane actually doesn't fly straight through the air, it flies at more of an angle, like, this [demonstrates with hand]

I- ok

P2- I know that when you fly, just due to the structure of the wings, and the plane

I- ok

P2- so, um,

I- can you tell me more about that angle, why would that have an angle…

P2- why it flies through like that? Um, the weight of the plane, number one, there's a lot of weight in the back of the plane, which throws it a little bit off balance, and two, um, when a plane actually flies [minor distraction from P2's son investigating the video camera tripod] when a plane actually, when it's flying at an angle like this, what you're actually doing is you're equalizing the pressure above and below, on that wing, which is helping it maintain a stable flight if you were to have to fly through this way you create pressure difference which, um, in the lift of the wing which is going to try to lift it up this way anyway so… [demonstrates with hand]

I- mm hmm

P2- flying through

I- ok, have you ever been to an air show?

P2- yes

I- how do those planes fly upside-down?

P2- [laughs] ah… I never thought about that… um… I'm trying to think… well when you start a plane, you're controlling it with the rudder on the back, and ah, flaps, so, well, when you, when you're flying through the air, and you tilt the plane, with the rudder in the back you create pressure differences on one side of the wing or the other

I- mm hmm

P2- which will naturally just rotate it around and, um, so it's, and then y'know, just to maintain flight you have to sort of , uh, keep in mind um, your position in the air, and try and maintain, well if you just want to keep rolling around in the air you'll just keep the pressure greater on one side than on the other and that will just naturally force it around

I- mm hmm

P2- as you go into a spiral and so flying upside down, then, um, a plane will fly as well upside down as it will right side up because again you have pressure greater above than below so, it's not…

I- you were telling me about a curve of a wing though, curved on top, concave on the bottom, so how would it be able to fly upside down?

P2- it's going, well that's true, it's going to force it down naturally

I- so what's going on there?

P2- um, well you have flaps and rudders to maintain the pressure, to level out the pressure difference to keep it up in the air

I- mm hmm

P2- so… yeah, for instance, if you like notice on the tail of a plane um, yeah what you would do is on the tail of a plane is instead of having say your rudders down, or straight off in flight or down in flight [recording momentarily drowned out by P2's son making noise] or equal the pressure and it's going to help maintain a lift on the plane

I- what are flaps and what do they do?

P2- flaps, flaps um, they add um, they add a flexibility or availability to… to monitor or differentiate your lift patterns because the wing is fixed, you can't change that, so what the flaps will do is they either increase drag or they decrease drag or they change the momentum of the airplane

I- mm hmm, where are flaps located?

P2- flaps are located, you have them on the back, on the tail, and then you also have them on the very back of the wing

I- ok where on the back of the wing itself are they located in relation to the body, where the wing attaches to the…

P2- they're closest

I- closest

P2- they're closest to the body

I- ok are there any other surfaces that move on a wing?

P2- ah, other than the flaps, um… hmmm… not that I can think of

I- ok

P2- no, that's, that's the flaps, and there's different kinds, I mean you have some that go up and some that go down so I mean, you've got different sets of flaps

I- mm hmm

P2- that do different things

I- So there's more flaps, there's more than one flap on a wing…

P2- I think there's more than one yeah I'm trying to think when I looked outside the plane the last time I looked did it go up or down… yeah I have seen actually some that go down and you have a smaller, you have a larger set here and you've got a smaller over there and so actually I've seen some go down and some flip up this way so, y'know, depending on the design of the plane

I- Now you said you've flown in a two-seat Cessna like a 152

P2- yeah, yeah

I- what um, do you remember anything about those wings and the flaps or whatever on them as compared to maybe like a 747 or a 767

P2- um, if I remember right they were bigger and they took up more of the wing

I- in which…

P2- in the smaller plane

I- in the smaller plane…

P2- is that right? No… I was spotting wolves and I wasn’t paying too much attention to the flying, it was so small, it kind of freaked me out a little at first [laughs] um, and actually it was, actually they were smaller, I believe the flaps were smaller

I- mm hmm

P2- it was actually sort of like a biplane with wings on top and then a smaller set on the bottom

I- mm

P2- so, yeah, yeah, that’s how that one was

I- ok, all righty,

P2- and the tops didn’t have flaps, if I remember right, but just the bottom wings did

I- oh ok

P2- mm hmm

I- um, ok

P2- it was a little single prop

I- ok, we’re going to move into a couple of these manipulatives here

P2- ok

I- and what we’ll do, is I’d like you to take these hold them [passes cardboard and Styrofoam wings to P2] and tell me what you notice as far as any similarities and differences and if you could describe those similarities or differences and generally what do you think you’re looking at and

P2- ok, the similarities are um, that the shapes are pretty much the same, but the Styrofoam piece has a curved surface more like a plane.

I- ok

P2- than the flat piece here

I- so the shape you’re talking about looking down on the

P2- the shape looking down is the same, the size is approximately the same, uh, it's just the uh, oh thickness, y'know, is different, the thickness is different and the actual curvature

I- uh huh

P2- is a little different

I- ok, and do you have any idea why the curve is on that wing, can you tell me a little bit more about the curve of that Styrofoam wing?

P2- sure, the curves of the Styrofoam wing here, when the air flows over this way, over the top, uh, it slows the air down, decreasing pressure, while you've got underneath where airflow goes faster, increasing pressure, and that will provide lift to the plane

I- ok

P2- at the correct speed it will overcome the mass of the plane

I- and so that would make a difference over that cardboard

P2- uh, sure, because even if it's controlled strictly by tilting

I- ok

P2- you'd have to rotate this to get lift up and down whereas this ah, you don't have to, it can remain fixed

I- ok, all right, what I'd like to do now is, I have a carpenter's line level here,

P2- ok

I- and the reason I have this is, let's see, what do I want to start with… [minor distraction from P2's son] is I have this so we can hold the paper and gauge the levelness of the paper or y'know, whether it's level and then tilt it and, up and down a little bit [demonstrates with cardboard wing and line level]

P2- ok

I- and it's probably best if you hold it somewhat like that,

P2- ok

I- and, I've found, when I was playing around with it a little bit, that it's best to kind of hold it fairly lightly cause what I'm going to do is turn on the fan, I'm going to have you hold… the wing right about at that level there

P2- ok

I- that's what I've found pretty good airflow there and

P2- ok, like right there?

I- well maybe a little higher, about where that bend is in the uh, in the wires of the uh, enclosure

P2- sure, ok

I- and um, all right, we'll go ahead and turn that on [turns fan on]

P2- ok

I- and I'd like you to hold it level and pivot it slightly and describe what you, maybe just hold it with one hand,

P2- oh ok

I- so it's like you're the body of the airplane where it attaches

P2- oh sure, so if we're holding it level [hold cardboard wing model], it's, it's, you're feeling a little bit of vibration but, but y'know, I'm feeling a neutral, I'm not feeling any kind of a… push or pull, or pressure on it so…

I- ok, and as you tilt it slightly one way or the other describe what you're feeling

P2- as I tilt it slightly up I feel um, the pressure moving it, wants to push the wing back towards me

I- mm hmm

P2- the paper back towards me… and if I feel, uh, and up, back and up, and if I tilt it downward, I feel like it wants to push it down and back

I- ok, and maybe tilt it even a little more

P2- yeah

I- strongly

P2- yeah, there we go… oh yeah, I mean like you can feel like it, y'know, just wants to go back and up, and back, so… [pivots cardboard wing model up and down and end to end]

I- ok

P2- and depending on how I curve it this way and that way then the direction it wants to go

I- ok, let's try the same thing with the Styrofoam wing, you just want to put the level right on that flat part

P2- ok, put it right here… let me be sure I get it level… if I hold it just about level…

I- again, if you just hold it with your right hand and describe what you’re feeling

P2- ok there we go ummm…. I guess again, a little vibration but not much um, not much pressure, y’know I feel like it, yeah not much, I mean I feel like maybe a little bit more pressure on it but nothing much

I- pressure in which way?

P2- uh, up, like it wants to just lift up

I- so when it’s level…

P2- like it just wants to lift up

I- ok

P2- this way

I- and did you feel that with the cardboard?

P2- no

I- when it was level

P2- no I didn’t, no, but I definitely, y’know, again when I, when I tilt it back towards me um, it just wants to go up and back, and then down, it wants to go down, down and back

I- ok

P2- but um, when I hold it level it… it feels like it wants to go up a just little bit

I- ok

P2- mm hmm

I- all righty, ok, I think we’re all set with that

P2- ok

I- all right, now what I’d like to do is… ok what I’m going to have you do now

P2- mm hmm

I- is, I’ve just got a piece of paper, I’ve got a piece of cardboard along the edge just to help stiffen it a little bit and I’m going to ask you to raise it up till it’s just under your mouth and blow over it, and first off, I’d like you to predict what you think will happen when you do that, so the air is just going over the top of it and no air is going underneath

P2- if it’s going just over the top, and just underneath, or underneath, um…

I- not underneath

P2- or not underneath, just on top, ah, that the, [holds piece of paper] this would want to push down, the piece would want to push down

I- ok

P2- and the paper, actually might lift up a little bit

I- and why would the paper lift up?

P2- I'm not sure, it's just a feeling I have…

I- that's fine!

P2- ok, but um… I'm thinking the air would flow down this way would push down here… and the, it'd want to kind of do this, I don't know I'm just thinking [demonstrates with hand]

I- ok, go ahead and give it a shot

P2- ok, go like this just go…

I- yeah

P2- [blows over top] is that right?

I- yeah

P2- ok

I- can you see what it's doing?

P2- it looks like it's trying to lift up a little bit…

I- ok

P2- mm hmm…

I- what do you think is happening there?

P2- I'm trying to think of speed… I'm just trying to think, I know that as air goes, as air goes here, hmmm, cause I know it's bringing the paper…. [continues to blow] now it's bringing the paper up just a little bit… so somehow I know that the pressure is decreasing, or inc… decreasing up here and increasing down here [lifts paper with hand]

I- mm hmm, ok

P2- air pressure is

I- ok, how about the speed of the air?

P2- the speed of the air has increased up here, [momentary distraction from P2's son] is increasing down here and uh, or the speed is, is increasing up here and decreasing down here

I- ok

P2- mm hmm

I- all right

P2- it was contrary to all my, what I was thinking because… well no… well yeah because it was normally… slow… well… it's kind of like having a wing upside down, the pressure being… [P2's son starts making cooing sounds] yeah that's what I'm thinking too [laughs] exactly! You read my mind son… cause we're increasing pressure here, or increasing wind speed here,

I- mm hmm

P2- which is decreasing pressure, lifting up the paper, so if it's slower down here… is that making sense?

I- it really doesn't matter

P2- you can't tell me… it's whatever your answer is! [laughs]

I- yeah [laughs] yes, it's whatever your understanding and beliefs are…

P2- mm hmm…. I think I, I'm still having a hard time, I guess I'd have to see like a formula or, or have it explained to me in the physics, because

I- mm hmm

P2- y'know

I- ok

P2- yeah

I- no, that's fine

P2- ok

I- all right now, have you ever, I wonder if you've ever done this little trick, where you take two pieces of paper, and you hold them… I guess maybe a couple of fingers in between… so that they're holding… they're supposed to both hang down so they're pretty much parallel,

P2- mm hmm

I- and then you blow in between 'em,

P2- mm hmm

I- and I'd like you to do that but first, I'd like you to predict what you think will happen when you blow in between those two pieces of paper, are they going to… move apart?

P2- I think that they're going to move together…

I- and why is that?

P2- I don’t know, it just, like this? Holding them apart, I’m sorry, am I doing that…

I- yeah it is kind of…

P2- yeah… well I know when I do part of this, air is going to go out the sides, and out the bottom, it’s going to go out in all directions,

I- mm hmm

P2- cause airflow isn’t just, in one direction

I- mm hmm… I don’t know if we can get those held so they’re not…

P2- oh, so apart, like this?

I- yeah, somehow… for some reason they’re kind of wanting to stick together

P2- why don’t I try this way… here we go… let’s do this… ok

I- there you go

P2- there we go, hold it apart, ok, [blows] yeah it brings the paper together

I- ok

P2- [continues to blow] if you notice it brings the paper together at the bottom, not all through it, I don’t know if I can get it… [blows] yeah it seems to pull it more together here at the bottom

I- ok, what’s going on there?

P2- ummm… well again we’re increasing air flow, which would be decreasing pressure, which would be, increasing the airflow which is decreasing the pressure on the inside, which allows the air pressure on the outside to be greater, forcing the papers together

I- mm hmm, ok

P2- ok, ok, [momentary distraction from P2’s son]

I- all right, we’re almost done here

P2- ok

I- ok, I’ve got here, a drawing, and um, what does that look like to you?

P2- ah, it looks like a cross section of a wing

I- ok, now let’s say that this cross section of a wing is actually the edge of a wing, flying through the air, this would be the front

P2- ok, right

I- and um, what do you think is going to happen to the air, at that front edge?

P2- it’s going to split

I- ok, and if you could use some colored pencils here, whatever color you want, it doesn't matter

P2- ok

I- to maybe, draw what your…

P2- so what's going to happen, is airflow's going to come, here,

I- ok

P2- and it's going to split

I- ok

P2- and go over here… and under here

I- ok, so let's say we have one little parcel of air that gets split in two

P2- ok

I- we've got half of it going over the top and half of it going under the bottom, how are those going to move, uh, as one goes over the top, one goes under the bottom?

P2- ok, how's it going to move?

I- yeah

P2- you mean, oh, ok, um…

I- you talked about air having different speeds, depending on where it is…

P2- ahh, you know, now it just hit me, because the airflow, it's not going to slow down as it comes here, it actually has to speed up, it actually has to speed up as it comes over this part, because, and it'll slow down as it comes through here because it's going to meet, it's, it's like a volume of water, it's going to, I mean these two points are going to keep up with each other, one's not going to slow down, one's not going to speed up, so what happens actually is the airflow… goes faster over here, slower underneath here,

I- mm hmm

P2- to maintain the same point, of movement… so, as it goes faster up on top here, um, right, so air flow increases… which decreases your pressure, here, decreases, and of course it's the opposite here, airflow, decreases, which increases air pressure, here…

I- ok

P2- there you go, and that's how you get your lift

I- ok…

P2- that's, ah, that's, that's, that was, so, everything opposite, and, and it finally just hit me [laughs]

I- that's fine!

P2- duh! [laughs] duh! Yeah, I'm thinking, well wait a minute, because, cause yeah because airflow is not, yeah, it's not going to split off and move in, um… like one, like one parcel's not going to slow down while the other one speeds up, they're going to want to maintain, ah, the same, I want to say the same distance, of flow across the wing, so…

I- and why is that?

P2- ah, it's like a, ah… like a volume, like a volume of, it's… it's a median,

I- mm hmm

P2- air is a median, and, um, technically the air's not moving, what's moving is the plane, so as the plane slices through, I guess that's one thing about it, as the plane moves though, the air is actually standing still, and so while this stands here, and the plane moves through, um, one part's going to have to, for that point, for point A and to keep up, ah, one's going to have to move faster and one's going to have to move slower

I- ok

P2- I, I may not be explaining it right but that's, y'know to kind of keep it straight in my head

I- no, that's all right, however you want to explain it, um, so what's going to happen when these two parcels of air get to the back, of the wing?

P2- well what's going to happen is as they mix you're going to end up with actually, it's kind of a tornado effect, and they're going to start spiral, spiraling around, ah, one… cause what's going to happen is this part ,um, yeah airflow, as airflow increases and this is slower, yeah you're actually getting sort of a funnel effect, and the air is going to spiral around each other until some where back at this point, um, it will become, it will become the same, it'll become the same speed or the same, ah, or same pressure again

I- ok

P2- cause you're having two differences in pressure, and so you actually do get sort of a, um, a spiral effect off the back of the wing

I- ok, so if you're saying that… if I understand you correctly, that these, this parcel that's been split in half, those two halves… how are they going to move, to that back edge of the wing?

P2- ummm… it's not so much that they move to the back edge, it's that the wing itself moves through

I- ok, ok

P2- the medium so it's actually, it's the wing moving through the medium, not the air flowing over, the medium

I- ok

P2- so…

I- will those two halves of that parcel… get… as the wing moves through it…?

P2- as the wing moves through it they eventually, yeah, eventually they merge, they come together, and eventually will stabilize and just

I- ok

P2- go, they'll go back to an equilibrium, they'll go back to either stable, or say you had five miles per hour they'll go back to being five miles per hour

I- ok

P2- so, is that what you're asking?

I- well, yeah, yeah it was

P2- ok

I- kind of, um, let's see how I want to… the thing about asking these questions is…

P2- you don't want to give away the answer

I- without leading any which way

P2- exactly, yeah

I- but, um,

P2- cause I also, the thing is the airflow not only goes this way and this way it also comes off, this way and it also goes back toward the plane…

I- ok, tell me more, tell me more about that

P2- um, I guess if you're, if you're looking down on the wing, there's my beautiful wing drawing… you've got airflow, and you're in, the airplane's moving this way, ok, you've got airflow coming down that way, uh, which goes over and under [draws], you also have the airflow moving *this* way, and you've got airflow moving off the end of the plane, that way, it doesn't just, it doesn't just move in one direction actually, it wants to move off in all directions um, I know that's why they have the winglets here, is to maintain, um, cause you lose like a third of your lift…

I- mm hmm

P2- by the air moving off this way, that's why they have a little winglet, which keeps the air flow over the wing itself

I- does every wing have a winglet on it?

P2- not every wing does, no, no, but your bigger airlines will, and they're not very big, they're very small, uh, actually, and they're just these little pieces that sort of jut up and that is actually, I think it's like they lose like a third of your lift, without the winglet

I- hmm

P2- that actually increases your lift, um, that much, um, so then you've got, what is it, it just kind of curves around it just makes this part of the wing more effective

I- mm hmm, ok

P2- um, but yeah so you've got all this airflow, and I know… yeah, I, I guess, I don't know how, I'll try to get at, hopefully what you're saying, but yeah when it comes, when the airflow comes off this wing it comes off the back of the plane…

I- so they're moving…

P2- they're moving a different, well, um, I guess they are moving at different speeds, or the pressures are different, I guess it's not so much to say the speed, it's the pressure

I- mm hmm

P2- um, the pressure of the air is different, coming off, and when they do come back together, ah, they don't just, y'know, they *will* converge this way, y'know they *will* come together, and as I mentioned they spiral around and eventually come off

I- ok

P2- and um, I, the only reason that I can even explain it that way is because I know this is why you have to maintain a certain distance between takeoffs

I- mm hmm

P2- between airplanes

I- mm hmm

P2- so… hmmm… yup, so it’s the same, it actually, it’s actually all the same, the same body of air, the same body of, um, air, yeah, so now when you’re talking about… I guess when you’re talking about differences in airflow or differences in airspeed your really only talking about that which initially is affecting the wing

I- ok

P2- and it changes in pressure, and then…

I- now I’m going to go back to a question I asked earlier, related to this

P2- mm hmm

I- let’s say that this is a cross section of a wing, while the plane is parked on the ground,

P2- mm hmm

I- and you’ve got a very strong wind

P2- a strong wind

I- blowing into that, directly into the front,

P2- um, it has the same effect, instead of this moving, instead of this moving through the air, you’re now having the air move over the wing, so it’s creating the same principle

I- ok

P2- um, you’re having the exact same effects

I- ok

P2- so, um, and again, when it comes off the back end here, if it’s strong enough you’ll still see the same split of, ah, pressure differences, want to come out, but eventually, y’know eventually it’ll, it’ll form back to a stable equilibrium

I- ok, if you took the wings off of an airplane, and stuck sheets of plywood on there,

P2- mm hmm

I- do you think the airplane would fly?

P2- yes, it would have the ability to fly, however it would take, ah, a greater amount of speed

I- mm hmm

P2- it take a greater, a uh, a tremendous more amount of force, cause you’re now taking all the physics of, of uh, lift and airflow, I mean you’re, you, you, are no longer taking advantage of natural forces around it, but I think it could fly, I do believe it could fly, if, um, back in the old days that's kind of how they did it, that's why they weren't very successful with it

I- uh huh

P2- but it, [distractions from dogs]

I- all right the plywood on, how would…

P2- I was thinking more of a glider, I mean, how the plywood would work, ah, you'd have to have some way… to… you'd have to have some way to… to tilt the plane up, either a flap or something, um, you've got your straight wing here, you'd have something off the back, uh, to control up or down, y'know to get sort of a, ah, to create lift

I- ok

P2- you know, or you'd have to have something pulling the front of that plane up, or pulling that wing down [distraction from son]

I- if you had that same parcel of air that got split, one going over the top and one under the bottom, how would that move, in that case?

P2- if you didn't have anything, if you, if you didn't have anything to, to change the dimension, if it was just a plain flat board, you wouldn't, unless you changed the angle of the airflow, by somehow, like maybe dropping off a cliff or something like that, the thing would just keep going straight

I- ok, so it would stay up in the air?

P2- ahhh… would it stay up in the air? …. I think like a um, I guess like a glider,

I- mm hmm

P2- but then we're talking something that isn't flexible or doesn't, ah… I think that eventually it would have to come down, eventually

I- ok

P2- it's not going to maintain a uh, well I guess, in a, if, you were in an ideal world and there was no change in wind, if the wind's just coming straight on, and you're not changing the wings, um, and you have a constant force, of moving it through

I- mm hmm

P2- theoretically I guess it could stay aloft

I- ok, all righty now we're going to move over to this object here,

P2- ok

I- what does this look like to you?

P2- paper airplane!

I- paper airplane… ok, go ahead, I tell ya what, somewhere here, ah there we go, sometimes paper airplanes need paper clips to help adjust their… so first off I'd like you to just give that a toss and tell me what happens

P2- ok let's see here, [throws paper airplane] it went down, I mean it did an arc, towards the ground

I- ok, was it flying?

P2- ahhh, yeah, gliding…

I- ok

P2- yeah, yup, one more time…

I- all right, and um, how is it doing that?

P2- ahhh… oops [paper airplane nose is bent]

I- oh, don't worry about it, it's only a sheet of paper

P2- [laughs] um, let's see, gliding through, well you had some airflow, y'know, by throwing it, by throwing the plane, uh, it has some, you created some airflow, through, underneath,

I- ok

P2- which sort of helps sort of create a lift in the plane, it just kind of glided through until its speed decreased, y'know, natural thing, uh, friction, air friction, decreases your speed, as you decrease your speed you decrease the air flow and it eventually just goes right down on the ground.

I- ok, how would air flow around these wings as compared to say, a wing like this, like on a Cessna or 747?

P2- ahhh… let's see, ah, the, I would say it's not as aerodynamic

I- mm hmm

P2- it's not going to, ah, make full use of a principle of, um… I guess if you were flying something like this, [pointing to drawing of wing shape] compared to something like that, this would go a bit further [wing shape]

I- mm hmm

P2- ah, just because, in addition to just natural, pressures, you’re also creating a variation in the airflow

I- mm hmm

P2- where this you’re not [paper airplane]

I- ok, all righty

P2- so this one [wing shape] will maintain a longer lift, yeah this would fly a little bit longer than that [paper airplane]

I- ok

P2- yup

I- is there anything else you want to add to, anything else you’ve thought of, maybe a question I didn’t ask, that you had an answer for, or…

P2- no, no, actually, but I’m glad that we went through the whole thing because it just, y’know, it brings back some things that you learned a long time ago but you forget

I- mm hmm

P2- like the basic essentials of like, that

I- mm hmm

P2- yup

I- all right, well I think that that completes the interview

P2- oh, ok, that was painless,

I- good, all right, now I’ll turn off everything

P2- good, cause now you can answer some questions for me [laughs]

Appendix C

Joan Interview Transcription

(In transcription, **I** refers to interviewer, and **P3** refers to Joan)

Joan Interview Transcription (T3)

Interview Date: February 26, 2003 Place: John’s classroom at an upstate NY high school

I- Ok Joan, have you gone to (this school) all your life?

P3- yes

I- ok, [momentary distraction when another teacher comes in looking for John] um, what do your parents do?

P3- my mom used to be an accountant but she quit to take care of the kids, and my dad used to be an electrician but he’s retired

I- ok, um, have your parents ever been involved in anything having to do with airplanes or aviation?

P3- no

I- ok, [ed returns with a school tape deck, but it does not accept the microphone inputs] all right, ok I understand that you’re a senior now, and that you took physics last year

P3- yes

I- ok, and you were a junior obviously last year, and if I’m not mistaken, most students who take physics take it in their senior year?

P3- yeah

I- ok, how come you chose to take it last year when you were a junior?

P3- Because I had taken chemistry and biology the year before and I didn’t want to take it when I was a senior when I was taking AP biology

I- ok, cool, now is physics a mandatory class or is it an elective?

P3- it’s an elective

I- ok, and how come you took it?

P3- cause I’m majoring in science

I- oh, ok

P3- and I’m planning on becoming a veterinarian sometime…

I- oh cool, excellent! Now as far as taking physics, did you like the class?

P3- I liked the class, but not the extra stuff we did

I- oh, yeah?

P3- like the teachers [interruption by PA announcement]

I- I’m sorry, interrupted by the intercom, so you were, so you didn’t like the activities, or the labs, or what?

P3- it’s just that I didn’t find it very interesting

I- oh really? Ok, that’s fine… how well did you do in it?

P3- pretty well…

I- pretty well?

P3- yes, I was at the top of the class

I- were you? So, you did really well in it, but it was just kind of boring for you…

P3- yeah

I- ok, so uh, were there any parts of it that you enjoyed?

P3- it was last year, I really don’t remember

I- well, anything that sticks out in your mind as far as any of the topics you covered, anything like that?

P3- [shakes head no]

I- and if not that’s fine, I’m just asking questions, there are no right or wrong answers here…

P3- [shakes head] I can’t think of anything

I- that’s fine… and you already kind of addressed this, but, what do you plan to do after graduating high school?

P3- yeah, be a veterinarian

I- yeah, are you all set to go to college?

P3- I’ve only been accepted to one so far

I- yeah? Which one?

P3- RIT

I- cool! Good for you, that’s awesome, so you’re applying to a whole bunch of ‘em?

P3- I’ve applied to like four

I- oh man…I’m sure you’ll be accepted everywhere

P3- I hope so

I- and RIT is a pretty hard one to get into… ok, so we’re going to kind of move into the general questions, have you ever flown on an airplane?

P3- once

I- once, and how old were you?

P3- fourteen

I- ok, so not too long ago then, like three or four years?

P3- four

I- four years? Ok, and what kind of plane was it? Like was it a big passenger jet liner…

P3- yeah

I- as opposed to a little two or four seat plane?

P3- [nods head yes]

I- do you know anyone who is a pilot, like flies small planes or anything?

P3- um, I have some cousins, my dad's friends, who I don't know

I- ok

P3- so I don't really know anyone personally

I- ok, so…

P3- my cousins I don't see, they're in college

I- oh, ok, so it's not like they told you about flying or anything like that, ok… so do you have any ideas about what makes an airplane fly and go up into the air?

P3- I remember talking about it in physics once

I- yeah? What do you remember, I mean I, again, this is not a test or anything, I mean I'm just trying to see where your understandings are, so… just if you have any, bits of memory from when you took the class, and talking about it

P3- just drawing a cross section of a wing on the board and showing where the air flows

I- ok

P3- that's about it

I- ok, so the one time you flew on an airplane, can you describe to me what happens when the airplane takes off?

P3- well it felt a little bit like, if you're in a car, they just start, start going really fast, then it took off, and you didn't feel anything

I- mm hmm, ok, are there any… is there any particular part of the airplane that you think of as being very critical to the airplane being able to get up into the air?

P3- the engines

I- the engines? ok

P3- pretty much

I- ok, any other parts that you think are important

P3- the wings

I- ok, and can you tell me a little bit more about the engines and the wings and how it works, how the plane can get up, I mean it’s pretty amazing that something that huge can get up into the air

P3- well the engines give it like momentum, the wings can catch the air cause it’s moving that fast cause the engines catch the air and go up [starts moving hands more to express her ideas]

I- [realizes micro-cassette recorder is set to play, not record, and turns on record; audio transcription from micro-cassette from here on] the engines catch the air, ok

P3- the wings catch the air, the engines move the wings that fast

I- ok

P3- I guess

I- Oh, there’s no right or wrong, don’t try to second-guess yourself or anything, just tell me what comes to mind, that’s all I’m looking for… when you say that the wings catch the air, what do you mean by that? Can you describe that a little more, or…

P3- like the top’s bent, and the bottom’s more flat, so the air goes either slower or faster over the top, and that makes it push up, the air on the bottom pushes up

I- ok, all right, have you ever heard of the word lift?

P3- yeah

I- as applied to flying and airplanes, ok, what is that word mean to you, in that context?

P3- it’s um, air pushing on the bottom of the wing, keeping the wings up…

I- ok, is there a part of the plane that has more to do with lift than another?

P3- the wings

I- ok,

P3- I’m kind of stuck on those

I- ok, that’s fine… now you’re talking about engines pulling the wing, pulling the airplane through the air, or pushing it, whatever, whether it’s a jet engine, or propeller driven plane, and um, have you ever seen gliders, whether in reality, y'know, actually out flying around, or on TV or anything?

P3- yeah

I- how do those stay up in the air?

P3- well, they have their sail thing to catch the wind and the air, kind of like a parachute

I- mm hmm

P3- only not, like dropping a piece of paper, it doesn't fall straight down to the ground I noticed… it catches the air as it goes down

I- ok

P3- like that

I- ok, how does, how does a glider get up into the air?

P3- from a really high cliff or something, the ones I've seen

I- ok

P3- just jump off cliffs

I- ok, that's fine, that's one way to do it, um, ok, here's another word, aerodynamics, have you heard of that?

P3- yeah

I- and what does that mean to you? Can you tell me in your own words what that might mean?

P3- I've heard it more applied to cars, and stuff, just more streamlined, doesn't slow it down, doesn't catch the front air as much as possible, so it's not so…

I- mm hmm, ok… have you ever when you've been driving in a car, or being driven in a car, have you ever held your flattened hand, y'know, like this out of the car window while the car's going down the road?

P3- sure

I- ok, can you tell me what happens when you do that?

P3- you can feel the wind, air resistance

I- ok, if you're holding it, totally flat, what kind of sensation do you recall, or what do you think would happen even if you don't recall

P3- not much

I- not much? And as you start to tilt it one way or the other what do you think, what would happen?

P3- if you tilted it, it would be like wind was hitting it, your hand would move

I- ok, all right, um, if you've got an airplane that's parked on the ground, at an airport, and there's a really strong wind blowing right into the front of it, would that airplane try to fly? Do you think somehow it would try to get up into the air?

P3- sure

I- yeah? And why would it do that?

P3- cause it's the same thing as if it was moving, it's still having the wind coming…

I- ok, great… have you ever been to an air show? Or seen one on TV?

P3- well I think I went to one when I was really little

I- oh, ok, but you're probably familiar with like, some of the planes that fly in air shows, they fly upside down… and things like that, or do you…

P3- yeah I'm sure they do [laughs] I just…

I- how do you think an airplane can fly upside down?

P3- I have no idea…

I- no idea? Ok, fine, not a problem, ok I'm going to move into the other sections, ok I've got a couple of manipulatives, couple of things here, and if you could take 'em, and tell me what… if you can describe as far as similarities and differences between those two, and if you describe overall what you're looking at

P3- well, one's cardboard and one's Styrofoam,

I- ok,

P3- they're the same size, [picks up both wing models] both have flattened bottoms, one has a flat top, the other has a curved top

I- ok, do you think, or can you, uh, do you have any ideas on why that curve is in the Styrofoam wing, and why it looks more like a real airplane wing?

P3- um

I- and would that make a difference over the cardboard wing model in any way

P3- yes, the cardboard doesn't have a curve, this one is like the drawing that you showed me, right there [points to end of Styrofoam wing]

I- ok

P3- so the air would go over it, and maybe slow down or something like that, and the air would push up here, [points to underside of wing model] cause it was going faster

I- ok

P3- I'm not sure exactly

I- oh, that's fine, that's not a problem, but you're telling me about the wing, or the air, somehow is different, for the air that goes over the top of the wing, as opposed to the air that goes under the wing?

P3- yeah

I- ok, and if you could just tell me a little bit more about what you're thinking about that?

P3- that I think I'm remembering that there's a difference…

I- that there is a difference in the speed

P3- yeah…

I- that there is a difference, and that has something to do with… you were starting to say…

P3- oh, it has to do with how it's able to get up

I- with the lift?

P3- yeah

I- ok, all right, ok what I'm going to do now, is I'm going to turn on that fan in front of you, and uh, I'll take that wing back just for a second, I'll show you what I'd like you to do, actually we're going to start with the cardboard wing but, I have a little carpenter's line level here,

P3- mm hmm

I- and this is strictly to serve as a uh, measuring tool so we can judge when the wing is being held totally level, [demonstrates holding wing with level] and then as we start to move it back and forth a little bit… what I'm going to do is I'm going to turn on the fan and I'm going to ask you to hold each of these models in turn in front of the fan, and, um, probably the best spot to hold it is probably right about here, where this curve is, that seems to be, where the best airflow is, hold it y'know, maybe an inch or two back, and if you could hold it kind of lightly, so that, what I'm going to do is ask you to describe what you're feeling as you tilt the wing in different ways, ok?

P3- sure

I- and you can probably hold that in place with your hand [referring to the carpenter's line level] [turns fan on] ok start out first by holding it level, um, tell me what you're feeling

P3- [stands in front of fan] it's just vibrating a little

I- vibrating a little, ok, now if you want to start tilting it up or down a little bit, and tell me what you feel

P3- a lot more resistance

I- a lot more resistance? ok

P3- like it's being pushed down…

I- pushed down when you tilt the front edge down, and… up, when you tilt it up

P3- yeah

I- ok, anything else, or is that it?

P3- that's pretty much it

I- ok, why don't you switch to the Styrofoam wing… try to start out with it level, if you can, ok, what are you feeling?

P3- well it's shaking a lot more

I- shaking a lot more? Ok, do you feel anything other than the shaking? Y'know, as far as any differences between that wing and the uh, cardboard wing?

P3- no, it's just shaking

I- ok, start tilting it one way or the other and

P3- [tilts wing model up a bit] it goes up a lot more than the other one did, it goes up a lot more

I- ok, do you have any ideas on why that might be?

P3- well it should probably try to go up even when its level, but…

I- uh huh, and why do you say that? That it should probably be trying to go up when it's level…

P3- because we learned… because it's not like when it's on the runway, the airplane, it's starting like this, it works up to that

I- starting like what?

P3- like, on the runway, it starts flat, it doesn’t start like that, [demonstrates with wing model that the plane starts on the runway with wings level, not already tilted] then when it gets going it slowly goes up

I- ok, ok, great, I’ll go ahead and turn this off [turns off fan] all right now I’m going to see if maybe you remember this, if you’ve ever done it before, but um, I’ve just got a plain piece of 8 ½ by 11 copy paper here, and I’ve got a strip of cardboard taped to this edge just to strictly kind of hold it a little more stable on this end, and what I’m going to ask you to do, is to, and you can tell me if you’ve ever done anything like this before, is hold it up, just lightly with your fingers, just so it’s right underneath your mouth, [demonstrates] and then I want you to blow as hard as you can right over the top of it, first I want to ask you what you think will happen when you do that?

P3- um, maybe the paper will go up?

I- maybe the paper will go up? And why…

P3- I don’t know I’ve never done this before

I- no? and why, are you just taking a guess, or do you …

P3- yeah, it’s just a guess

I- ok, so go ahead, and give it a shot, and see what happens

P3- [blows over paper, which rises quite a bit]

I- and, I guess your predication was correct

P3- yeah

I- now, it’s interesting… that went up, but no air was going underneath it…

P3- true

I- what do you think

P3- [shakes her head, thinks a moment] um, it was moving faster, that’s what I said, I don’t know

I- which air was moving faster

P3- this one [moves left hand over top of paper]

I- going over the top

P3- yeah

I- ok, ok, I’ll take that back [takes paper with cardboard strip back] next thing is, I’m going to hold, I’m going to show you how I would like you to hold, maybe with a couple of fingers, I’m going to hold these pieces of paper parallel so they’re hanging down, [demonstrates] and they don’t seem to want to cooperate very much, I’d like them both to be like perfectly straight up and down and parallel, but uh, hold these a little ways away, and then I’m going to ask you to blow right in between them, and before you do that I’m also going to ask you what you think will happen

P3- they’ll go together

I- they’ll go together? And why is that?

P3- because in the last one it moved in the direction of where the faster air was

I- ok, you want to give that a shot?

P3- [blows in between] I didn’t do it right [blows again] did anything happen?

I- yeah it did, they did go together, I know it’s kind of hard to see when your head is right over it, so ok, so that, again, now I’m going to ask you, cause you were talking about air… having differences in the way it goes over and under a wing, after you’ve done these two little things here does that give you any more… uh, how do I want to say this, things to think about as far as that wing shape, with the curve?

P3- uh, maybe the curve makes the air move faster over the top

I- ok, do you recall learning anything… I’m sorry, don’t be embarrassed or anything, good, do you recall learning anything about if air moves faster, what might happen to some of the other properties of the air?

P3- no

I- no? ok, that’s fine, ok, move this over here, [moves wing models out of the way] all right, now we’re going to move to this drawing, what does that look like to you?

P3- it looks kind of like an airplane wing, kind of

I- kind of an airplane wing? You mentioned something before about (your teacher) putting up a drawing on the board, is it anything like that?

P3- yes, kind of,

I- if I give you this back [hands back Styrofoam model wing], can you kind of point out on here, what that might sorta kinda look like…

P3- this part, right there [points to end of wing]

I- ok, so it’s like you’re looking in at the end of the wing

P3- yeah

I- like a cross section, ok, all right, I want you to pretend that that is a real wing, flying through the air… and on the front edge here, which corresponds to this edge, what do you think is going to happen to the air at this front edge of the wing?

P3- it's going to get divided

I- it's going to get divided? Ok, I've got some colored pencils here, and, if um, if you could draw what you mean by divided, and what may be happening with, you mentioned air having differences going over and under, if you could draw with y'know, one or more of the colored pencils what you uh… are talking about

P3- [draws]

I- ok, ok you're saying that it goes faster here over the top than the bottom?

P3- yes,

I- ok, so let's see, let's pretend that we've got a packet of air, that comes right into the front edge of the wing here, [points to front edge of wing in drawing] we'll be trying to get a little more detailed here, and that packet is split in two, can you draw, above or below, a relative motion of those two?

P3- what do you mean?

I- well you're saying that there's a difference in speed, of the air flowing over and under the wing,

P3- ok

I- and can you somehow draw with another color or whatever, like, two packets of air, one moving under the wing and one moving over the wing, and say at different points in time, how those are going to be moving, in relationship to each other?

P3- [draws]

I- and if you can tell me, I see you're drawing arrows of different lengths and such

P3- mm hmm, more arrows, it seems to my knowledge, I don't know, it just seems that this air has further to go, so it just takes longer, to get from here…

I- ok, so you're saying that, if I'm understanding you correctly, that the piece of air that's flying, the piece of air that's moving underneath the wing, is moving faster, or slower, than the piece of air that's moving over the top?

P3- well, I was thinking like it was going the same speed but this one has to go further

I- it has to go further but they're going the same speed…ok, what's going to happen at the back edge of the wing, are they going to get to the back edge at the same time, or are they going to get there at different times, or…

P3- I don't know…

I- well I'm just asking because you're saying that they're moving at the same speed, but this one has farther to go over the top

P3- this is why I'm not into airplanes, I keep thinking I'm wrong, it seems like this will reach, before this one…

I- ok, so the one going underneath would get to the back edge before the one going over the top,

P3- I guess…

I- that's fine, that's fine, that's perfectly fine… and here's kind of a goofy question, if you took the regular wings off of an airplane, a 747 or something, just put some big sheets of plywood on instead, that were flat on top and bottom, do you think that airplane could fly?

P3- probably not

I- yeah, how about if you tilted those wings, somewhat, [demonstrates with hands] while the plane is on the ground, kind of like holding your hand out the car window…

P3- it might go up, it might break

I- it might break ok, all righty, um, all right, one last thing, what have I got here?

P3- a paper airplane

I- a paper airplane, ok, go ahead, I've got a, a paper clip on it that you can take off, or move around however you want, but I'd like you to throw it and tell me what happens when you throw it

P3- ok [throws it] it spun around in circles

I- it spun around in circles, was that flying?

P3- I'm not sure really, I wouldn't want to be in that plane

I- me neither, but do you think that for the little while it was in the air

P3- yeah for a little while

I- I mean, some paper airplanes are a lot better than others, when I interviewed (your teacher) he was showing me some of the ones that he does with you guys in physics that are pretty cool and elaborate, and some of them stay up in the air and I guess there's some kind of contest you have, you go down to the gym, and throw some and there's like distance and time… so, forgetting about my skill or lack thereof in folding that paper airplane, when you think back to some of the planes, some of the paper airplanes that did stay up in the air for quite a while or that really went quite a long ways, were those flying, in the sense of a regular airplane?

P3- yes

I- yeah?

P3- sure, sure

I- and, why do you think so or not?

P3- because they were up in the air, they hadn't crashed yet

I- ok, that's fine, is there anything else that you…

P3- no, not really

I- no that's fine, actually, that was nice and brief, and hopefully painless for ya, that's all the stuff that I had to ask… thank you very much!

P3- you're welcome

I- don't forget your gift certificates, [$10 pizza, $10 movie] thanks again

P3- no problem

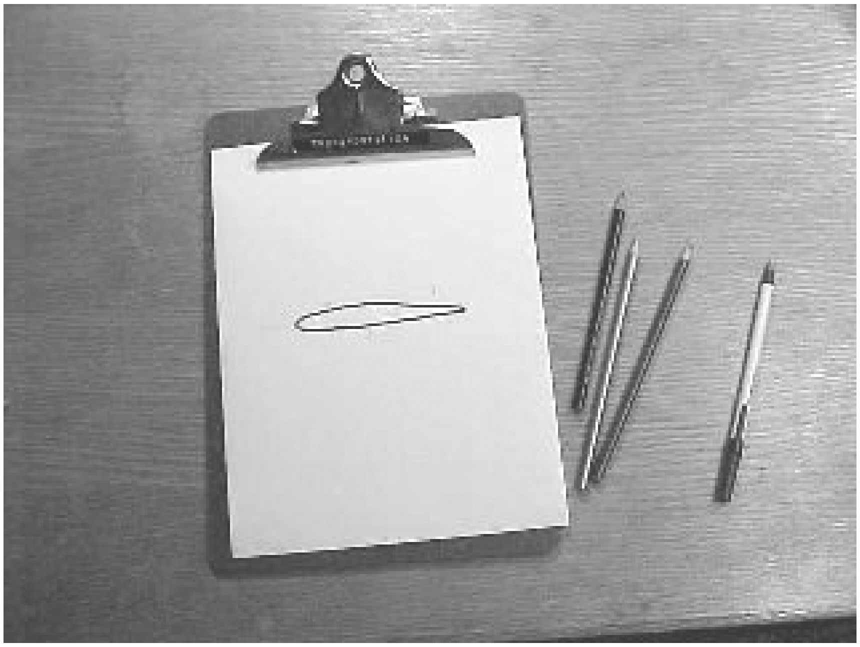


Figure 1

Drawing Utensils Used in Interview

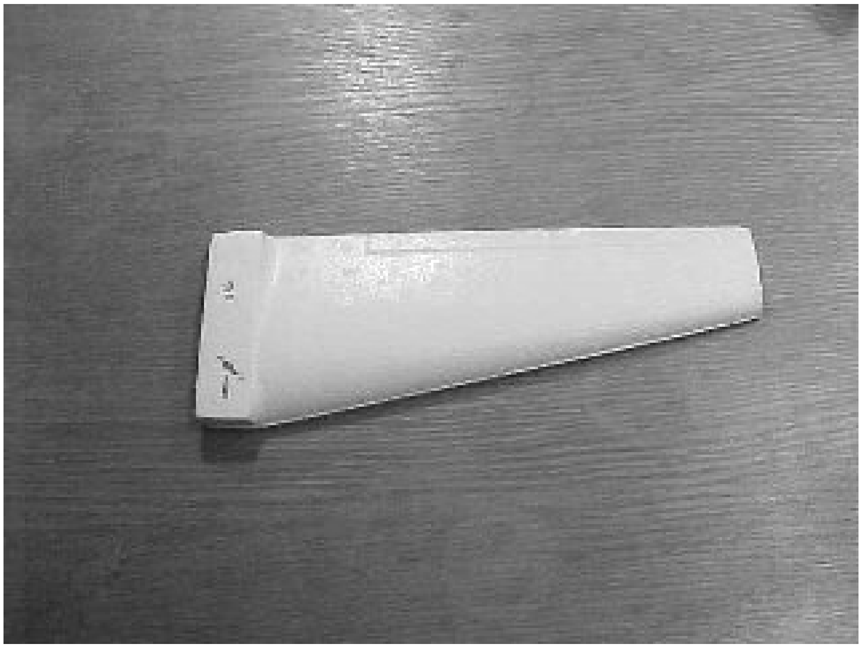


Figure 2

Styrofoam Model Wing

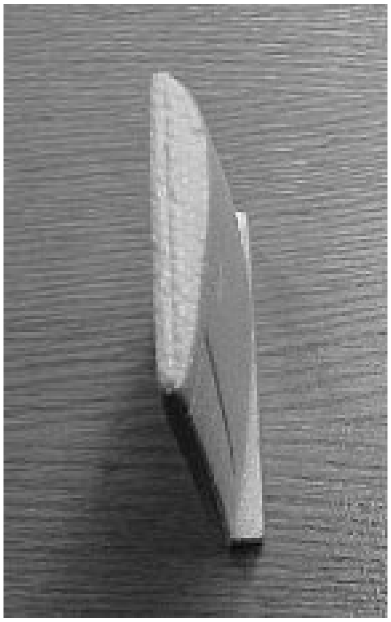


Figure 3

End View of Styrofoam Model Wing

Showing "Realistic" Curvature

(front of wing toward top of photo)

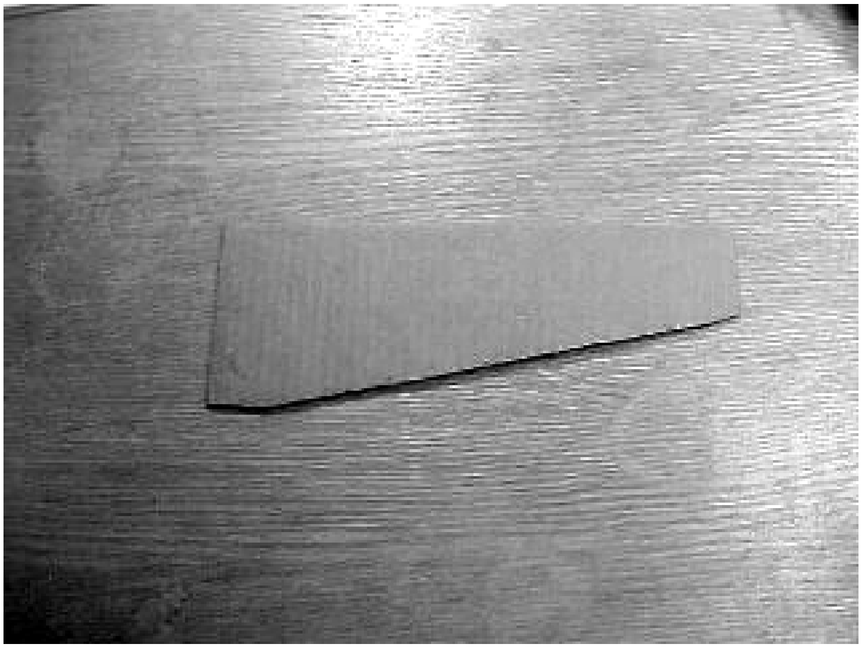


Figure 4

Cardboard "Wing"

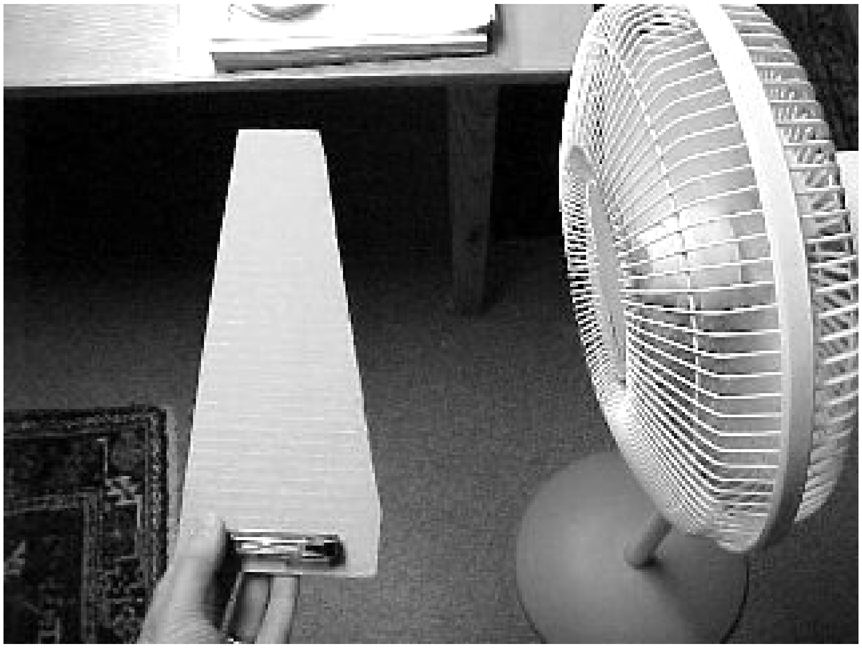


Figure 5

Illustration of holding the cardboard model wing,

with carpenter’s line level, in front of fan

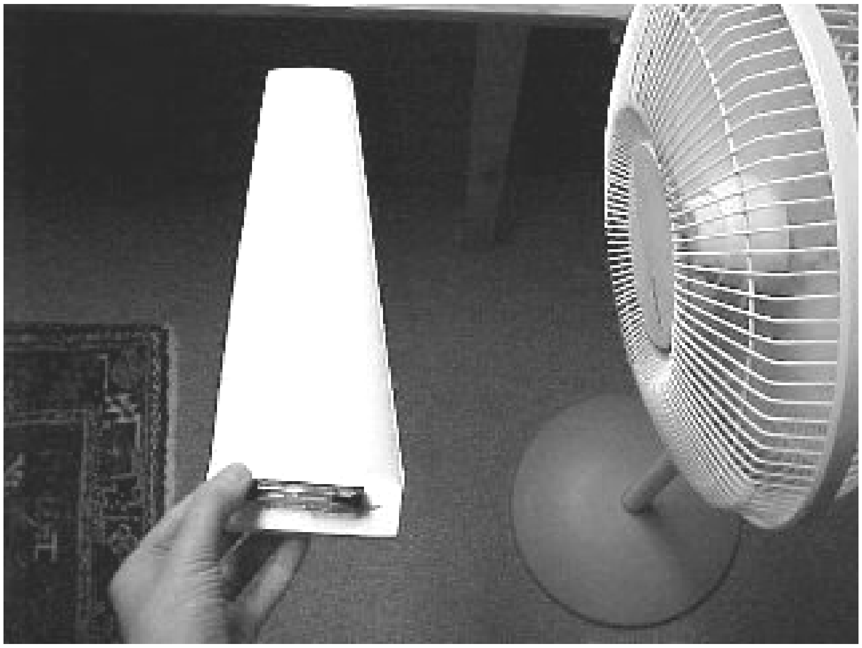


Figure 6

Illustration of holding the Styrofoam model wing,

with carpenter’s line level, in front of fan

Figure 7

Sheet of paper being held on edge and allowed to droop down

Figure 8

Holding a piece of paper and blowing air over the top, causing the paper to rise up.

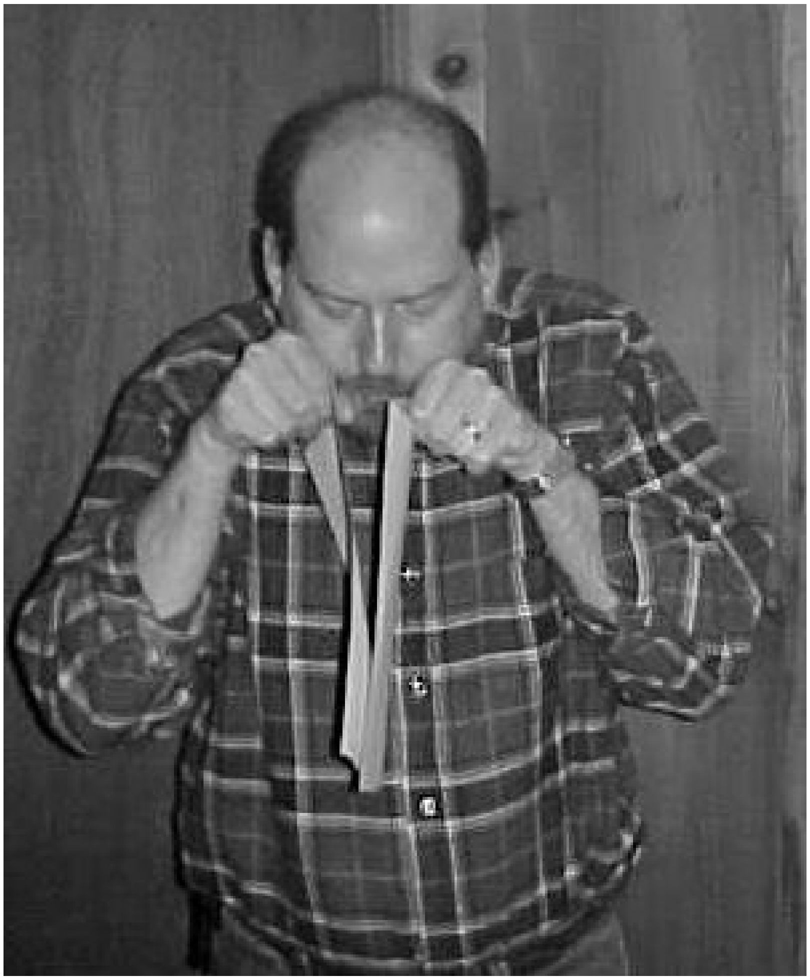


Figure 9

Blowing in between two pieces of paper,
causing them to come together

Figure 10

The wing shape illustration provided to participants
to draw on

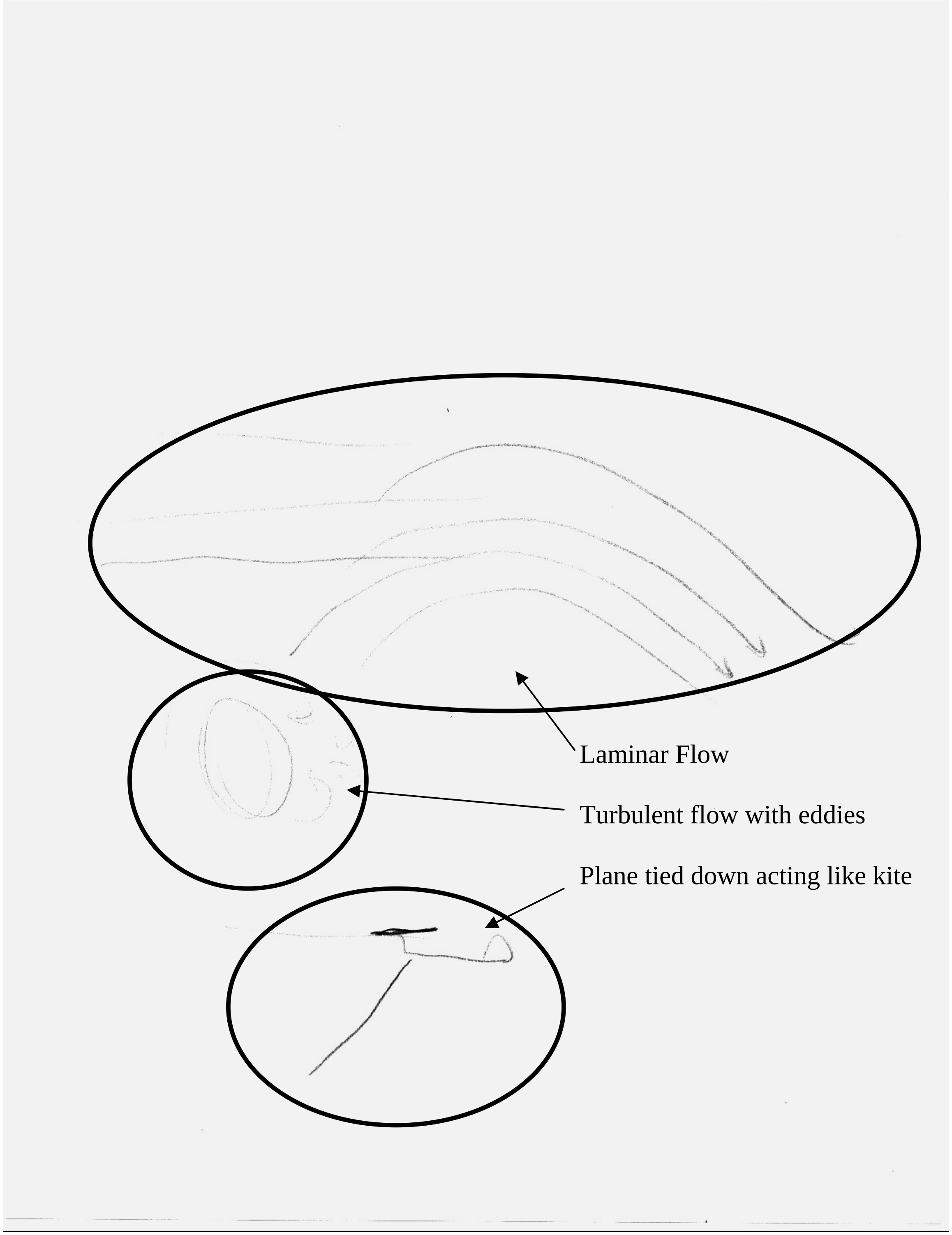


Figure 11

John’s drawing showing laminar flow and an airplane tied down, acting “like a kite”

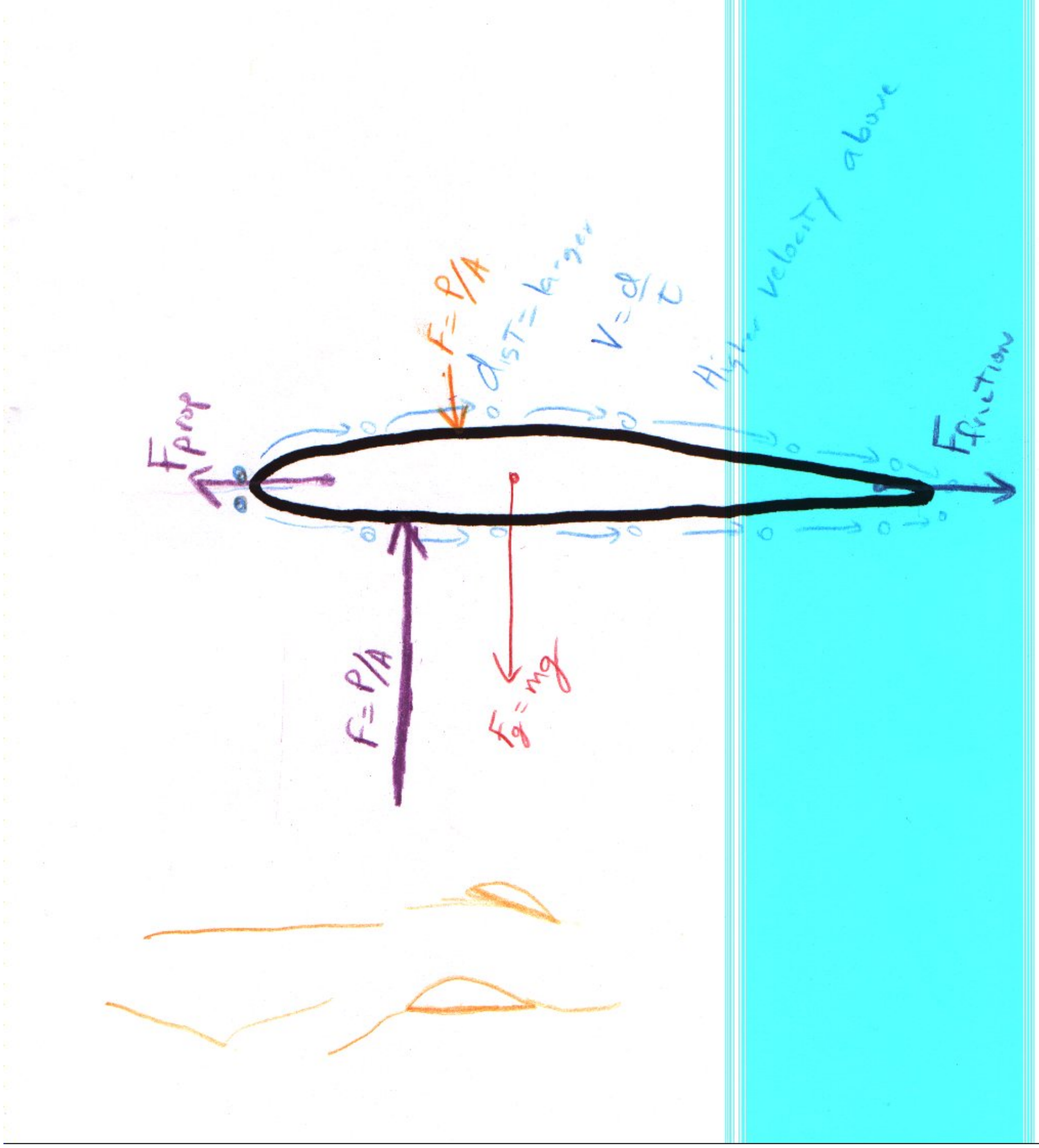
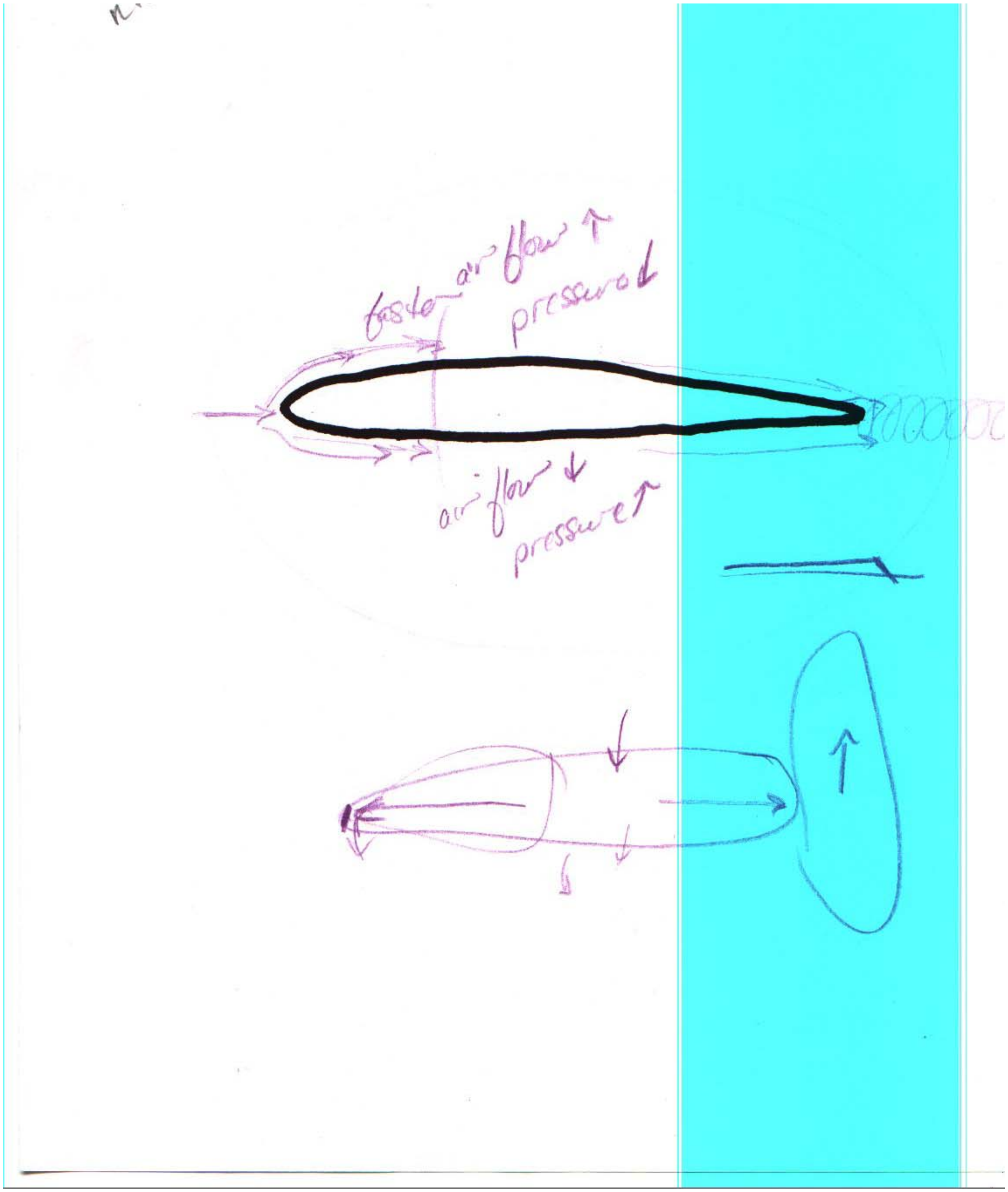


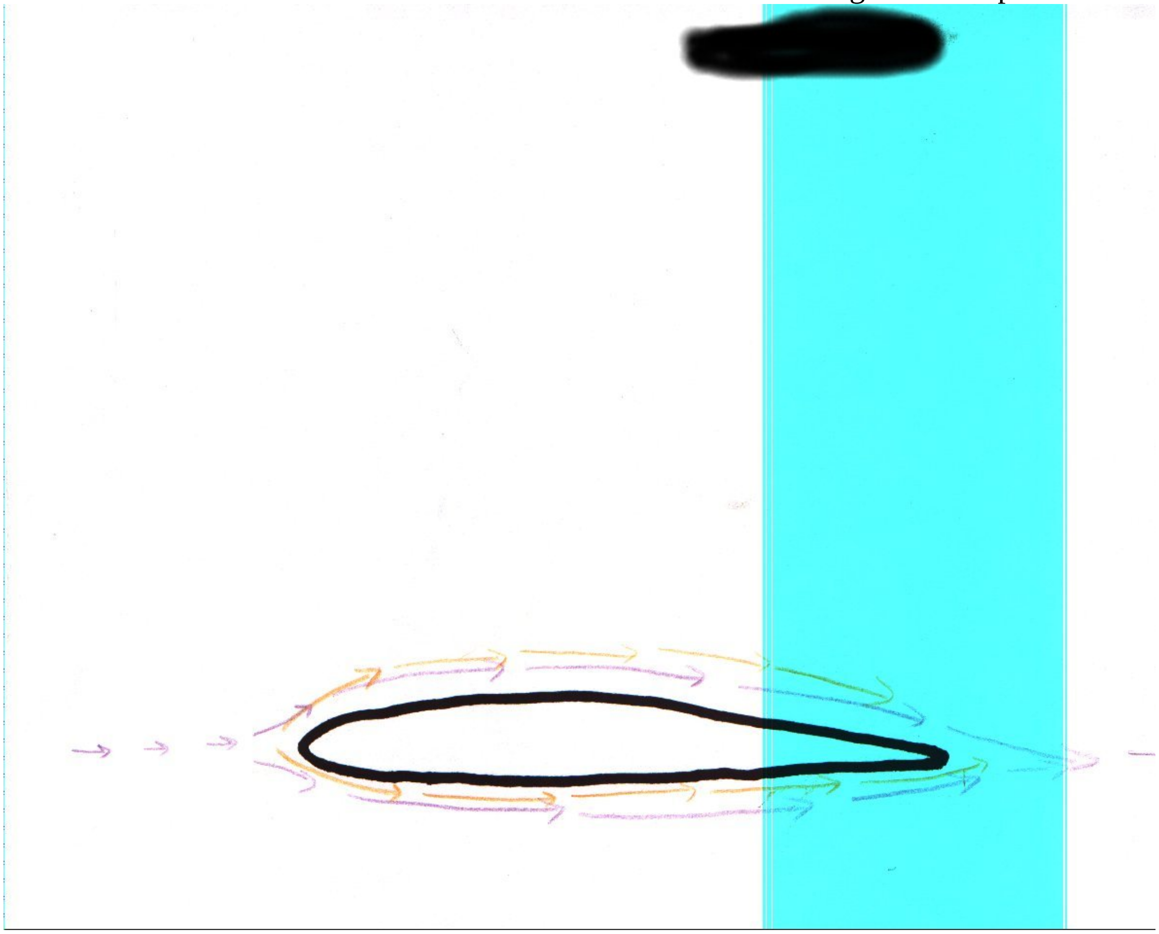
Figure 12

John’s drawing of air movement around a wing & forces acting on a wing



<u>Figure 13</u>

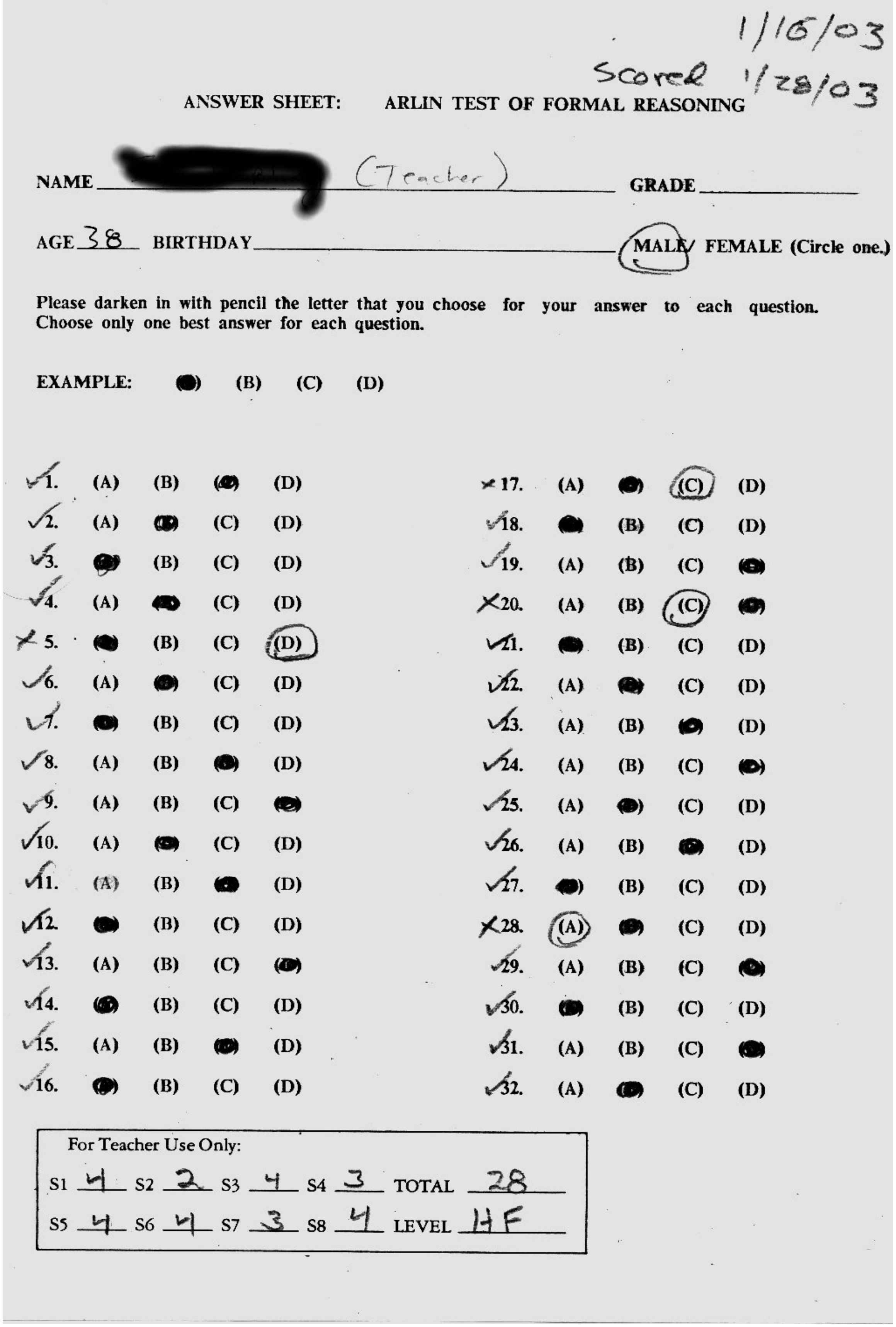
Jane’s drawing of air flow around a wing



[redacted]

Figure 14

Joan’s drawing of air flow around a wing



1/16/03

Scored 1/28/03

ANSWER SHEET: ARLIN TEST OF FORMAL REASONING

NAME [redacted] (Teacher) GRADE ____

AGE 38 BIRTHDAY ____ [✓ MALE] / FEMALE (Circle one.)

Please darken in with pencil the letter that you choose for your answer to each question. Choose only one best answer for each question.

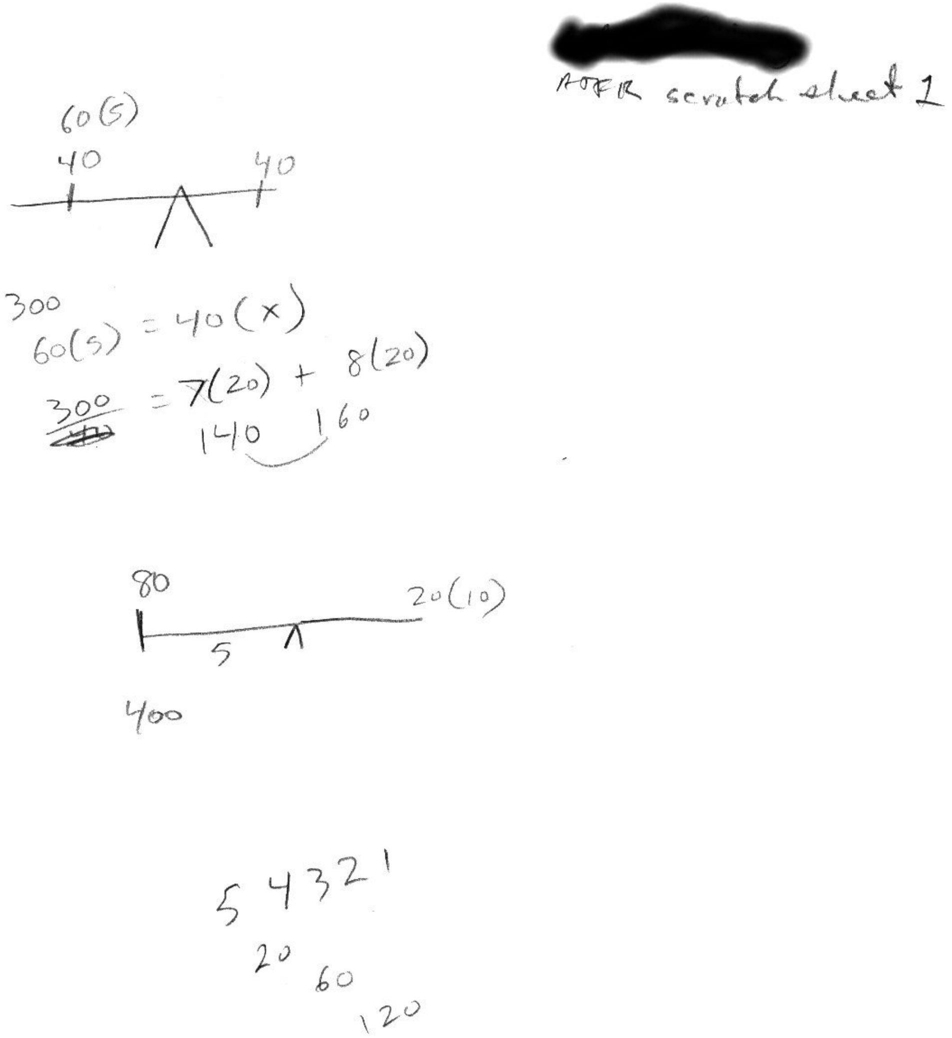
EXAMPLE: ● (B) (C) (D)

✓1. (A) (B) ● (D)
✓2. (A) ● (C) (D)
✓3. ● (B) (C) (D)
✓4. (A) ● (C) (D)
✗5. ● (B) (C) [✓ (D)]
✓6. (A) ● (C) (D)
✓7. ● (B) (C) (D)
✓8. (A) (B) ● (D)
✓9. (A) (B) (C) ●
✓10. (A) ● (C) (D)
✓11. (A) (B) ● (D)
✓12. ● (B) (C) (D)
✓13. (A) (B) (C) ●
✓14. ● (B) (C) (D)
✓15. (A) (B) ● (D)
✓16. ● (B) (C) (D)
✗17. (A) ● [✓ (C)] (D)
✓18. ● (B) (C) (D)
✓19. (A) (B) (C) ●
✗20. (A) (B) [✓ (C)] ●
✓21. ● (B) (C) (D)
✓22. (A) ● (C) (D)
✓23. (A) (B) ● (D)
✓24. (A) (B) (C) ●
✓25. (A) ● (C) (D)
✓26. (A) (B) ● (D)
✓27. ● (B) (C) (D)
✗28. [✓ (A)] ● (C) (D)
✓29. (A) (B) (C) ●
✓30. ● (B) (C) (D)
✓31. (A) (B) (C) ●
✓32. (A) ● (C) (D)

For Teacher Use Only:
S1 4 S2 2 S3 4 S4 3 TOTAL 28
S5 4 S6 4 S7 3 S8 4 LEVEL HF

Figure 15

John’s ATFR Answer Sheet



[redacted]

ATFR scratch sheet 1

$60(5) = 40(x)$

$\frac{300}{} = 7(20) + 8(20)$

140 160

5 4 3 2 1

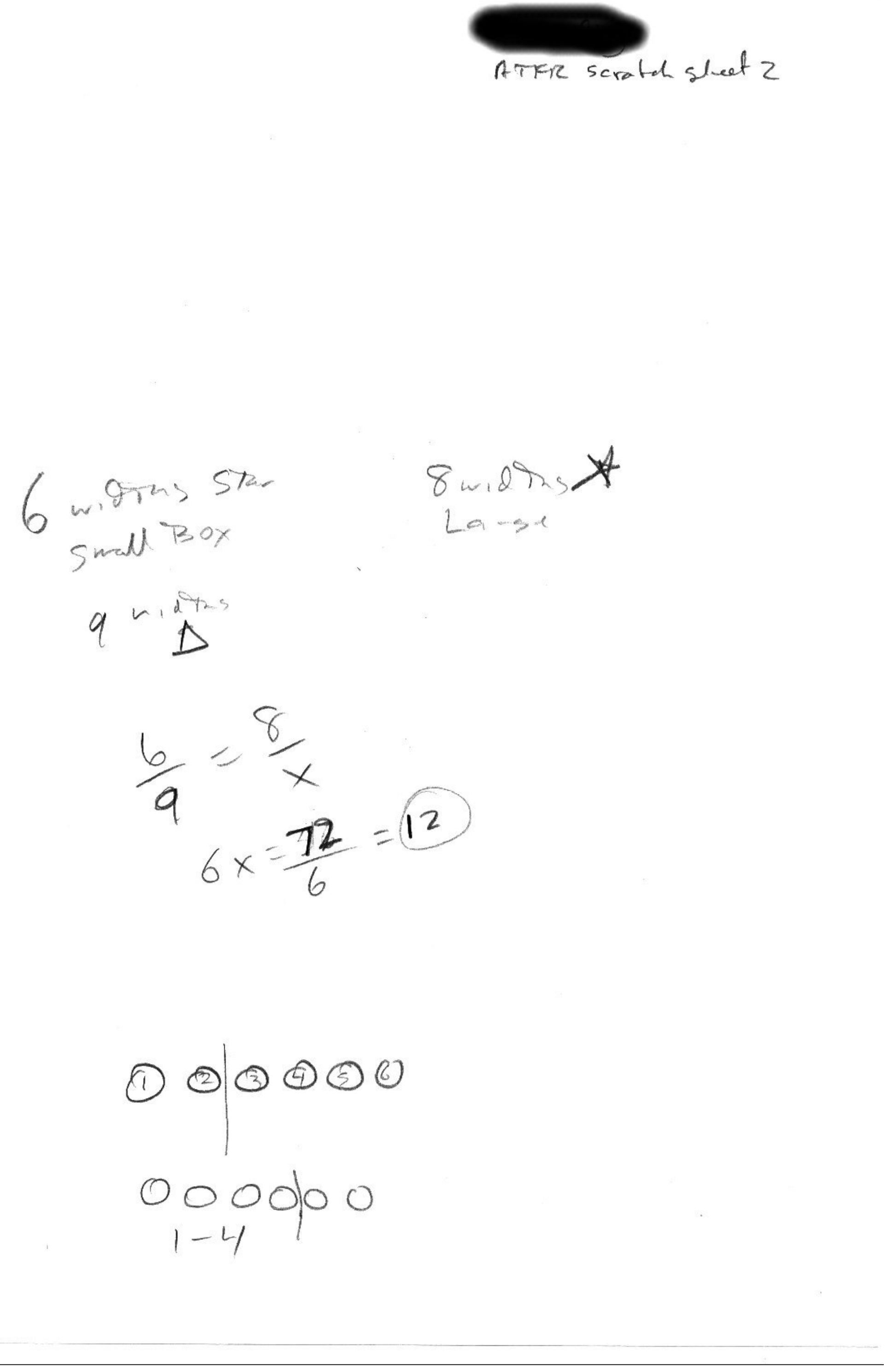
20

60

120

<u>Figure 16</u>

John ATFR scratch sheet 1



[redacted]

ATFR scratch sheet 2

6 widths Star
small Box

8 widths ★
Large

9 widths
△

$$\frac{6}{9} = \frac{8}{x}$$

$$6x = \frac{72}{6} = \boxed{12}$$

Figure 17

John ATFR scratch sheet 2

18

[redacted]

ATFR scratch sheet 3

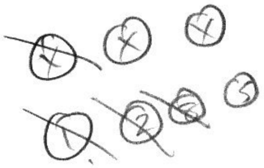
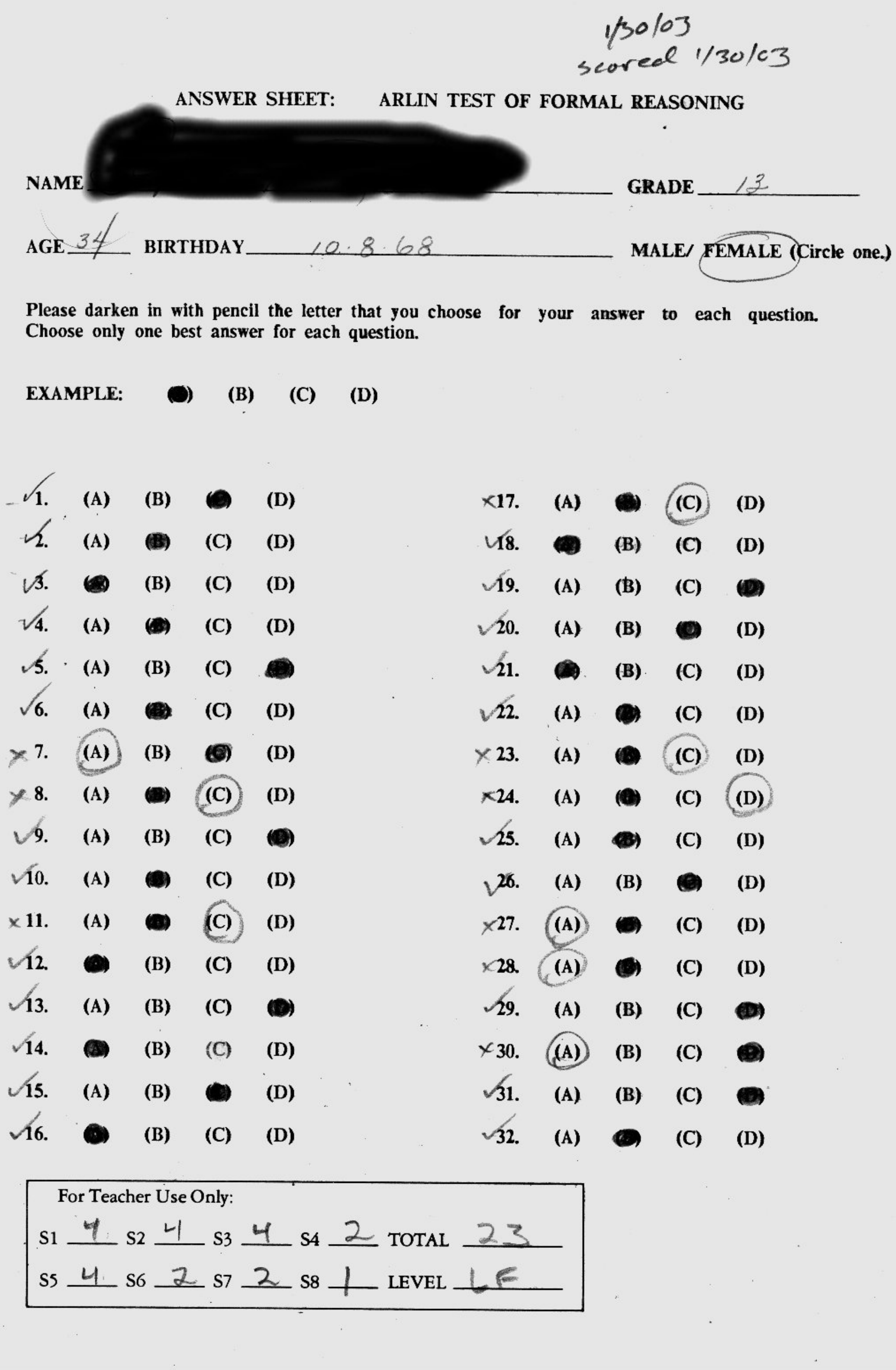


Figure 18

John ATFR scratch sheet 3



1/30/03
scored 1/30/03

ANSWER SHEET: ARLIN TEST OF FORMAL REASONING

NAME [redacted] GRADE 13

AGE 34 BIRTHDAY 10·8·68 MALE/ [✓ FEMALE] (Circle one.)

Please darken in with pencil the letter that you choose for your answer to each question. Choose only one best answer for each question.

EXAMPLE: ● (B) (C) (D)

✓	1.	(A)	(B)	●	(D)	✗	17.	(A)	●	[✓ (C)]	(D)
✓	2.	(A)	●	(C)	(D)	✓	18.	●	(B)	(C)	(D)
✓	3.	●	(B)	(C)	(D)	✓	19.	(A)	(B)	(C)	●
✓	4.	(A)	●	(C)	(D)	✓	20.	(A)	(B)	●	(D)
✓	5.	(A)	(B)	(C)	●	✓	21.	●	(B)	(C)	(D)
✓	6.	(A)	●	(C)	(D)	✓	22.	(A)	●	(C)	(D)
✗	7.	[✓ (A)]	(B)	●	(D)	✗	23.	(A)	●	[✓ (C)]	(D)
✗	8.	(A)	●	[✓ (C)]	(D)	✗	24.	(A)	●	(C)	[✓ (D)]
✓	9.	(A)	(B)	(C)	●	✓	25.	(A)	●	(C)	(D)
✓	10.	(A)	●	(C)	(D)	✓	26.	(A)	(B)	●	(D)
✗	11.	(A)	●	[✓ (C)]	(D)	✗	27.	[✓ (A)]	●	(C)	(D)
✓	12.	●	(B)	(C)	(D)	✗	28.	[✓ (A)]	●	(C)	(D)
✓	13.	(A)	(B)	(C)	●	✓	29.	(A)	(B)	(C)	●
✓	14.	●	(B)	(C)	(D)	✗	30.	[✓ (A)]	(B)	(C)	●
✓	15.	(A)	(B)	●	(D)	✓	31.	(A)	(B)	(C)	●
✓	16.	●	(B)	(C)	(D)	✓	32.	(A)	●	(C)	(D)

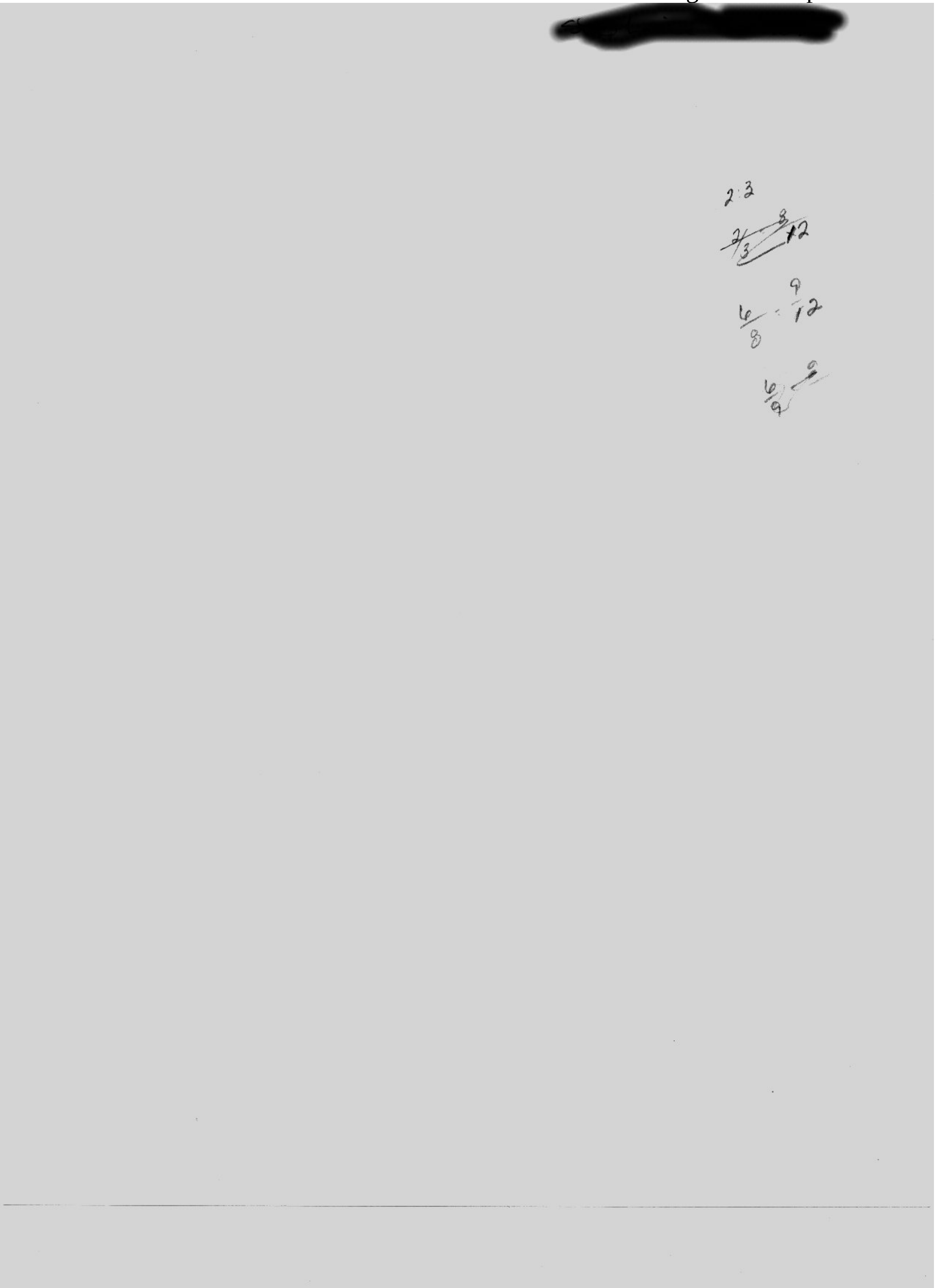
For Teacher Use Only:

S1 4 S2 4 S3 4 S4 2 TOTAL 23

S5 4 S6 2 S7 2 S8 1 LEVEL LF

Figure 19

Jane's ATFR Answer Sheet



[redacted]

$2:3$

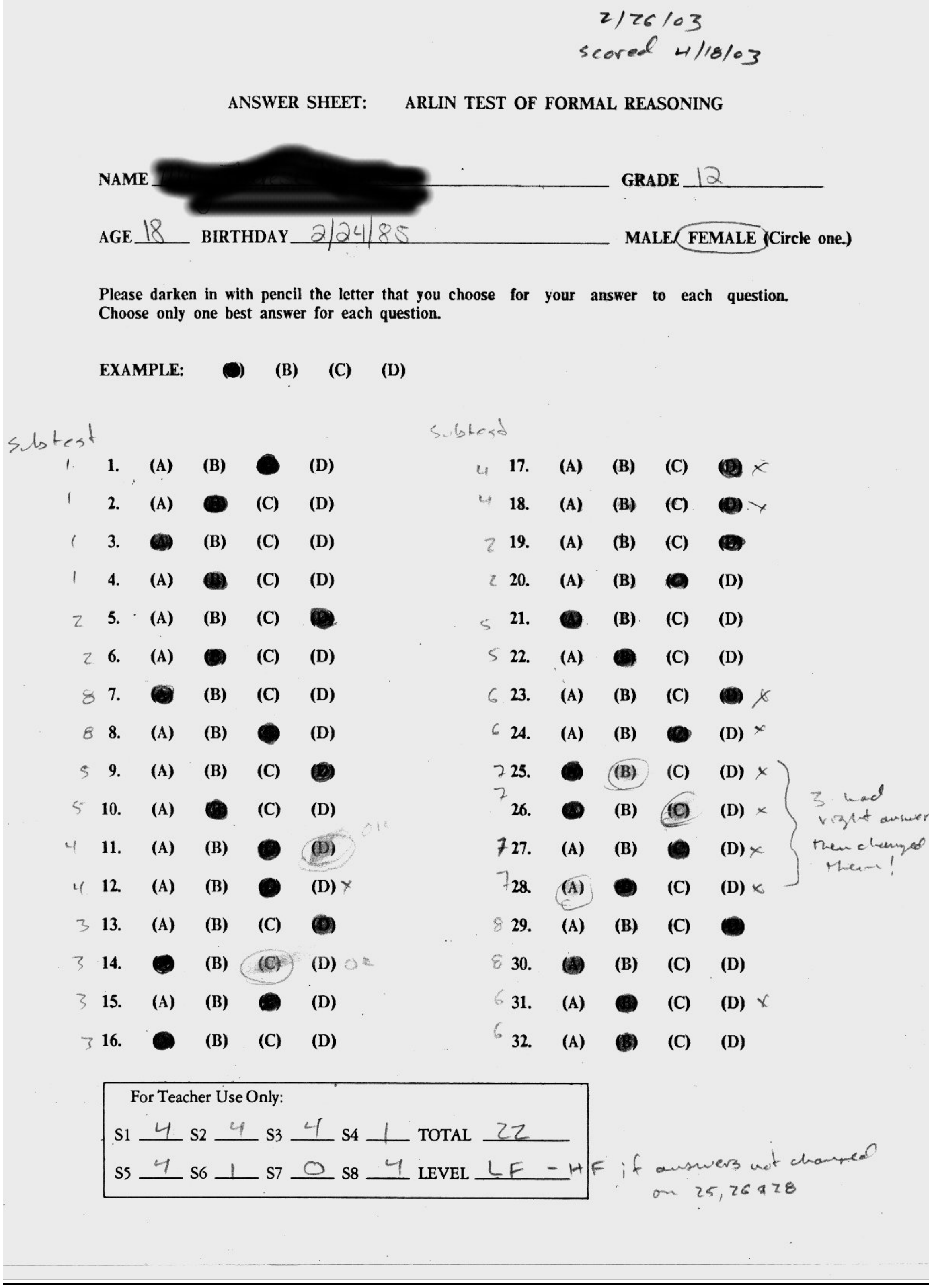
$\frac{2}{3} \cdot \frac{8}{12}$

$\frac{6}{8} \cdot \frac{9}{12}$

$\frac{6}{9} \leftarrow 9$

Figure 20

Jane’s ATFR scratch sheet



2/26/03
scored 4/18/03

ANSWER SHEET: ARLIN TEST OF FORMAL REASONING

NAME [redacted] GRADE 12

AGE 18 BIRTHDAY 2/24/85 MALE/ [✓ FEMALE] (Circle one.)

Please darken in with pencil the letter that you choose for your answer to each question. Choose only one best answer for each question.

EXAMPLE: ● (B) (C) (D)

subtest

1	1.	(A)	(B)	●	(D)	
1	2.	(A)	●	(C)	(D)	
1	3.	●	(B)	(C)	(D)	
1	4.	(A)	●	(C)	(D)	
2	5.	(A)	(B)	(C)	●	
2	6.	(A)	●	(C)	(D)	
8	7.	●	(B)	(C)	(D)	
8	8.	(A)	(B)	●	(D)	
5	9.	(A)	(B)	(C)	●	
5	10.	(A)	●	(C)	(D)	
4	11.	(A)	(B)	●	(D)	OR
4	12.	(A)	(B)	●	(D)	x
3	13.	(A)	(B)	(C)	●	
3	14.	●	(B)	(C)	(D)	OR
3	15.	(A)	(B)	●	(D)	
3	16.	●	(B)	(C)	(D)	

subtest

4	17.	(A)	(B)	(C)	●	x
4	18.	(A)	(B)	(C)	●	x
2	19.	(A)	(B)	(C)	●	
2	20.	(A)	(B)	●	(D)	
5	21.	●	(B)	(C)	(D)	
5	22.	(A)	●	(C)	(D)	
6	23.	(A)	(B)	(C)	●	x
6	24.	(A)	(B)	●	(D)	x
7	25.	●	(B)	(C)	(D)	x
7	26.	●	(B)	(C)	(D)	x
7	27.	(A)	(B)	●	(D)	x
7	28.	(A)	●	(C)	(D)	x
8	29.	(A)	(B)	(C)	●	
8	30.	●	(B)	(C)	(D)	
6	31.	(A)	●	(C)	(D)	x
6	32.	(A)	●	(C)	(D)	

3 had right answer then changed them!

For Teacher Use Only:

S1 4 S2 4 S3 4 S4 1 TOTAL 22

S5 4 S6 1 S7 0 S8 4 LEVEL LF - HF if answers not changed on 25, 26 & 28

Figure 21

Joan's ATFR Answer Sheet

[redacted]

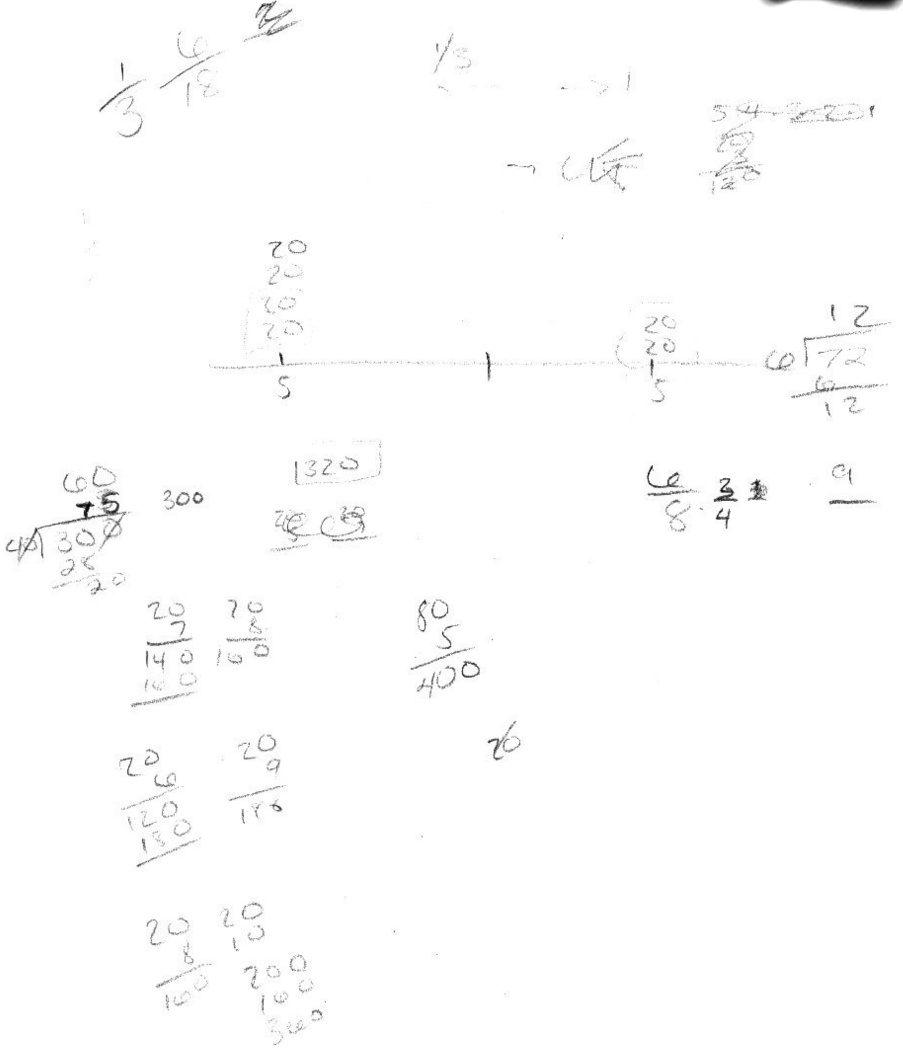
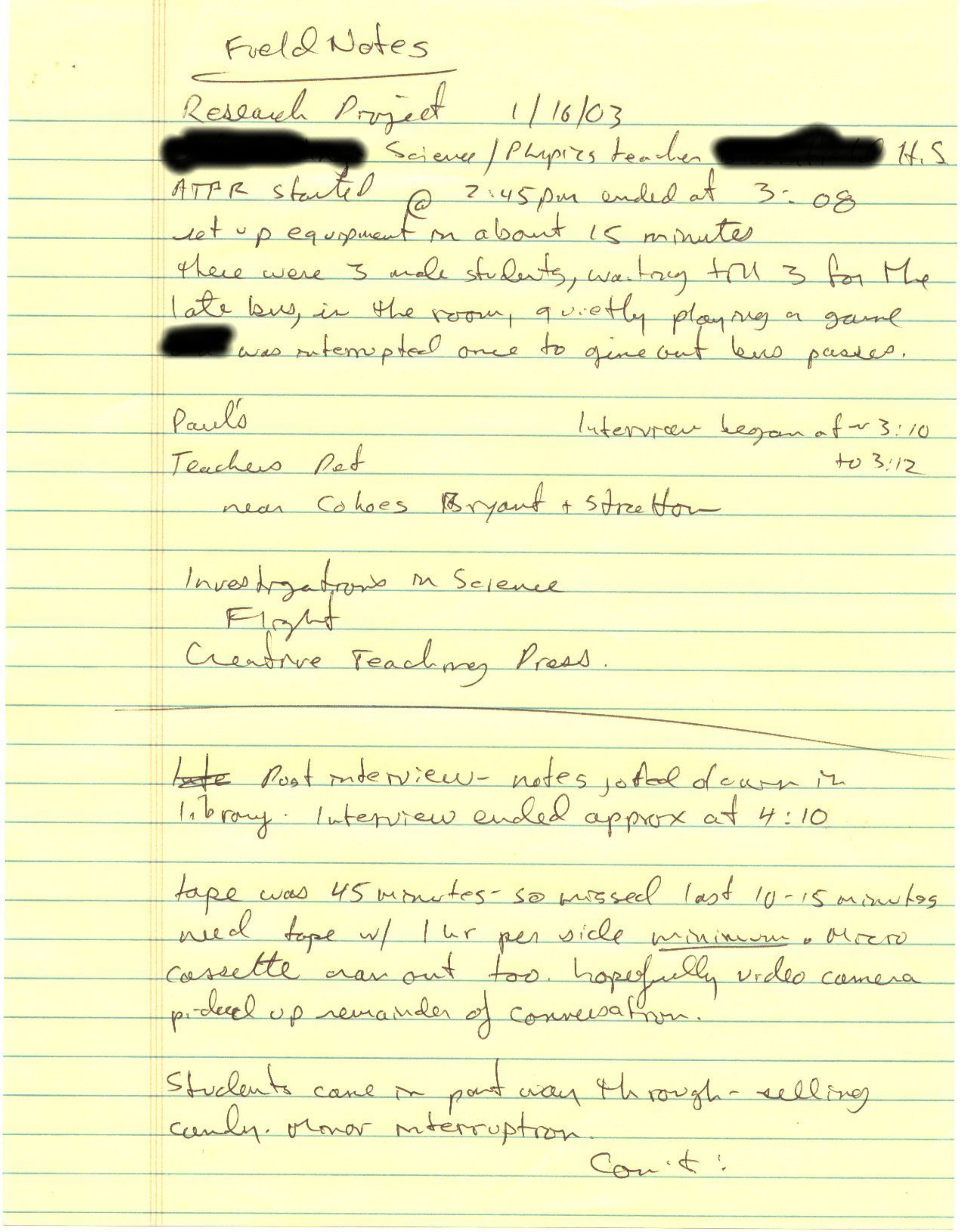


Figure 22

Joan ATFR scratch sheet



Field Notes

Research Project 1/16/03

[redacted] Science / Physics teacher [redacted] H.S

ATFR started @ 2:45pm ended at 3:08

set up equipment in about 15 minutes

there were 3 male students, waiting till 3 for the late bus, in the room, quietly playing a game

[redacted] was interrupted once to give out bus passes.

Paul's

Teachers Pet

near Cohoes Bryant + Stratton

Interview began at ~3:10

to 3:12

Investigations in Science

Flight

Creative Teaching Press.

~~Late~~ Post interview - notes jotted down in library. Interview ended approx at 4:10

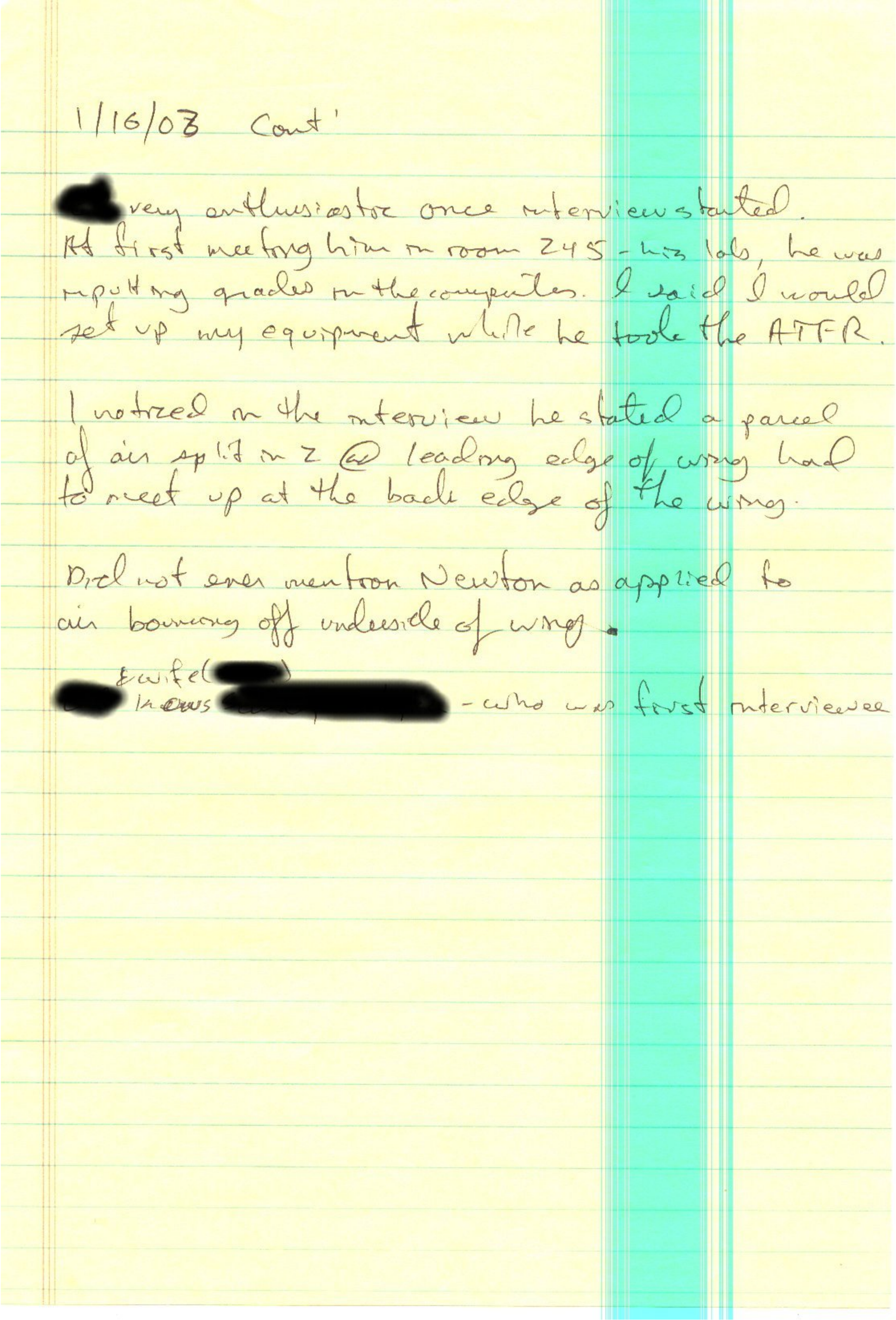
tape was 45 minutes - so missed last 10-15 minutes need tape w/ 1 hr per side minimum. Micro cassette ran out too. hopefully video camera picked up remainder of conversation.

Students came in part way through - selling candy. minor interruption.

Con't:

Figure 23

John interview field notes 1



1/16/03 Cont'

[redacted] very enthusiastic once interview started. At first meeting him in room 245 - his lab, he was inputting grades in the computer. I said I would set up my equipment while he took the ATFR.

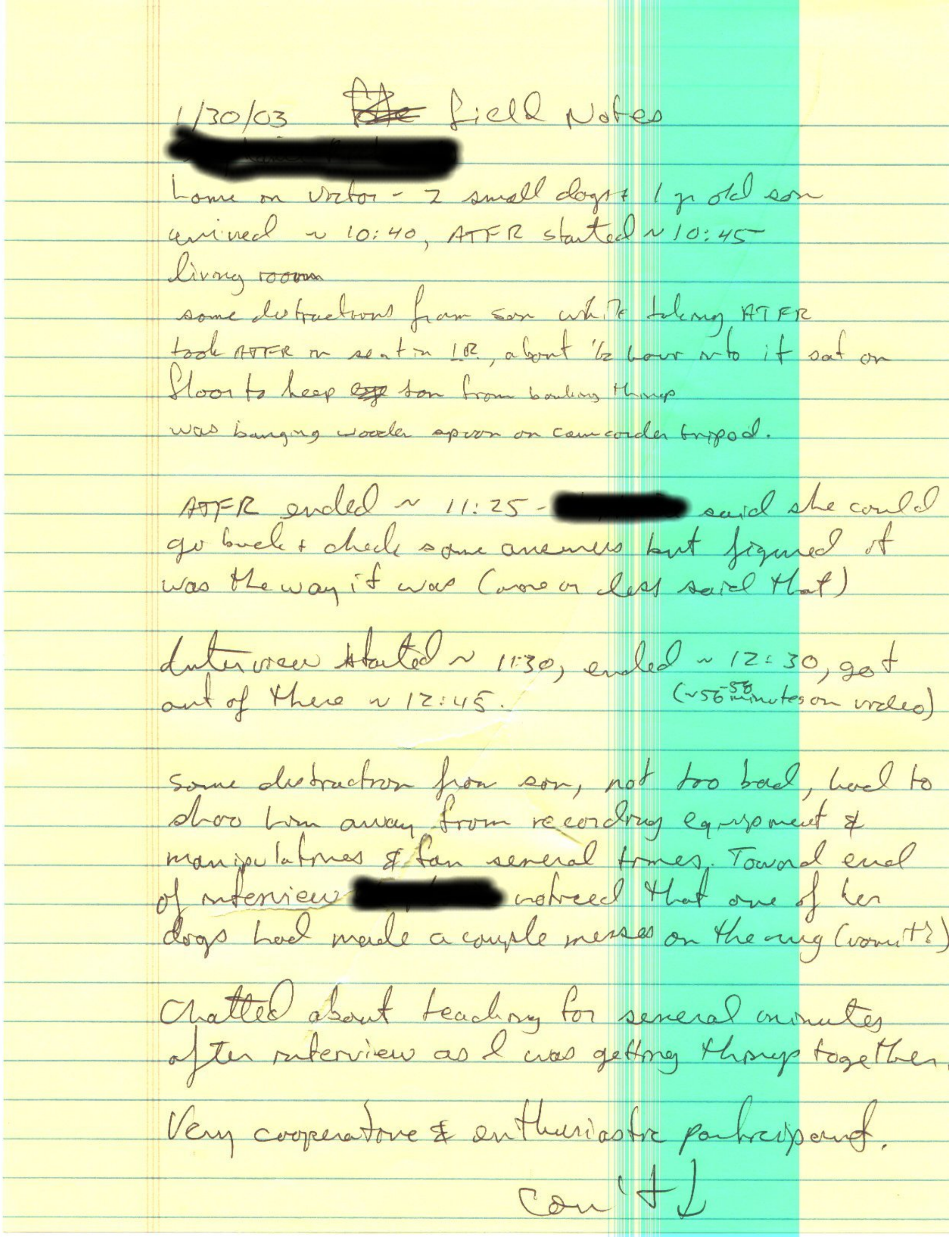
I noticed in the interview he stated a parcel of air split in 2 @ leading edge of wing had to meet up at the back edge of the wing.

Did not ever mention Newton as applied to air bouncing off underside of wing.

[redacted] & wife ([redacted]) knows [redacted] - who was first interviewee

Figure 24

John interview field notes 2



1/30/03 ~~[illegible]~~ Field Notes

[redacted]

home on vacation - 2 small dogs + 1 yr old son
arrived ~ 10:40, ATFR started ~ 10:45
living room
some distractions from son while taking ATFR
took ATFR on seat in LR, about ½ hour into it sat on
floor to keep ~~[illegible]~~ son from bothering things
was banging wooden spoon on camcorder tripod.

ATFR ended ~ 11:25 - [redacted] said she could go back + check some answers but figured it was the way it was (more or less said that)

Interview started ~ 11:30, ended ~ 12:30, got out of there ~ 12:45. (~56-58 minutes on video)

Some distraction from son, not too bad, had to shoo him away from recording equipment & manipulatives & fan several times. Toward end of interview [redacted] noticed that one of her dogs had made a couple messes on the rug (vomit?)

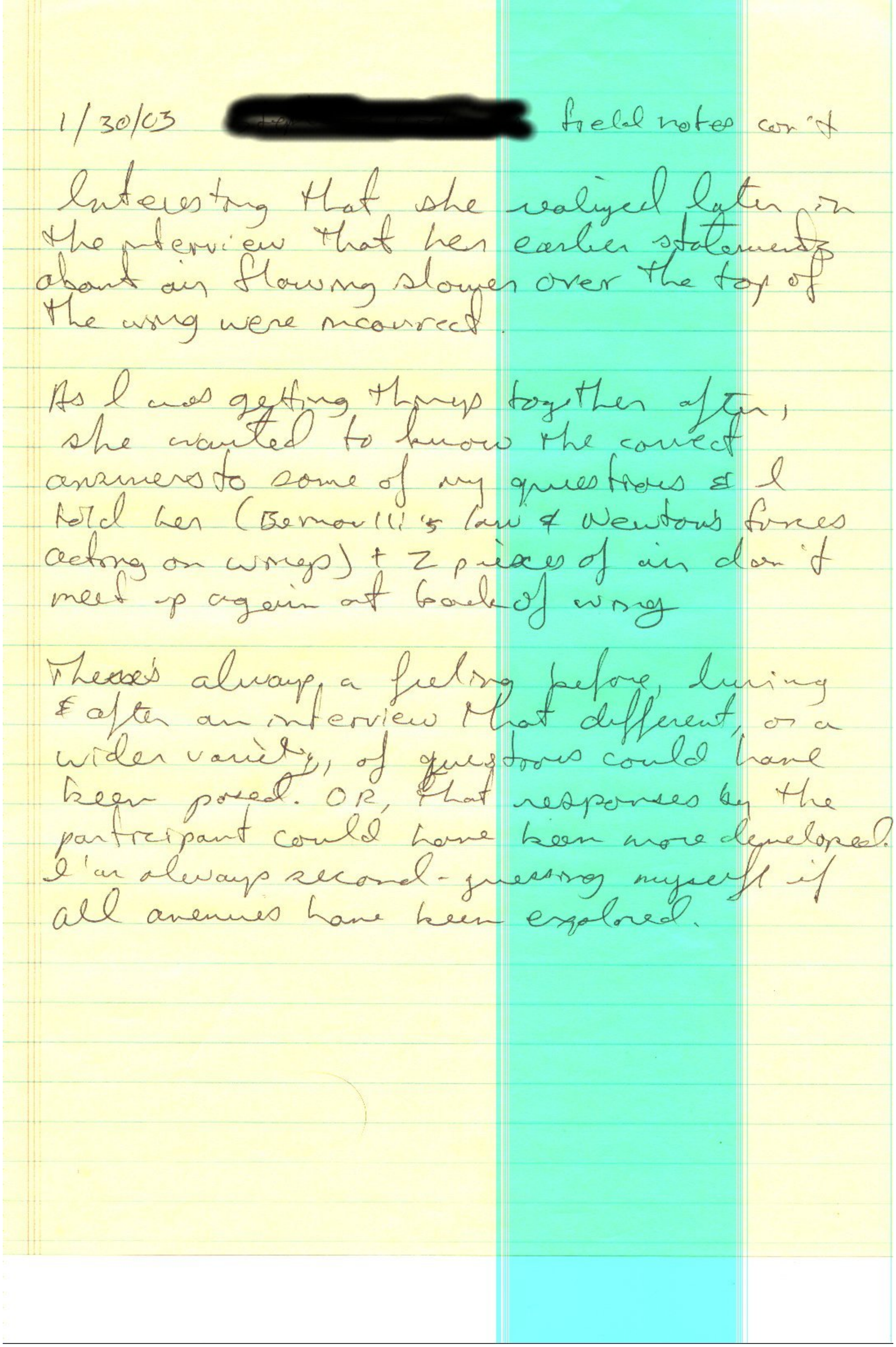
Chatted about teaching for several minutes after interview as I was getting things together.

Very cooperative & enthusiastic participant.

Con't ↓

Figure 25

Jane interview field notes 1



1/30/03 [redacted] field notes con't

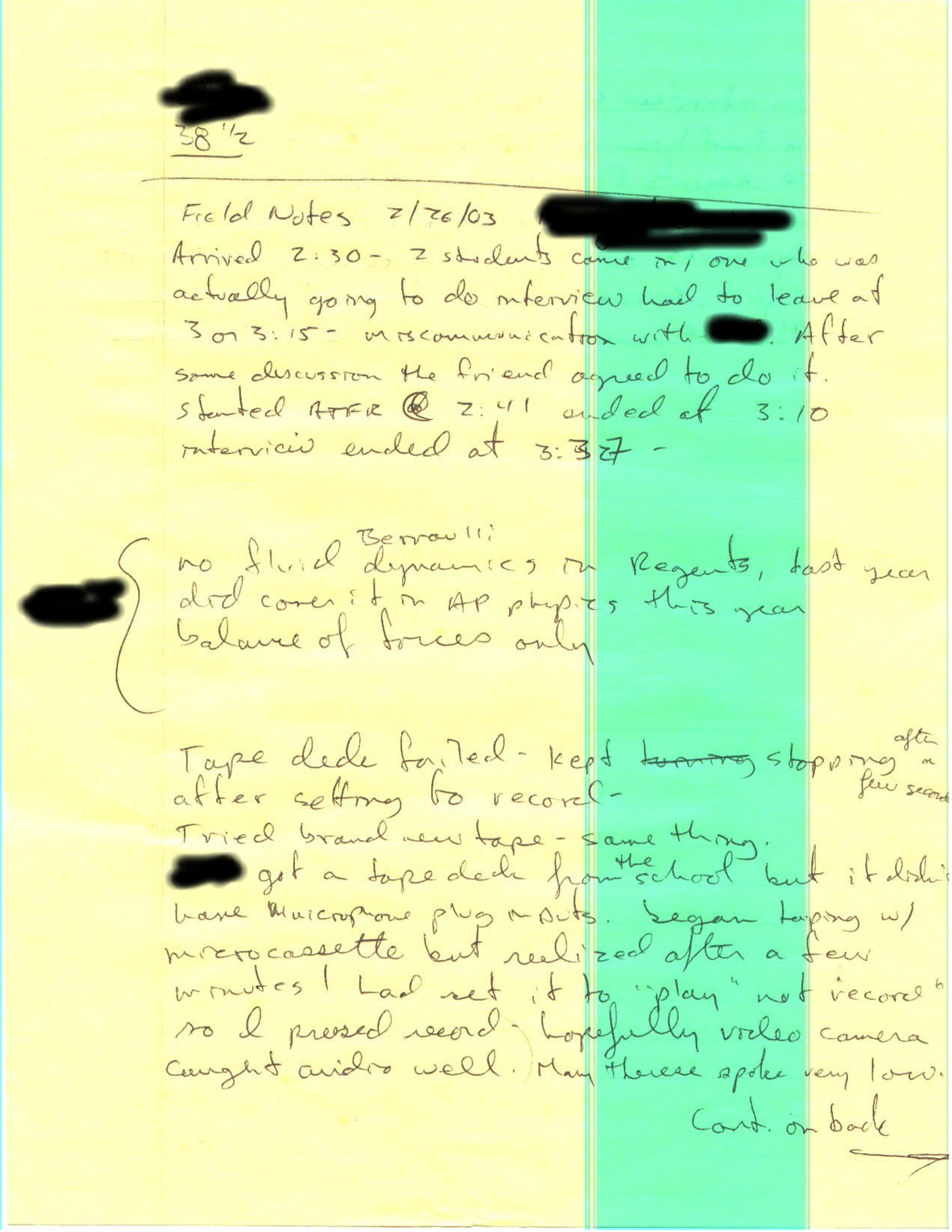
Interesting that she realized later in the interview that her earlier statements about air flowing slower over the top of the wing were incorrect.

As I was getting things together after, she wanted to know the correct answers to some of my questions & I told her (Bernoulli's law & Newtons forces acting on wings) + 2 pieces of air don't meet up again at back of wing

There's always a feeling before, during & after an interview that different, or a wider variety, of questions could have been posed. OR, that responses by the participant could have been more developed. I'm always second-guessing myself if all avenues have been explored.

Figure 26

Jane interview field notes 2



[redacted]

38 ½

Field Notes 2/26/03 [redacted]

Arrived 2:30 - 2 students came in, one who was actually going to do interview had to leave at 3 or 3:15 - miscommunication with [redacted]. After some discussion the friend agreed to do it.

started ATFR @ 2:41 ended at 3:10

interview ended at 3:37 -

[redacted]

no fluid dynamics in Regents, Bernoulli; last year did cover it in AP physics this year

balance of forces only

Tape deck failed - kept ~~turning~~ stopping after a few seconds after setting to record -

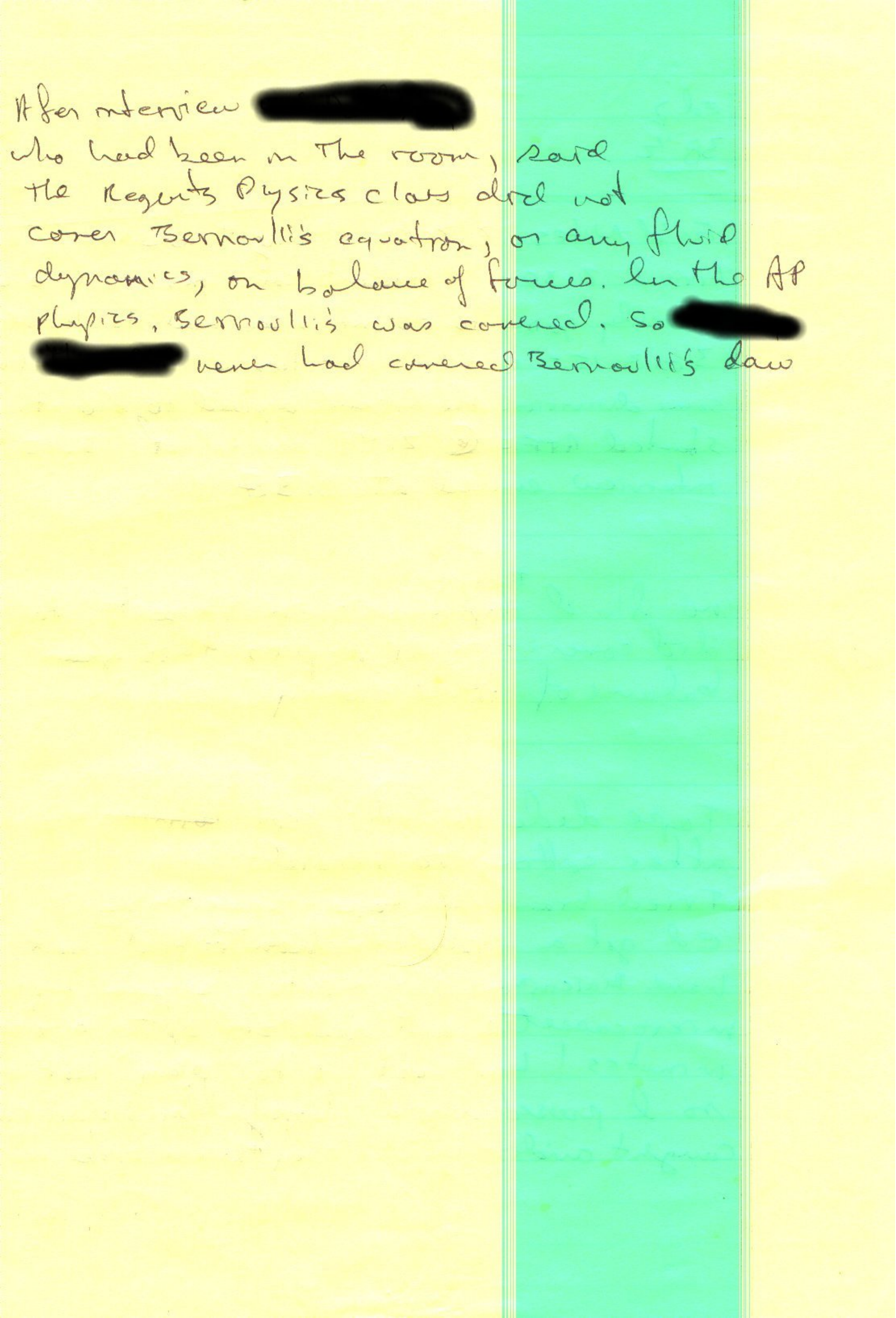
Tried brand new tape - same thing.

[redacted] got a tape deck from the school but it didn't have microphone plug in outs. began taping w/ microcassette but realized after a few minutes I had set it to "play" not "record" so I pressed record - hopefully video camera caught audio well. Mary Therese spoke very low.

Cont. on back

Figure 27

Joan interview field notes 1



After interview [redacted]
who had been in the room, said
the Regents Pysics class did not
cover Bernoulli's equation, or any fluid
dynamics, on balance of forces. In the AP
physics, Bernoulli's was covered. So [redacted]
[redacted] never had covered Bernoulli's law

<u>Figure 28</u>

Joan interview field notes 2