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A DEMONSTRATION OF SIMPLE AIRFOILS: STRUCTURAL DESIGN AND MATERIALS CHOICES

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A DEMONSTRATION OF SIMPLE AIRFOILS: STRUCTURAL DESIGN AND MATERIALS CHOICES

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KEY WORDS: airfoils, composites, strength/weight ratio, structural testing

PREREQUISITE KNOWLEDGE: This unit is appropriate for a high school materials science class or lower-division college courses in structural engineering, materials science, or aeronautical engineering. Prepare for the project by explaining the following: the way that an airfoil shape generates lift (Bernoulli effect), the importance of airfoil shape regarding lift/drag ratio, and the structural requirements of a wing.

OBJECTIVE: Students will build and evaluate simple wing structures, and in so doing will learn about materials choices and lightweight construction methods.

EQUIPMENT AND SUPPLIES: Listed below are the materials required to conduct the project. The suggested quantities (see Table 1) should be sufficient material to construct three each of the six airfoil variations listed in Table 2,

TABLE 1. Materials for Building 18 Wings (including 50% excess)

Quantity, Each	Description[a]
36	Balsa sheet 1/16" x 3" x 36"
18	Balsa leading edge 3/8" x 5/16" x 36"
16	Balsa trailing edge 1/8" x 3/4" x 36"
12	Balsa 1/8" x 1/4" x 36"
9	Spruce 1/8" x 1.4" x 36"

(a) Wood is typically measured in English units.

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TABLE 2. Wing Structural Variations

Variation	Description	Wt, g[a]
BW	Ribs 6 cm apart, balsa spars	38.9
BN	Ribs 3 cm apart, balsa spars	55.4
BWS	Ribs 6 cm apart, balsa spars, shear webs	53.0
SW	Ribs 6 cm apart, spruce spars	52.1
SN	Ribs 3 cm apart, spruce spars	56.9
SWS	Ribs 6 cm apart, spruce spars, shear webs	55.4

(a) Weights are those of the set built for this presentation, included here for reference. These were the weights used for the stiffness/weight and strength/weight ratios calculated below.

including 50% allowance for wastage and mistakes. All required supplies can be purchased at any good hobby shop for under $200 (1991 prices).

- a piece of fibrous ceiling tile about 60 x 120 cm, with a flat finish. Use back side if no flat tiles are available. (Before applying adhesive, the parts of the airfoil are pinned to the ceiling tile to ensure proper alignment; reference lines are used to control component orientation and spacing.)
- cyanoacrylate adhesive for model building; common brands are Zap or Hot Stuff
- bicarbonate of soda
- T-head pins, medium size
- transparent polyester covering material, Monokote (or equivalent) brand
- special iron designed for use in model construction
- special high-temperature heat gun designed for use in model construction
- steel templates, approximately 3 mm thick (cut to Clark Y airfoil shape, with notches for spars).
- X-Acto or equivalent hobby knives, with straight pointed blades

PROCEDURE: The various parts of a wing are illustrated and labeled for orientation in Figure 1. Figure 2 illustrates the actual airfoil size, which may be scaled larger or smaller using a photocopier. [Note that the two notches are placed to fit spars sized 0.64 cm by 0.32 cm (1/4 in. by 1/8 in.).] The six construction versions, all using the Clark Y airfoil, are listed in Table 2. The Clark Y was chosen for construction ease, since it is nearly flat-bottomed. These six versions are identical in cross section, but differ in the amount and placement

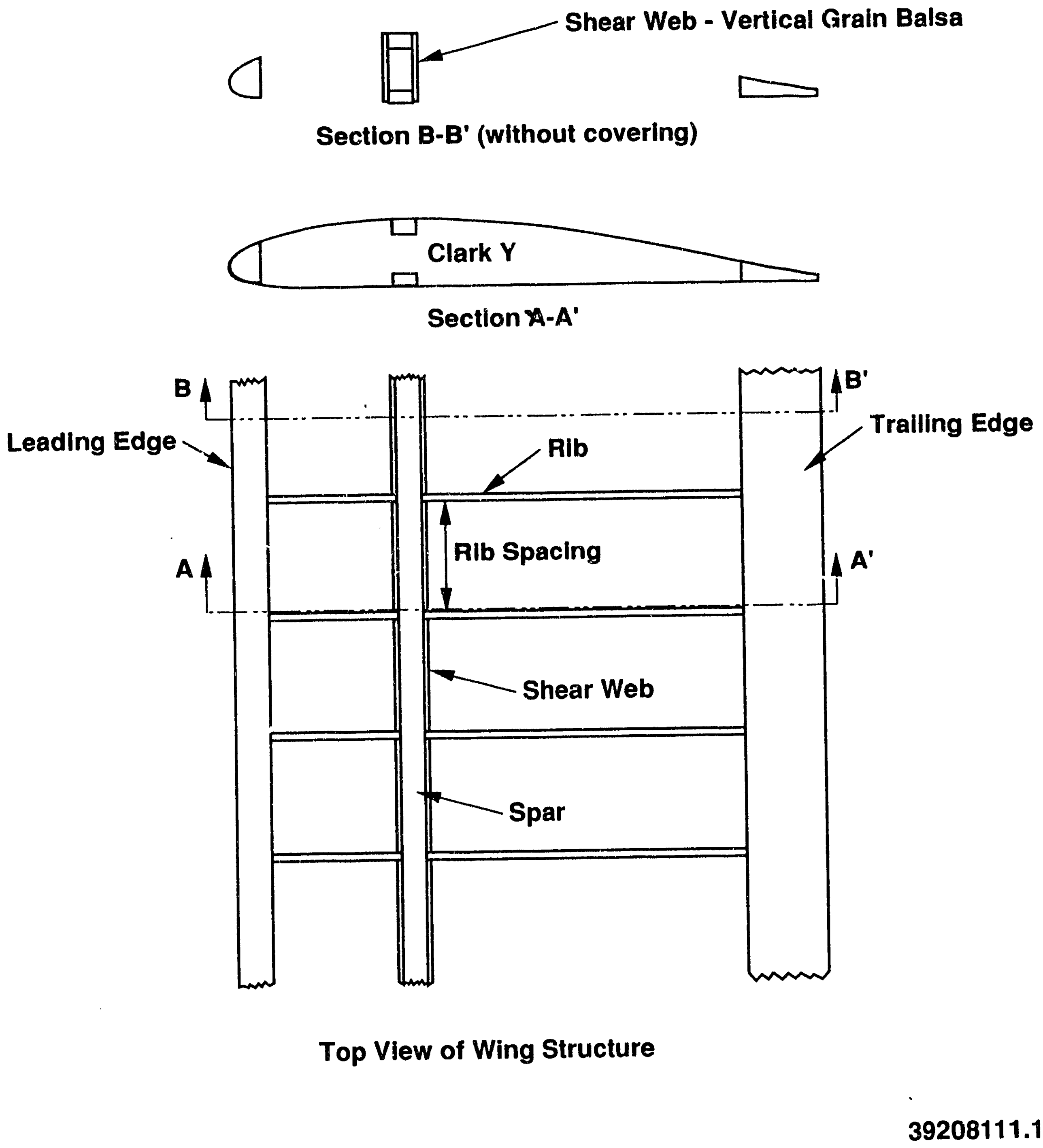

FIGURE 1. Construction Details of a Model Airplane Wing

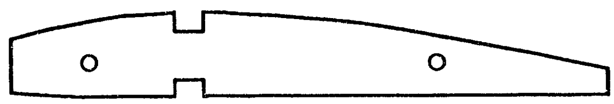

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FIGURE 2. Clark Y Airfoil, Actual Size Used in This Project

of internal reinforcements and in the use of either balsa or spruce as spar material. Assign each team of two or three students the task of constructing one of the six airfoils.

Construction: To make the ribs, the students will need to cut rectangles slightly larger than the templates from 1.6-mm (1/16-in.) sheets of balsa. Since the balsa rectangles will be clamped between the templates, oversized holes should be drilled in the balsa rectangles to match those in the templates. Next, carve and sand the ribs to the shape of the templates (avoid sanding the templates themselves). To make the notches for the spars, glue a 10-cm strip of 150-grit sandpaper to the 1/4-in. face of some scrap spruce spar wood. Sand the spar notches in the ribs, using care to avoid enlarging the notches in the templates.

Cover the building board (ceiling tile) with wax paper to prevent bonding the wing to the board. Pin the bottom spar in place on the building board. Pour bicarbonate of soda into a long narrow tray and dip each rib into the soda before placing it onto the bottom spar. The tiny amount of soda that clings to the rib accelerates the reaction rate of the cyanoacrylate and strengthens the bond. Hold each rib perpendicular to the building board, taking care that each closely follows its reference lines. Apply the cyanoacrylate; the bond will be complete in 2 to 3 seconds. (Use the cyanoacrylate in a well-ventilated area and avoid breathing the fumes.) Set the top spar securely into the notches, and apply cyanoacrylate to the joints. Pin leading and trailing edges in place using a 3-mm (1/8-in) shim under the leading edge, since the airfoil is not quite flat; then bond with cyanoacrylate.

If shear webs are to be attached to the spars, cut the webs so the grain is perpendicular to the building board, then bond to the front and back surfaces of the top spar with cyanoacrylate. The wing may now be removed from the building board and the shear webs bonded to the bottom spars. Glue a doubler of scrap spar material to the outer ribs at either end; this will prevent warpage as the covering material shrinks. Carefully sand the structure as necessary, and use a vacuum cleaner with brush to remove balsa dust. At this point, prepare the covering material by cutting it approximately 3 cm larger on all sides than the wing. Follow manufacturer's instructions for applying the covering, first tacking it in place using the iron, then using the heat gun to shrink the film.

Testing: Record the weight of each airfoil before testing for strength and stiffness. Then, using a clamp that fits the shape of the airfoil's top profile, fasten the airfoil to the edge of the workbench, allowing approx. 35 cm of the airfoil to hang free, like a cantilever. Since deflection under load is a cube function of length, the free length should be carefully controlled. Attach a plastic or cloth bag or small plastic pail to the top spar using strong string and duct tape. See Figure 3 for details. Using a meter stick fixed to a base, measure the distance to the nearest millimeter from the lower wing surface to the floor.

To measure the relative stiffness of the airfoil, apply weights (used wheel weights from a tire store will do) until a deflection of 1 cm is attained; weigh the container and weights, and record this weight. Continue to load the airfoil until failure occurs; record the failure weight and the approximate deflection at failure. Be careful to avoid destroying the wing when failure occurs by suspending the weight container within 5 cm of the floor. When the airfoil fails, the distance the weight must drop to the floor is limited. After failure, examine the structure to locate the failure site, taking this information into consideration along with observations made during testing.

Discussion: In discussing cause for failure, students should speculate on what could have been done differently during construction. For instance, because all of our test structures failed in compression at the interface between the wing and the clamping fixture, a buttress at this point would be appropriate. If time permits, have students build and test a second airfoil (same cross section as the first) using their proposed remedies for increasing strength and stiffness and for minimizing weight. Alternatively, students may wish to simply duplicate their first airfoil, being more careful with wood selection and construction. Allow interested students to construct original designs, as long as their airfoils remain within the initial parameters of dimension, shape and material. An example of an original construction would be an airfoil cut from polystyrene insulation foam, using electrically heated wire and templates on each end. This airfoil could be covered with balsa sheeting bonded with epoxy. In spite of the weight penalty for such an airfoil, the improvements in strength and stiffness are impressive.

Plot the class's test results, using a simple bar graph like Figures 4 and 5. On the x-axis plot structure type; on the y-axis, plot either the weight to cause 1-cm deflection divided by the wing weight or failure weight divided by the wing weight. Observe and discuss scatter and trends. (Instructor should save results to use for comparison with subsequent classes.)

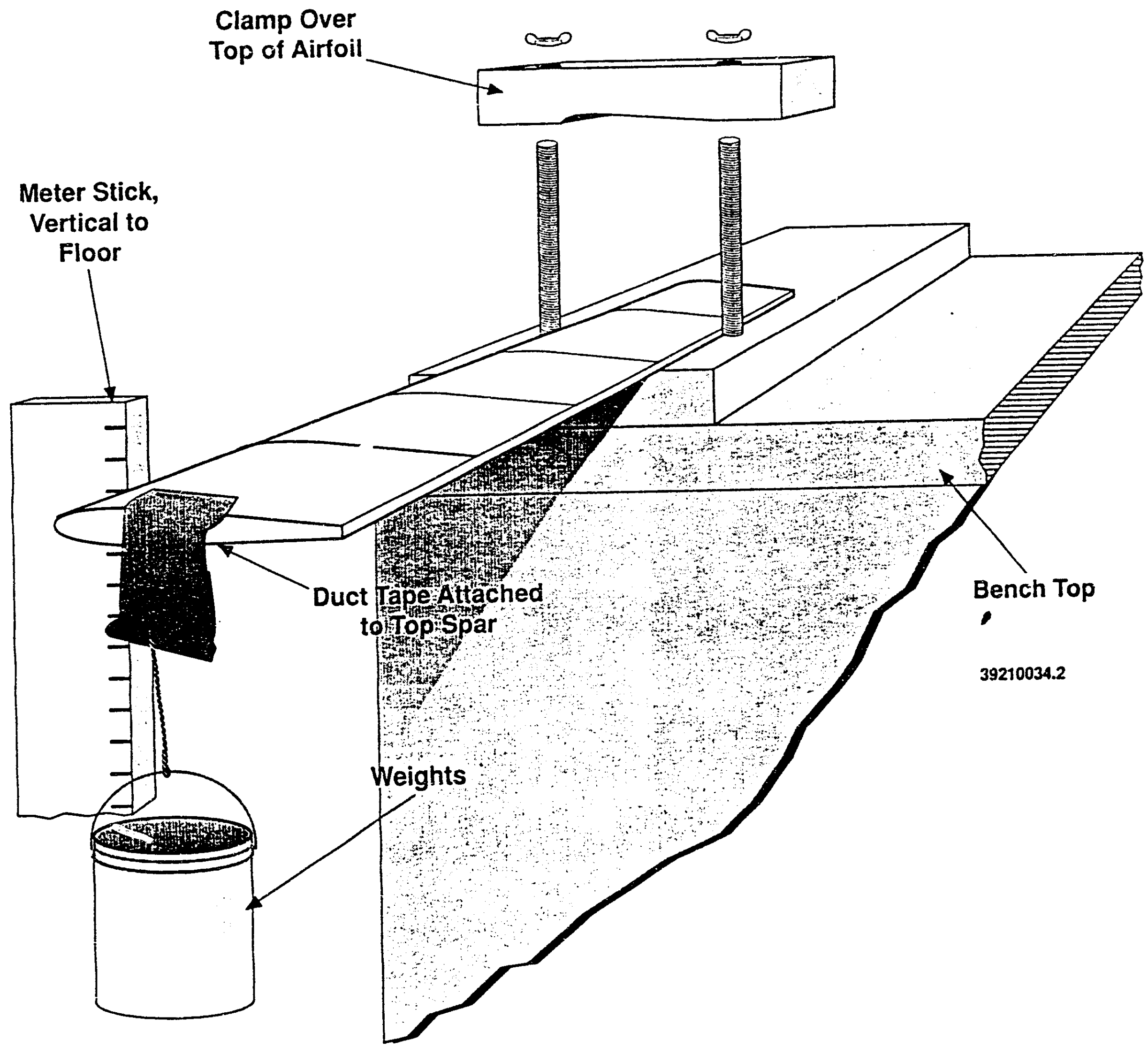

FIGURE 3. Arrangements to Test Stiffness and Strength of Airfoil Sections

Based on tests conducted to prepare this presentation, Figure 4 shows the weight required to cause 1-cm deflection divided by the airfoil weight, which is proportional to the stiffness/weight of the various wing variations. On the strength of this single data set, the stiffness of wings built with either spar material appears to be substantially improved when shear webs are used. This is logical, because the combination of shear web and spar forms a box beam. The lightest structure, BW, shows stiffness/weight superior to airfoils built with spruce spars, except where shear webs were used. Finally, the airfoil with spruce spars had the highest stiffness/weight ratio, but only when shear webs were provided. Figure 5 shows the weight required to cause structural failure divided by the wing weight, for each of the six versions. The structures made with balsa spars and shear webs performed impressively for its weight, better than either spruce-spar wings not using shear webs. Although the shear-webbed wing made with spruce spars had the highest strength/weight, the difference was less than 10% more than the shear-webbed wing made with balsa

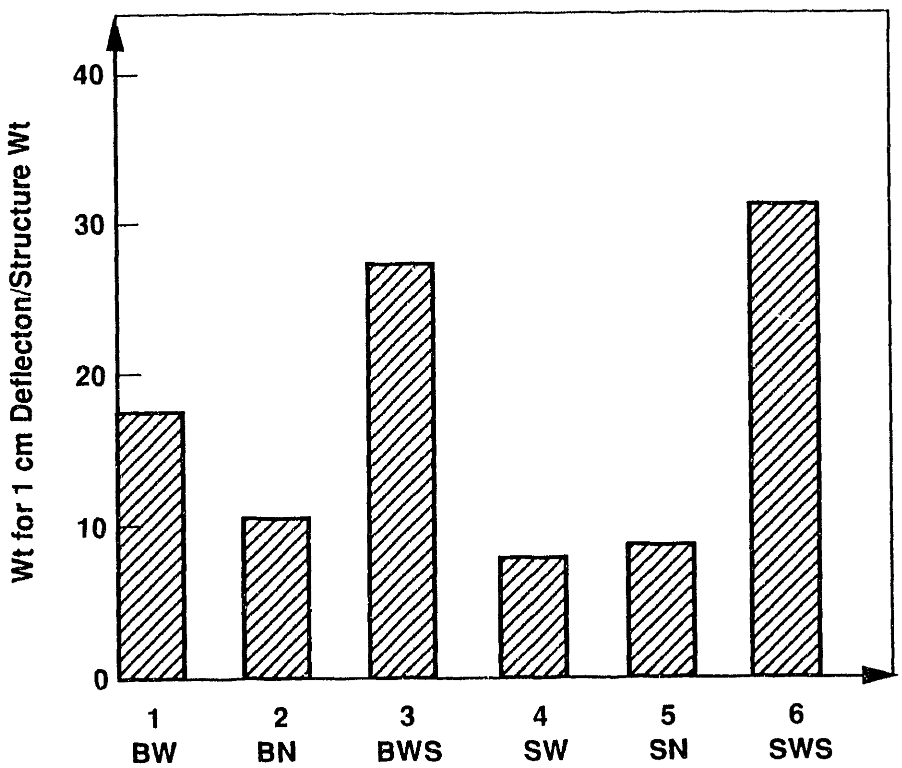

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FIGURE 4. Stiffness/Weight Ratio of Six Structural Version of Same Airfoil

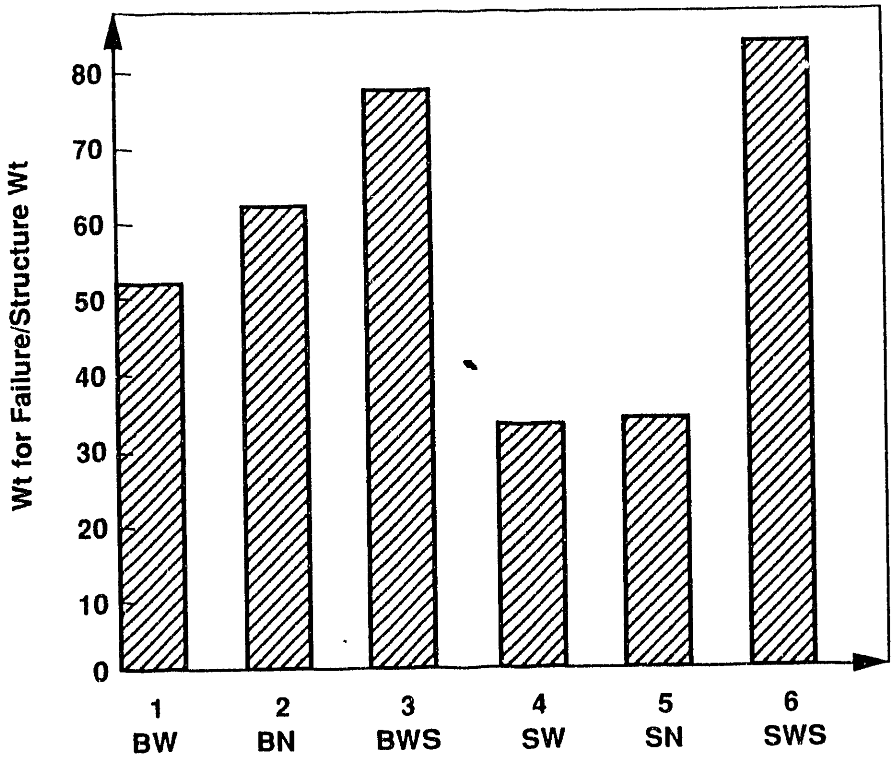

FIGURE 5. Failure Weight/Structure Weight Ratio for Six Structural Versions of Same Airfoil

spars. Of course, in an actual airplane wing design, the strength and stiffness would be critical factors in themselves and would only be divided by weight for purposes of comparison, as in this project.

INSTRUCTOR'S NOTES: The model airplane hobby offers students an excellent introduction to the basic techniques of producing the light, strong structures that make flight possible. Based on the principals of aircraft modeling, this project requires students to build an airfoil of constant cross section and to compare several variations of structural design and materials. Simple tests of the resulting airfoils enable comparisons of performance as a function of structural weight. Students should discuss whether the more elaborate construction methods are justified on the basis of added weight. Using modern materials and methods, airfoil construction and testing can be accomplished within the time and economic constraints of the classroom without requiring advanced craftsmanship of the students.

Note that the materials and construction techniques used to construct model airplanes may be unfamiliar to the average student. However, one or two students in many classes may have had experience in this particular hobby.

These students will be a valuable resource to the class, especially during the first round of airfoil construction; make use of such students.

SAFETY: Avoid breathing the fumes of reacting cyanoacrylate. In addition, take care not to bond fingers together with the cyanoacrylate, which adheres quickly and tenaciously to skin. If this should happen, use the debonding chemical available at hobby shops, or wait ten minutes before slowly rolling the bonded surfaces apart. Do not pull fingers directly apart or use sharp blades to cut skin surfaces apart. Take extra care to avoid getting glue into eyes.

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