N90-24361

USING TEMPLATE/HOTWIRE CUTTING TO DEMONSTRATE MOLDLESS COMPOSITE FABRICATION

J. Mario Coleman
Engineering Technology
West Texas State University
Canyon, TX

PREREQUISITE KNOWLEDGE REQUIRED

A person duplicating the following experiment should have some basic skills with handtools and simple woodworking machines.

OBJECTIVE

The objective of this experiment is to provide a simple, inexpensive composite fabrication technique which can be easily performed with a minimum of equipment and facilities. This process eliminates expensive female molds and uses only male molds which are easily formed from foam blocks. Once the mold is shaped, it is covered with fiberglass and becomes a structural component of the product.

EQUIPMENT AND SUPPLIES

Hand Tools

Flexible steel tape
Combination square w/centering head
Twist drills, 9/64", 1/4"*, and 3/8"
Scratch awl
Handscrew clamps w/10" openings
Level, 24"
Wood rasp
Wrench, 1/2"
Adjustable drafting curve
Scissors
Metal straight edge, 36"
*Spade bit, 11/16"

Wood Products

1 - 4' x 8' sheet, 1/8" hardboard
*1 - 2" x 4" x 24"
2 - 14" x 15", 3/8" plywood
6 - 3/4" x 2" x 2" blocks
1 - 10" dowel rod, 3/8"
1 - 18" dowel rod, 1/4" with one end sharpened
2 - boxes toothpicks

Machines

Scroll saw
Drill press
Belt sander
Large portable fan
Vacuum cleaner

Metal Products

1 - 12" all-thread 3/8" with 2 nuts and washers
12 - 2 1/2" double headed nails
* 2 - 20" - 11/16" O D electrical conduit
* 2 - 2 1\2" machine screws with 2 wing nuts & washers
*24" stainless steel aircraft safety wire, .041D

Miscellaneous

1 roll duct tape
1 bottle rubber cement
1 pint white latex paint
*10' heavy gauge lamp cord
Dust mask, disposable
4 plastic mixing cups, 8 oz.
10 stir sticks
35" chalk line cord
1 felt tip marker
1 paint brush, 2" nylon
*1 variable voltage transformer
Rubber gloves, disposable
Plastic coffee can lids

Epoxy and Foam

1 - Safe-T-Poxy kit, 1 1/2 gal.
1 - Epoxy pump or balance beam
(See section on Instructor Notes for info on using Safe-T-Poxy)
10 - sheets polystyrene insulation board, 2" x 2' x 8'
1 - sheet polystyrene insulation board, 3/8" x 2' x 8'

**Items marked with * are necessary for making and using the hot wire cutter. See section on Instructor Notes for details on the hot wire cutter.

PROCEDURE

Developing the Templates

Many foam plugs for composite products can be easily formed by hotwiring around templates placed on foam blocks. This moldless process works extremely well for prototypes, proof-of-concept products, and home/school one-of-a-kind projects. Two of the most popular items which can be hotwired are airfoils and boat hulls. The cutting and forming of a fourteen foot canoe hull was selected for the following experiment because of its simplicity. It is only necessary to

reproduce 1/4 of the canoe's contour because a mirror image can be made to achieve the total width of the templates. After 1/2 of the canoe hull is cut, another set of foam blocks is then cut by using the templates in the reverse order.

When selecting a canoe design, keep in mind that a white-water/ river canoe has a rounded bottom and a lake/fishing canoe has a flat bottom. The cross-sectional contour may be taken from a production canoe by gauging the outside with a flexible, irregular curve and transferring it to paper. A CADD program can also be utilized by establishing the X,Y,and Z coordinates and allowing a plotter to draw the templates. In either case, the cross-sectional readings should be taken every ten inches starting at the center of the canoe and working outward.

Once the outside contour of each template is established, the inside contour is made by drawing a curved line two inches inside the outside curve. This two inch thickness is necessary to give the polystyrene arches enough strength to withstand the stress of laying fiberglass on their outside. It also allows enough thickness in some templates for double bolt holes at the centerline (see Photo 1 at the end of the experiment).

After the paper templates are drawn, they should be scissor-cut leaving about 1/4" border around the drawn outline. The template should then be glued to 1/8" hardboard using rubber cement. (Elmer's glue will cause the paper to wrinkle.) Cut out the templates using a scroll saw and then lightly sand the cut edge with a belt sander. It is critical that the edge be smooth to prevent the hot wire from hanging.

Identify each template with a number starting with #1 for the large center template and ending with #8 for the small end template. Mark a left and right symbol on each leg when the paper side of all templates is turned the same direction. Paint the opposite side of the templates with white latex paint so that the various marks can be easily read. Transfer the center line from the paper side to the painted side and then divide each leg into eight parts using the centering head on a combination square. Identify the lines that divide the parts with letters ranging from A to O. Line H will be the center line through which a 3/8" bolt hole will be drilled later. Drill 9/64" nail holes at lines A, D, L and O. Make sure each line on the painted side is identified the same on the opposite paper side and not on the opposite leg. The purpose of these lettered lines is to aid in controlling the speed when cutting the foam blocks.

The location of the bolt holes in the template is critical for the correct alignment of the foam. To position these bolt holes, each template should be temporarily attached (duct taped) to the jig table at its correct location (see Photo 2). A 10" long x 3/8" straight dowel rod with a level attached should be positioned between two templates and the ends moved up or down until the rod is level. (Two

people are required for this step.) The center line of the dowel rod should be marked across the template line H and then the procedure duplicated until all 3/8" hole centerlines are marked. Notice the double holes in the templates 3, 5 and 7.

Using the Templates

The positioning of the templates on the foam and keeping them turned the right direction is very important to keep the contour smooth. Begin with the #1 center template and the #2 for the first section to be cut (see Photo 3). Clamp five 2" x 2' x 8' foam blocks together using hand-screw clamps. Measure down from the top edge of the foam block and over from the end to locate the center point of the bolt hole. The position of this hole should allow the large template to come within 1/4" of the end of the foam block and 1/4" down from the top. Start the hole by piercing each side of the foam with a scratch awl; then use a sharpened 1/4" dowel rod to complete the hole by working from one side to the other. Push the 3/8" all-thread rod through the foam and allow it to stick out one inch on each side. The bolt hole in the foam will be much larger than necessary but it can be corrected later.

Attach the templates by placing them on the all-thread and securing them to the foam by hand tightening the nuts. (Use a washer between the nuts and the templates.) The all-thread must run horizontally and should be checked at this point by again measuring down from the top and over from the end. There is usually enough slack in the foam hole to allow some corrections to be made. When the all-thread position is correct, tighten the nut with a wrench until the foam just starts to compress. Check to make sure the templates are not reversed.

The final alignment is made by placing a level on the bottom ends of the templates and rotating them slightly on the all-thread until they are level. Force double headed nails through the template nail holes and into the foam. The foam blocks are now ready to hot wire.

Place the large foam blocks on a workbench and secure them by using large hand-screw clamps. Before starting the cut, make sure the throat of the cutter is deep enough to be able to go completely around the templates without having to back up. This may require rough cutting a corner or two from the foam block. It is best to have two people operate the cutter so that each can watch the cutting operation and keep the wire against his template. The person cutting around the largest template should call out the lettered lines as he reaches them. This allows the other person to gauge his cutting speed.

The outside contours are cut first and then the inside. The four corners should be square and the ends flat. Corners can be cut square by stopping the wire at the corner of the template, counting to three, which allows the center wire lag to catch up, and then proceeding

around the corner.

When the cuts are completed, it is impossible to remove the cross-section because it tapers both directions. It will be necessary to remove some of the uncut foam before the cross-section will slide out. Be careful not to ruin the large foam block for cutting some of the other cross-sections. When the cross-section is removed, it will look like the one in Photo 4.

The remaining cross-sections are cut using the same steps as above. When proceeding to the next set of templates (numbers two and three), it is best to set them in place on the jig table and then place them on the foam exactly in that position. Remember that the templates must always be turned the same direction and that they are reversed when cutting the opposite end of the canoe. When all cross-sections are cut, no two will be the same.

The polystyrene insulation boards are just under two inches thick and when five are put together the total thickness is 9-5/8". An additional foam piece must be cut from 3/8" insulation board by turning the cutter vertically in a vise and cutting around a single template (see Photo 5). The template is held in place by several pieces of duct tape looped with the adhesive side out and compressed between the template and the foam.

Gluing and Shaping the Cross-Sections

The body of the canoe can now be formed by resting the cross-section ends on the jig table and gluing the 2" pieces together. Since there are ninety foam cross-sections, the gluing will go much faster if two or more people participate. Glue the sections in sets of five plus the 3/8" spacer and hold them together with toothpicks. The glue should be Safe-T-Poxy as described in the Instructor Notes section and should be placed no more than 3/4" inside the outside curve of the foam pieces. These pieces are 2" thick and must be thinned to 1" during a later step. This is done with a small hot wire cutter which will not cut through the glue if it is allowed within an inch of the inside curve. When all sets of five are glued, then glue these sets together.

The end caps for gluing should be rough cut a little larger than the #8 template. Use 3/8" or thicker plywood with a 1/8" cord hole drilled in the center. Several 3/4 x 2" x 2" spacer blocks should be cut and a saw kerf cut to their centers to allow them to slip over the cord.

When all the foam pieces are glued and are in position, pass a heavy cord through the canoe body and through the center holes in the end caps. Secure each end of the string by tying it around a nail and then tighten the string by putting spacer blocks between the nail and

the end caps (see Photo 6). This unites the foam pieces into a solid unit which can be adjusted on the jig table.

Check the contour of the canoe bottom to make sure it is smooth with no low places. It may be necessary to put spacers between the foam blocks and the jig table to get the contour smooth. This can be done by releasing the string tension, removing some toothpicks, and raising or lowering the foam blocks. After the adjustments are made, the string is tightened again. Make sure that all foam pieces extend at least 1/2" beyond the edge of the jig table on both sides. This allows the fiberglass to drape straight down off the foam and not create a corner at the jig table. It is best if the canoe body is glued to the jig table to keep it from moving while forming and shaping.

The canoe ends are formed from solid scraps which were cut earlier from the foam cross-sectional arches (see Photo 7). The solid ends are easy to shape and provide additional flotation. Use Safe-T-Poxy and put it close to the center of the foam blocks so that it will not create a problem while shaping. Use toothpicks to temporarily hold the blocks in place. Drill two 1/8" cord holes in the outer edges of the end caps and put two lengths of heavy cord along the canoe sides to hold the ends in place. Put tension on the strings and allow the epoxy to cure.

When all sections are glued and the rough form of the canoe has taken shape, it is time to smooth the outside contour. This is done by carefully removing the excess foam with a wood rasp (handle removed). This is a messy job and a dust mask is necessary. Rubber gloves, a large fan, and a shop vacuum cleaner are handy for this step. The long axis of the rasp should be held parallel to the long axis of the canoe. The rasp should be moved in alternating 45 degree strokes. The shaping should be done until the desired contour is obtained. When completed, the canoe plug should look like the one in Photo 8 which is ready to be covered with fiberglass and epoxy.

INSTRUCTOR NOTES

Hot Wire Cutter

The items marked with an asterisk in the Equipment and Supply section are necessary to construct the hot wire cutter. Refer to Photos 5 and 10 for pictures of the wire cutter.

Start by boring two 11/16" holes across the 3 1/2" dimension of the 2" x 4". These holes should be centered across the 1 1/2" dimension and 1 1\2" from each end. Then drill a 1/4" hole 1/2" from one end of each piece of 11/16" conduit. Insert the pieces of conduit into the holes in the 2" x 4" with the 1/4" holes out. This should be

a snug fit, with the 1/4" holes aligned with each other.

Drill a small hole starting at the center of the 1/4" machine screw heads and angling out of the threaded portion of the screw just below the head. Mount the machine screws in the 1/4" conduit holes with a washer and a wing nut on the outside of the conduit. Tighten the nuts until two threads are exposed; then string the .041 stainless steel wire through the center holes in the machine screws. Secure the wire ends around the threads of the machine screws and then tension the wire by tightening the wing nuts.

Attach one wire of the heavy duty lamp cord to each piece of conduit by using sheet metal screws in a hole drilled 1/2" from the 2" x 4". Connect the other end of the lamp cord to the transformer output and the hot wire cutter is ready to use.

The transformer should be adjusted to between fifteen and eighteen volts, which will give enough heat to easily slice through the foam. Some trial cuts may be necessary to gauge the correct voltage and speed of cutting. The wire should be kept tight and never allowed to turn red. A SERIOUS BURN WILL OCCUR IF THE SKIN MAKES CONTACT WITH THE HOT WIRE.

Safe-T-Poxy

The resin matrix used in this experiment is Safe-T-Poxy, which is produced by the Hexcel Corporation. It was specially formulated to be low in toxicity and does not have the objectionable strong smell that other epoxies and polyesters have. It comes in kits with 7/8 gallon of resin and 2/5 gallon hardener (see Photo 9), and costs around sixty dollars per kit. When using a balance beam or small scale, mix the epoxy 100 parts resin to 44 parts hardener. An epoxy pump like the one in Photo 9 makes mixing easier, faster, and more convenient when large amounts are to be used. This dispenser meters the correct ratio of resin and hardener and costs around $160 from one of the suppliers listed in the supply section.

The resin and hardener should be mixed in a waxless or plastic cup and then stirred thoroughly for about two minutes. There is a forty-five minute working time at 77 degrees F and a curing time of ten hours. The mixture may be brushed or poured on and then smoothed with a squeegee made from a plastic coffee can lid.

Future Applications

Template/hotwire cutting can be used to make rough mold cavities for small parts. Photo 10 illustrates the process for cutting a mold for a wind turbine blade tip. A small tip section was cut from the blade and secured to a two-inch block of foam. Using the air foil tip

section as a guide, a cavity was hotwired in the block of foam. A wire was placed around the airfoil before cutting to increase the size of the cavity which will allow defects caused by exotherm to be removed from the casting. After the cavity was cut, it was lined with duct tape and filled with a mixture of Safe-T-Poxy and microballons. The duct tape allows the cured casting to be easily removed from the mold as shown in Photo 11. After shaping, the blade tip looks like the one shown in Photo 12.

The products which can be formed by using template/hotwire cutting are limited only by one's imagination. With only slight modifications of the canoe experiment, a person can produce kayaks, racing shells, catamaran pontoons, small fishing boats, and snow sleds. Bodies for cars and recreational vehicles (go-carts, dune buggies, etc.) can also be formed by this process.

The lost foam process is an extension of template/hotwire cutting and works very well when making containers or cases. A gas tank can be formed by hotwiring a specially designed plug and then covering it with fiberglass and resin. When the skin is cured, a small opening can be made for the filler pipe and a solvent (lacquer thinner) poured into the foam causing it to dissolve. Cases are made the same way except they are sawed into two halves and the foam is removed by chipping. Examples of this process include racket cases for tennis/racketball, snow ski cases, battery boxes and tool cases for small power tools.

Conclusion

Template/hotwire cutting is not a process which demonstrates the latest in technical advancements. However, once a foam plug is cut, the learning process involved with covering it with fiberglass and resin teaches many of the important concepts used in the composite industry. This cutting process allows more freedom in design and reduces lead time. It can also be used as a substitute for the expensive presses and molds used to form products in industry.

The primary disadvantage of this cutting process is finishing the product after several layers of fiberglass cloth have been applied to the foam plug. Additional filling, sanding and painting operations are required to fill and smooth the fiberglass weave. This is not necessary on a molded product which has a built-in smooth painted outer surface.

The purpose of this experiment was to demonstrate the ease of forming composite products by hotwiring foam plugs from blocks of polystyrene. Because of the time restriction, it was not possible to explain the other steps involved in fabricating the complete canoe. A lab manual is being prepared which explains each step in making the canoe and gives many worthwhile pointers on using foam, reinforcing fibers, resins and related supplies.

REFERENCES

Budinski, Kenneth. Engineering Materials: Properties and Selection, 3rd edition. Reston, VA: Reston Publishing Co., 1989.

Heimann, Erick. Do It Yourself With Plastics. New York: E. P. Dutton (Sunrise), 1973, pp. 226-27.

Meyer, Raymond W. Handbook of Polyester Molding Compounds and Molding Technology. New York: Chapman & Hall, 1987.

Richardson, Terry. Composites: A Design Guide. New York: Industrial Press Inc., 1987.

Schwartz, M. M. Composite Materials Handbook. New York: McGraw Hill, 1984.

SOURCES OF SUPPLIES

1. Local builders supply (Builders Square, Payless Cashways, etc.)
   polystyrene insulation board 2" x 2' x 8' $5.00
   required wood products

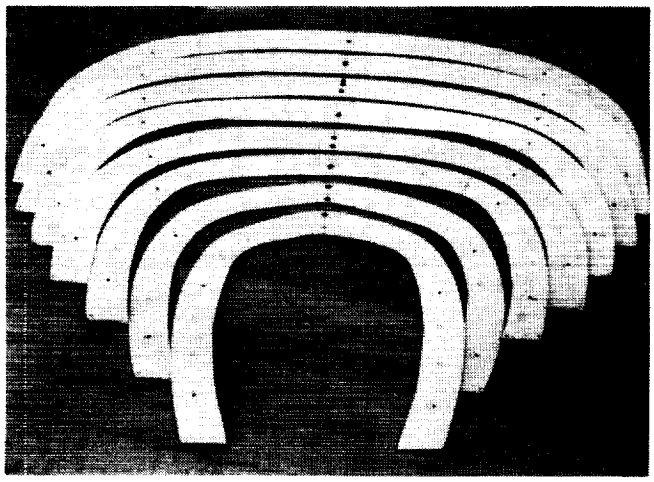
2. Local discount stores (Wal-Mart, K-Mart, etc.)
   duct tape, mixing cups, dust masks, toothpicks, rubber cement, lamp cord, chalk line cord, rubber gloves (pharmacy), mixing sticks (pharmacy: tongue depressors), etc.

3. Aircraft Spruce and Specialty Co.
   Box 424
   Fullerton, CA 92632
   714-870-7551
   1-800-824-1930 (orders only)
   epoxy, epoxy dispenser, fiberglass cloth, transformer, etc.
   catalog - $5.00

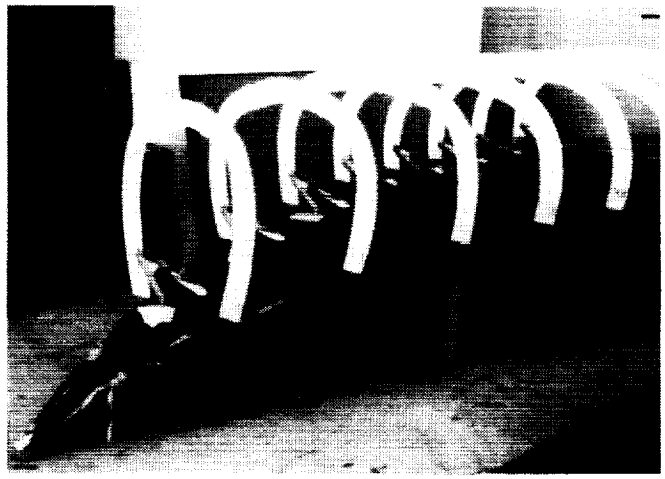
4. Wicks Aircraft Supply
   410 Pine Street
   Highland, IL 62249
   618-654-7447
   1-800-221-9425 (orders only)
   (same supplies as Aircraft Spruce)
   catalog - $5.00

5. Advanced Plastics
   11212 E. 112th Street N
   Owasso, OK 74055
   918-664-5410
   resins, reinforcing cloth, etc.

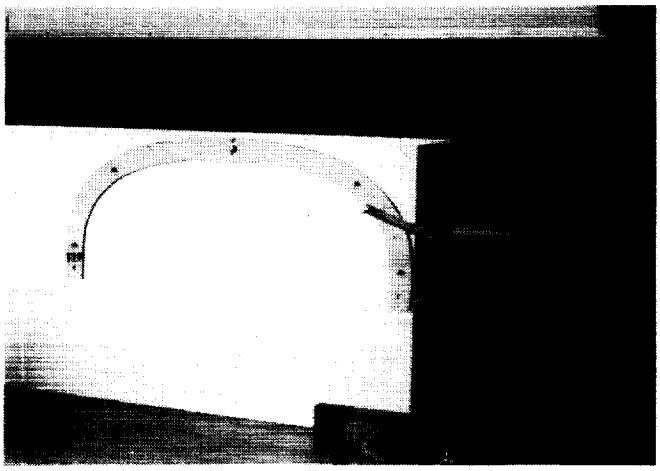
PHOTOGRAPHS



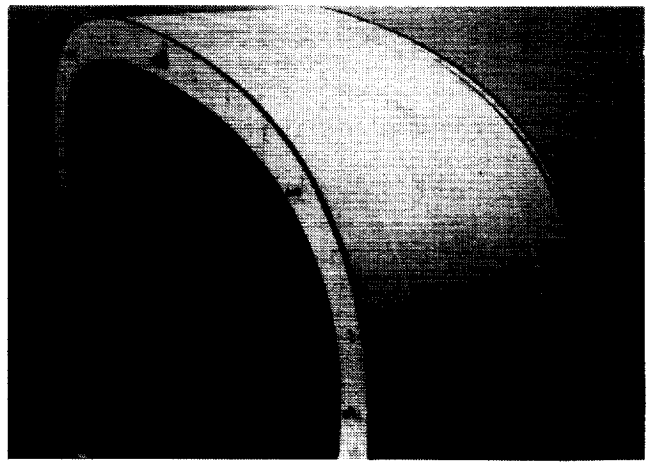
1



2

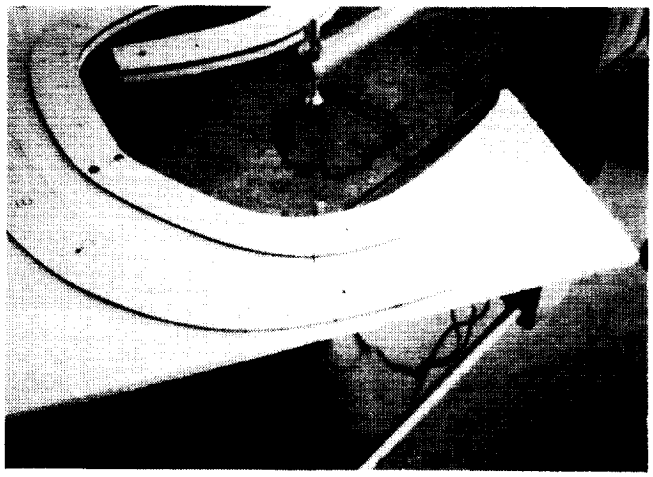


3

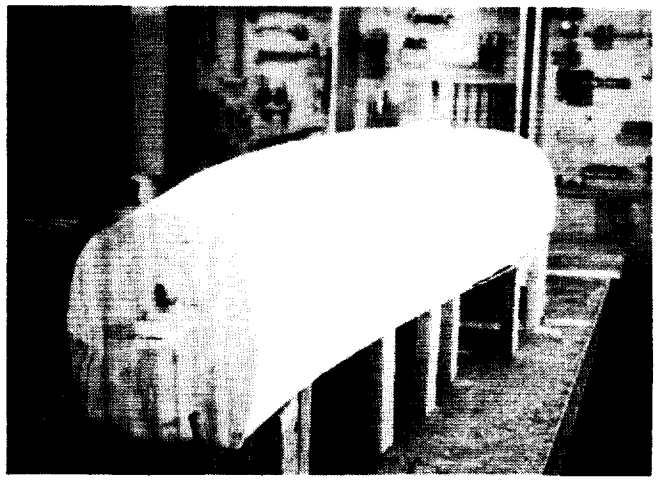


4

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

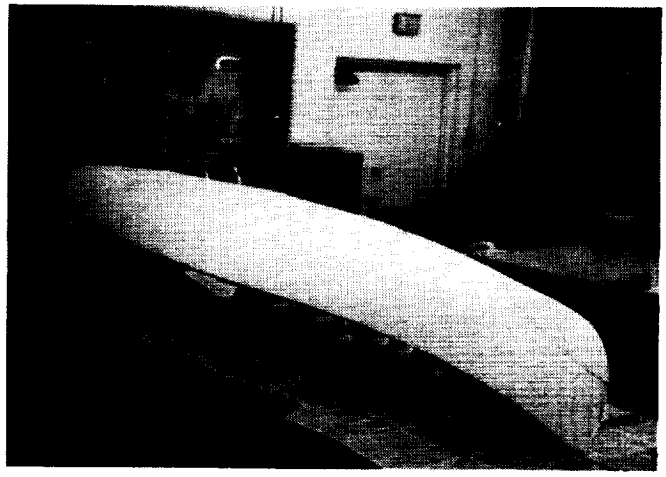


5



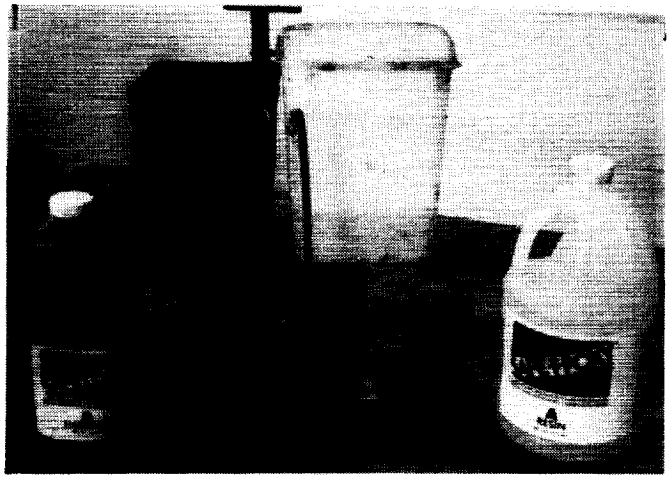
6

7

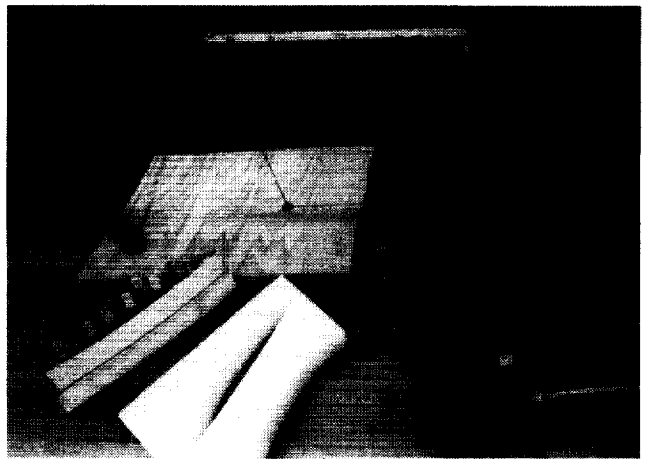


8

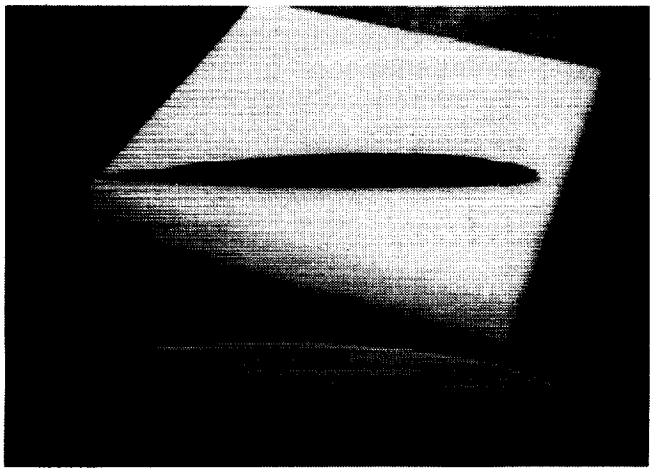
PHOTOGRAPHS



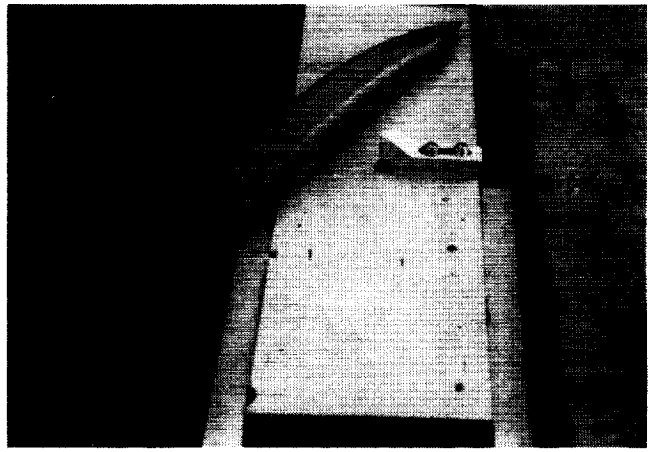
9



10



11



12

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH