Resin Infusion - Same Goo, New Tricks

By George Saunders and Karl Whittnebel

Canoehenge: Four decks and three hulls pulled using Resin Infusion

This is the story of how we built the parts for four International Canoes. It is basically also the story of a few deranged individuals that like to spend weeks bent over in chicken coops, itching all over.

For those of you that are unfamiliar with the saga of canoe shapes in the U.S., a brief review is probably in order, to put the current effort into some sort of historical context. Some time ago, Bill Beaver, obsessing compulsively over hull shapes as naval architects are known to, decided he could probably design something within the Nethercott rule that performed measurably better than existing boats across a range of wind and wave conditions. Since the rule allows tolerances of ±10 millimeters at specified measurement stations on the hull, significantly different hull shapes can result when the tolerances are pushed. The shape Bill designed differed in several respects from most boats in existence at the time.

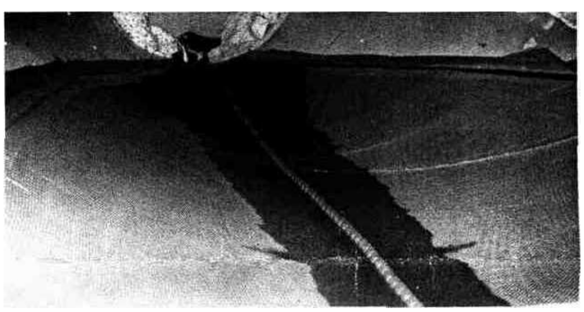
A prototype boat was built by Bill for Rod Mincher, and seemed to live up to expectations, so Bill took a month of leave from work and built a female mold for the hull shape up at Ted Van Dusen's shop in Massachusetts. Apart from an unfortunate incident whereby the shop-vac filled Bill's sleeping bag with fiberglass dust, the project went off without a hitch and resulted in a high-temperature mold suitable for use with prepregs materials and autoclaved cures. Somewhere around the same time, Eric Chase fabricated some deck molds from sheet aluminum for both the fore and aft decks, permitting the construction of sandwich laminate decks for the first time (previous canoes had been decked with light plywood, requiring bracing from beneath for the aft deck and requiring the foredeck to be treated rather gingerly). Prior to the latest building flurry, nine all-composite prepreg boats had been pulled from this set of molds by Bill Beaver, Ted Van Dusen, Eric Chase, George Saunders, Micah Gummel, and Del Olsen.

Although the weight and structural properties of prepreg construction are difficult to argue with, the technique has several disadvantages for the amateur boatbuilder. Chief among these is the need for an autoclave capable of maintaining 250 degrees Fahrenheit for several hours, along with a tool (mold) capable of tolerating these temperatures. In addition, the prepreg materials are spendy and somewhat sticky to work with, and must be kept frozen until use. These limitations, though trivial to some members of the fleet, are daunting to others and essentially preclude the use of prepreg materials for the home builder.

Until recently, the only alternative available to the average boatbuilder for constructing composite boats using molds was the wet layup. This tried and true method has resulted in many competitive canoes over the years, both cored and non-cored, but it also suffers from several well-known drawbacks: exposure to epoxy vapors and goo, requirement of completing the layup in a specified period of time prior to epoxy cure, sub-optimal resin to reinforcement material ratios, incomplete wet-out and laminate voids. For the solo boat builder, the second limitation may represent a significant obstacle, requiring either assistance with the layup or a staged approach. For the solo boatbuilder, the second limitation may represent a significant obstacle, requiring either assistance with the layup or a staged approach.

Given the limitations of both wet layup and prepreg construction, a quest was clearly required for the proverbial holy grail of amateur composite boatbuilders: a method that would permit us to avoid the limitations of both wet layup and prepreg construction, while still allowing those of us without access to autoclaves to construct high-quality composite parts in the comfort of our own garages or basements. Fortunately for us, the limitations of both wet layup and prepreg construction prompted manufacturers to begin experimenting with other methods of construction many years ago, others had encountered these limitations and, for a variety of reasons, causing them to develop the proverbial Third Way of composite part construction.(formerly associated exclusively with double-talking politicians). Were it not for the forward thinking of these giants (including the U.S. Department of Defense), none of what you are about to read would have been doable, because we sure as hell never

In the current, nonpolitical context of this article, the Third Way consisted of Vacuum-Assisted Resin Transfer Molding, or VARTM. The basic idea of this technique is simple: lay the reinforcement materials up dry, compact them under vacuum, and then use the vacuum to pull glue in from outside the bag which subsequently progresses through the dry layup. The progress of the glue through the layup can be monitored visually, and when complete, the inlets are clamped-off and the part is allowed to cure. Using this method, one can proceed piecemeal with the layup, working alone in a spare hour here or there, putting the vacuum assembly together at a leisurely rate, and only when ready pulling a vacuum on the part, mixing the glue, and infusing.



Resin being infused into the foredeck laminate

This method has several other advantages. It provides a very high part quality, both structurally and cosmetically, because all voids in the laminate are completely filled or at least coated with epoxy, minimizing air spaces. It provides a complete wet-out of balsa cores, effectively isolating each block of balsa in the core from every other block and thereby minimizing the potential for water to spread laterally through the core in the event of a skin puncture. Because the laminate is compressed prior to introducing epoxy, a more optimal ratio of resin to reinforcement material is obtained. Finally, human exposure to potentially harmful epoxy vapors is minimized by reducing both the time one actually works with the epoxy and the technical difficulty of what one has to do with it. Using this method, one merely mixes the epoxy and pours it into a bucket, from whence it is sucked in fully automated fashion into the laminate.

Dr. Karl shown mixing resin, taking all safety precautions. Can't you drink your micro brew, and wear a respirator at the same time?

Of course, being aware of the theoretical advantages of a method and actually building a boat with it are two different things. Bill Beaver conducted a series of infusion experiments at work that eventually resulted in the production of a 13 ft Hamilton Class Cutter (model) for the Navy, and Bill' s full bore conversion to this new infusion religion. About the same time, on a different road to Damascus, Ted VanDusen was experimenting with vacuum infusion for impregnating large braided masts. It was Ted' s experiences that lead us to the holy man himself, MAS Epoxy guru Tony "Huck" Dilemma (short for Huckleberry Finn), manufacturer of a low temperature infusion resin, about whom we shall have more to write later.

Having identified infusion as a possible answer to our boat building prayers, we decided to stage a recovery mission to New England to retrieve the molds required to make our dream a reality. A plan was hatched to travel to New England, lay up a couple of hulls during a week of work, and return to the mid-Atlantic region. Tony volunteered to show us the ropes of infusion, and the use of his shop for that purpose, over the 4th of July holiday. The shop turned-out to be a chicken coop in Tony' s back yard, but apart from that the plan went reasonably smoothly and we were able to pull a very high-quality hull out of the mold after a few days of cloth cutting and pasting punctuated by cold beer, a canoe regatta, and some great food.

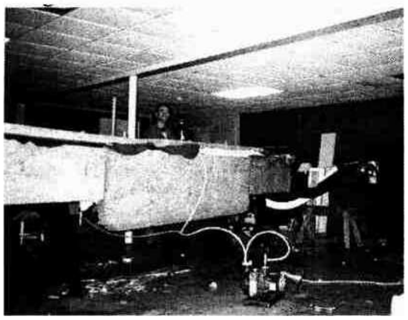
Inspired by our early success, we returned to the Chesapeake, molds in tow. To add some spice to the journey, George decided to sabotage our trailer tire by leaving a carpenter' s knife blade lying flat on the trailer in front of the tire, to jostle over to the edge and fall, ever so precisely, in a longitudinal fashion to the road bed, where two one-hundredths of a second later it was run over by the trailer tire in such a manner that the offending blade sliced a one-inch gap through the steel belted face and inserted itself wholly into the interior of the tire. This sequence of events became clear only at the tire store, after removing the affected tire from the rim. Confronted with the offending blade, George exclaimed "Shit, we screwed ourselves!" It was rather reminiscent of that scene toward the end of the film Reservoir Dogs, in which Harvey Keitel, after having killed several people to defend his friend from accusations of being a police informant, discovers that his friend actually IS a police informant. Only in our case, George was both Harvey Keitel AND the police informant, nobody got killed, and nobody made a movie out of it. Fortunately, I was able to wrestle the blade from George' s hand before he could inflict any serious damage on himself.

In a stroke of genius, George' s former landlord decided to sell the house George was living in last fall. Consequently, George sought temporary refuge in his parents' house, while waiting to hear about some impending long-term travel for his job. What he didn' t tell his parents was that he was really moving home to turn their basement into a canoe factory. This space proved in many ways ideal for purposes of canoe construction. In particular, the presence of a heat source was of critical importance to our infusion efforts, for reasons that will become clear shortly.

Building as we were in George' s basement, it was only fair that he be the first to infuse a boat there. We replicated the Massachusetts chicken coop process with as much fidelity as possible, overlooking only one crucial bit of data: basements in southern Maryland in December are much cooler than chicken coops in Massachusetts in July. As a consequence of this fact, the epoxy infused into George' s boat was approximately four times more viscous than the epoxy infused into Tony' s boat in MA. This difference in viscosity proved important, as the epoxy had a much more difficult time advancing through the laminate, and kicked-off before completely wetting-out the laminate.

Perplexed and discouraged, we nonetheless salvaged the boat completely by rigging-up a second infusion bag over the uninfused laminate, and repeating the process (with warmer resin this time). The reinfusion went very well and resulted in a part whose quality is almost indistinguishable from that of our earlier effort. The only blemishes that remained were several easily fixable dimes sized spots on the mold side of the laminate.

In part to prevent this from happening again, and in part to improve part quality and reduce cure time, we elected to attempt to heat the mold and laminate prior to infusion. This effort led to several iterations of ovens constructed from an old bathroom ceiling exhaust fan (double squirrel cage type), clothes dryer vent conduit (rated to 180F), galvanized tin, and rivets, a Sears Roebuck wood burning stove, and several sheets of rigid foam insulation salvaged from the scrap pile at a rooftop rebuilding project on an unnamed federal building in Washington, DC. Sheets of foam were erected around the mold on all surfaces, and hot air was pulled by the squirrel-cage fan from the wood burning stove, through some custom tin ductwork and dryer conduit, and into the mold to heat everything up. Although at high temperatures (i.e. anything over 200F air temp at the wood stove) the squirrels would start to complain and go on strike, overall the system eventually allowed us to achieve mold temperatures of 175F on a variety of parts, using only some electricity for the fan and a fair amount of George' s parents' firewood pile. Depending upon actual temperatures achieved, some minor problems with print-through due to shrinkage of resin rich areas between balsa blocks were encountered, such that future hulls will likely be pulled from the mold primed but not painted to allow for subsequent minor fairing.



Itchy oven, wood oven, vacuum pump, & Karl in the background.

When we began this process, several people inquired as to the weights of our infused hulls, out of concern that improved wet-out of core may also lead to an undesirable increase in weight over open layup or prepreg construction. Although we do not have a large database for comparison, our hulls have been emerging from the mold with paint, primer, rudder and daggerboard trunks, untrimmed, at 45 to 47 pounds. Aft decks using the same technique have ranged from 17 to 21 pounds untrimmed. It should be noted that all aft decks had at least 6" to 10" to be trimmed of near the transom and 4" to 6" at the peak of the v-bulkhead across the full width of the part. Foredecks untrimmed have been in the neighborhood of 11 pounds. From what we have been able to determine, these figures are comparable to the wet layup results achieved by others, and will permit maximum correctors to be carried by the completed boats.

Rather than go into elaborate detail on painting/priming molds in advance, methods used to rig an intra-bag infusion manifold, pull vacuum reliably on a variety of molds, and keep epoxy out of the vacuum pump, I will save those topics and others (preferred micro-brews, uses of the saws-all for car stereo installation, etc.) for a subsequent article. In conclusion, we have found infusion to be a reliable technique for the production of high-quality, sandwich composite International Canoe hulls.

WARNING now ends the wonderful prose composed by Mr. Wittnebel! Get out your drool covers and prepare to be put to sleep by an engineer's composition of the elaborate details alluded to by Karl. You may also want to don your crash helmet to avoid the embarrassing marks left by an uncontrolled session of "jello neck", followed by 0.5 sec REM sleep, followed by a sudden jolt of your head hitting the desk!

Mold Prep

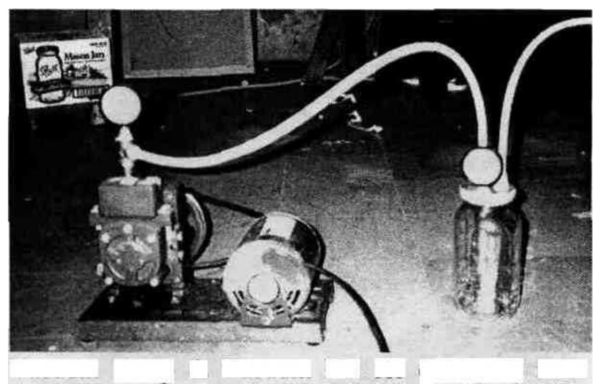
In my apartment "Mold Prep" usually requires a wayward block of cheese in the far corner of the refrigerator and several weeks. In Canoe construction, the term means something entirely different, and, so I' ll give you the condensed version here. In general we used a three step approach to mold release, waxing, poly vinyl acetate (PVA) application, and paint/primer. Step 1, use a good quality wax, in our case Partall#2 Paste Wax and a random orbital buffing machine. The key property of the wax is a complete lack of silicon, which if present will cause "beading" when you attempt to spay the PVA. The molds being used for this project were well seasoned, so prior to laminating each part we cleaned the surface with water and applied only two thin (but complete) coats of wax. (Had the molds been unused for a time, a more extensive three-coat application would have been used). After waxing and buffing are complete, the area where the vacuum tape will be placed should be masked off. Step 2, spray PVA starting with an almost imperceptible mist emerging from the spray gun and working up to a dense fog, allowing the PVA to dry completely dry between coats to avoid runs. Keep applying PVA until the mold surface transitions from individual droplets to a glossy green sheen (requires close inspection). Finally, apply primer on top of the PVA. If your feeling lucky, apply paint before then primer, but we had print through problems I would attribute to shrinkage of the resin rich areas between the balsa block which will require some minor fairing before the final finish can be applied but initially the primer-only approach is probably more sensible. One tooling specific issue that should be mentioned is the installation of the dagger board and rudder trunk forms into the NoGo55 hull mold: The two blocks of aluminum should be clean and waxed similar to the hull mold and should be installed with silicon caulking prior to spraying the PVA. The intent is to create a vacuum tight seal at the two attaching bolts not to bond the trunk forms into place. The previous warning about the nastiness of silicon should be heeded and the minimum amount of silicon required for a good seal and minimal "squeeze out" should be used.

Tooling / Tool Description

The tooling we used covers the sophistication scale, from a high temperature capable all carbon hull mold at the high end, to tortured aluminum deck molds at the middle of the scale, ending at the "it makes you itch a lot" recycled rigid foam for our wood fired "oven". As described previously the hull mold was of the No-Go-55 shape designed by Bill Beaver with a very generous flange around the shear line (minimum depth of approximately 8"). Bolted and sealed into the bottom of the mold were two aluminum blocks around which the trunks were formed integrally with the hull. The fore deck mold was a single sheet of aluminum that was tortured into a conical shape with wood frames for support. The aft deck mold was also tortured aluminum which integrally formed the aft deck and v-bulkheads. ' The two heat sources for this project were a small ceramic heater for local heating/circulation and wood fired stove as the primary heat source.

High Tech Heat Producing Device.

Heat was contained in a rigid foam box constructed around the mold after acceptable vacuum had been achieved and maintained. Back to the foam for a minute...it had several great properties including self supporting rigidity, ease of assembly (push pin style with long nails), full configurability and best of all free thanks to your tax dollars and an unguarded scrap pile. The only down fall was that...well you couldn' t walk within ten feet of this stuff with out scratching yourself uncontrollably, and if you had to actually handle it...forget it, just fill the hot tube with calamine lotion and dive in! Heated air was pumped from the wood stove to the foam box via a custom sheet metal hood powered by an old bathroom vent fan (...that as it turn out has a thermally protected electric motor). The vacuum pump used for the whole operation was a Welch Model 1400 Duo-seal Pump, which is a two stage vane pump submerged in oil. As long as I have owned this pump it has pegged every vacuum gauge I' ve been willing to pay for. For a resin trap I used a half-gallon mason canning jar with an aluminum plate for a lid, vacuum tape for a seal, and screw in barbed fittings to attach vacuum hoses—cheap, readily available, and it worked like a charm.



Vacuum Pump & Vacuum Pot for collecting resin before it can enter the pump.

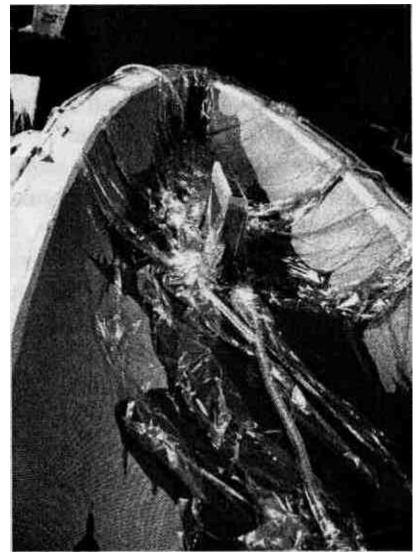
Laminates and Laminating

We used two different laminates during this misadventure, one was all carbon and the other was a blend of carbon and glass. The decision about what laminate to use was based on the success of existing boats with similar laminate schedules and an attempt to build light durable boats. I consulted with several people including Ted VanDusen, Erich Chase, and Bill Beaver concerning laminates. Hull and deck laminates will be described from the mold surface inward with fore and aft direction as 0° and athwart direction as 90°. Hull and Deck Laminate: All Carbon 1 layer 6oz. glass 0/90. 1 layer 5.7oz plain weave carbon 0/90, 1 layer 5.7oz plain weave carbon ±45°, 0.25" Superlite Balsa Core, 1 layer 5.7oz plain weave carbon ±45°, 1 layer 5.7oz. plain weave carbon 0/90, or Blend of Carbon and Glass 2 layers 6oz. glass 0/90, 1 layer 5.7oz plain weave carbon ±45°, 0.25" Superlite Balsa Core, 1 layer 5.7oz plain weave carbon ±45°, 1 layer 6.0oz. glass 0/90 with local doubling. The ±45° layers started just forward of the shrouds and ended aft of the seat tracks. The aft deck ±45° layers covered the entire v-bulkhead to just aft of the seat tracks. The fore decks were two layers of the material of choice against the mold, balsa core and one layer of material inside with local doubling. The materials were placed in the molds dry and Super 77 spray adhesive was used sparingly to hold things in place. The core was fit in place as tightly as possible, including stuffing balsa shavings into uneven seam. Small scraps of cloth were glued in place over seam to hold things tight during the remainder of the lamination and bagging process. Notes: When the curvature of the mold was gentle enough the balsa was placed in the mold scrim side against the mold surface to reduce the volume of the resin rich pockets between the balsa blocks. Hulls and decks are fully cored including trunks. Special attention was also paid to ensure the "bridging" of materials was eliminated. Bridging will result in resin rich areas.

The Good Stuff-Infusion Set Up Details

We will pick up the infusion story with the laminate in place in the mold and trimmed to within and inch or so beyond the shear line along the flange. It is also assumed that the masking on the flange has been removed and the vacuum bag sealant tape has been place as far out on the flange as possible. The infusion process just begs for a mold with generous flange surfaces. The first step is to cover the laminate with peel ply. The peel ply should be trimmed so that it just fits inside the sealant tape and such that all laminate surfaces are covered. The next step is to place felt tape just inside the sealant tape and on top of the peel ply all the way around the flange to create a vacuum manifold of sorts. A subtle detail that should be noted here is that a one to two inch band of peel ply should separate the end of the laminate and the felt tape. The resin front slows considerably when it hits the single layer of peel ply and this prevents short- circuiting of the vacuum manifold and allows the resin front to equalize without sucking gallons of excess resin into the resin trap. (This is very important, right Karl?) Ok now we have a layer of peel ply and a continuous vacuum manifold now we need resin distribution media. Buy the real stuff from Naltex, red "chicken bag" as described by Karl. Sun and landscape screening look tempting but call Naltex-, this stuff is cheap and works. To illustrate how cheap I' ll share a Karl story: Karl took the task of ordering the distribution media for this little project and as it turns out the minimum order from Naltex is 100 yards. The total bill was around $121.00 with shipping, and typically for this much money the UPS guy brings you a small package. Having no idea how BIG 100 yard of this stuff is Karl left a polite note for the Man-in-the-Little-Brown-Truck to leave the package behind the shrub near the front steps so that the delinquent neighborhood youth would have no indication of the rich bounty of red plastic netting lying in wait just a few feet from Karl' s front door. Well as it turns out the shrub in front of Karl' s house is more like a Charlie Brown Christmas Tree, a twig with three leaves, and the Naltex box was a lumbering behemoth at five feet tall and two feet six inches square which contained enough Naltex to infuse the Titanic...twice. Reading the note, the UPS man looked at the shrub in question, then up at Karl quizzically and said "Do you know how BIG this thing is?"

Back to the infusion story...The resin distribution media should be cover all surfaces that need to infused below the shear line of the hull mold or to edge of the core for the deck molds. All joints in the Naltex should be overlapped the minimum distance possible (one inch or so). If you don' t follow this rule of thumb you will need a thin-bladed spackle knife and a hammer to get this stuff off when you are done. Thicker peel ply may be the solution here. The final step in the resin distribution process was affectingly called "plumbing". As everyone knows, all plumbing sessions must start with the loosening of the belt and appropriate southerly shift of the pants to expose the appropriate amount of... well you get the mental picture. The basic plumbing materials include Helicoil (spiral wire wrap material), polyethylene tubing, and appropriately sized barbed T-fittings. When lying out the plumbing one should assess the total area to be infused, and distribution of this area from the resin inlet to the vacuum outlets with the intent of equalizing the surface area between the two (the optimum situation is the have the resin front close in on all outlets at the same time). For the hull we had two resin inlets and two vacuum outlets. The inlets came in through large pleats in the bag and landed about 18 inches from the bow and stern. Along the keel of the boat a length of helicoil was placed UNSTRECHED, and split around the base of the trunks. The joint between the helicoil and the inlet tube was made with a barbed T-fitting. The outlets were formed with 12 inch lengths of helicoil centered on a barbed T-fittings and wrapped with standard bleeder material to protect the bag. The vertical part of the T was connected to the vacuum outlet hoses. The outlets were placed just aft of amidships on top of the felt tape. The aft decks had two inlets at the fore and aft extremes connected by a single length of helicoil and two outlets centered along the linear distance from the peak of the v-bulkhead and the transom. The foredeck had one inlet at the bow connected to a single length of helicoil along the center line and tow outlets about 1 feet 6 inches from the aft edge. It should be noted that the helicoil and the distribution media were dropped off about 1.5 inches from the aft edge of the foredeck to slow and even out the resin front. The UNSTEACHED note about the helicoil is important because the bag material will close off the resin flow by pulling down into the helicoil. The intent with the helicoil is to create a free flowing channel under the bag to allow the resin to flow unobstructed. The trunks were formed integrally with the boat and during the infusion process they become isolated from the vacuum source. This problem was overcome by placing four to six layer of felt tape on top of either trunk to serve as a "vacuum reservoir" (the extra volume of the tape under vacuum was enough to pull the resin the remainder of the way through the trunks once isolated). A final lesson learned was to use thick bag material (e.g. D-comp D300 or other suitable 2-3 mil)as, the thinner, 1 mil material would pull down into the distribution media and inhibit resin flow (it was also easy to damage



Hull laminate and bag during infusion. Note the integral dagger board trunk in the mold.

Material Usage / Labor Hours / Economics

The all carbon boats used the following material quantities in the laminate: 13 yards of glass, 38 yards of carbon, and 17 sheets of balsa. The parts were produced in approximately 64 man-hours once we had the process down. Cost was distributed as follows 70% Dry Materials, 11% Epoxy, and 19% Consumables with a total materials cost of approximately $1820.00. It should be noted for all you cheap asses out there that with labor these parts would cost approximately $3260 commercially (with a very conservative hourly rate $15 per hour with an overhead rate of 1.5) for just the hull pieces not joined, not rigged, and not painted. I include my self in the cheap ass category, otherwise I' d pay someone to build these things and I' d just sail them.

The carbon/glass boats used the following material quantities in the laminate: 48 yards of glass, 13 yards of carbon, and 17 sheets of balsa. The parts were produced in approximately 64 hours once we had the process down. Cost was distributed as follows 67%

Dry Materials, 13% Epoxy, and 20% Consumables with a total materials cost of approximately $1533.00. To emphasize the point for all you cheap asses out there these parts with labor would cost approximately $2973 commercially for just the hull pieces not joined, not rigged, and not painted. This is a conservative estimate because I haven' t marked up the materials to cover handling costs, etc.!

Things to note: An all carbon boat is not that much more expensive if you can buy the material in bulk, only $300 or so. Not bad, but some in the fleet have personal issues with the use excessive amount of carbon. Having the big pieces is only one fifth of the battle. Future plans include infusion of a seat and possibly carriage (this may be a stretch because of the tooling required.)

QUESTIONS

Ask George Saunders, saundersgm @ yahoo.com, (410) 267-0057 or try me on the 1C List Server.

SUPPLIES. CONSUMABLES, AND SOURCES

The first recommendation that I have is *build multiple boats* at one time. This has several advantages: 1) you can buy materials in bulk directly from manufacturer or at least at wholesale prices, and two 2) you always have company we building when building, which makes things go much faster.

BAG MATERIAL:

De-Comp Composites, Inc. Cleveland, OK Item: BF-D330 60" V-Fold (918)358-5881 http://www.decomp.com/

INFUSION MEDIA:

Naltex Austin, TX Item: 141-4336 Scrimp Media 60" (512)447-7000

POLYETHYLENE TUBING, FITTINGS, AND HELICOIL:

McMaster-Carr Dayton, NJ (732) 329-6666 http://www.mcmaster.com/

HELICOIL:

M. M. Newman Corp. Marblehead, MA
(800) 777-6309

PEEL PLY, BLEEDER, SEALANT TAPE, MOLD RELEASE, AND VARIOUS BAGGING SUPPLIES:

Wicks Aircraft Supply Highland, IL
(618)654-5858 http://www.wicksaircraft.com/
Aerospace Composite Products San Leandro, CA
(800)811-2009
http://www.acp-composites.com/

BALSA CORE:

Manufacturer: Baltek
Distributor: Composites One LLC Bristol, RI
Item: Baltek Superlite S-45 6mm(l/4) AL 104338
4.5# B2K (Kontour Cut)
(800) 343-3030
http://www.baltek.com/
http://www.compositesone.com/

EPOXY:

Phoenix Resins, Inc. / MAS Epoxies Cinnaminson, NJ Room Temperature Infusion Mixture
(888) 627-3769 http://www.masepoxies.com/

CARBON CLOTH:

Carbon Composites, Inc.
(888) 227-2266 http://www.carb.com/

GLASS CLOTH:

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Karl flexing all of his MANLEY MUSCLES lifts "Orange" for the camera