5. Sheet-metal tools can easily be formed to mold parts when only simple curves are involved. Use epoxy to make the backup structure, even when using aluminum ribs and stringers behind the tool face. Any rivet will provide a continuing and totally miserable source of vacuum leaks into the bagged assembly during cure. They are nearly impossible to seal after the tool is made, because the back side usually includes a little misfit between the flange and the tool face. Even extensive sealing along fitted surfaces on the rear side will leave a few persistent sources for leakage. If you must use rivets, sink them in epoxy or sealant as you drive them, so that you at least have a fighting chance to seal the tool face.
6. Because the tool is impervious to air, and the bag is sealed to the tool face, the loads that result from the pressure of the bag against the part do not distort the tool. Even so, it is a mistake to assume that the tool structure can be flimsy, because tool distortion will occur any time the tool is set up on an uneven floor or table top, or when you lean on it as you lay up the part. Due to the need for tool stiffness, the resins and construction methods that are used tend to maximize the modulus (stiffness) and the stability of the cured laminates used to make tools, but do not emphasize strength. The epoxy systems normally sold and used to make tooling do this job well, and most of them provide strength levels far higher than needed.

VACUUM BAGGING MATERIALS

The use of bag molding is so widespread that a number of supply companies have set themselves up to sell the many materials used in the process. Such companies as Hawkeye Enterprises, Airtech International, and Richmond (all in the Los Angeles area), and Taconic Process Materials in Santa Maria, handle a broad line of films, release fabrics, sprays, liquids and waxes, breather and bleeder plies, dam stock, zinc-chromate tape (used for sticking the bag down to the tool face) and many other specialty items. Figure 7-6 shows a typical layup used in the high-temperature autoclave cure of a complex carbon fiber-based part, with a nearly endless array of special-purpose materials. Fortunately, the simple room-temperature cure requirement of most individual builders avoids the need for using many of these materials. The items you will need can usually be obtained locally and at modest cost.

BAG FILM, for example, may be made of any flexible plastic film that is air-tight and won't dissolve in the resin. One of the best is the plasticized PVC film sold at most dry-goods stores for use in covering the mattress on a baby crib. Also, the moisture-barrier film that is sold at hardware stores, or the plastic drop-cloths that are sold at most paint stores are usable for room-temperature cures. "Visqueen" is a common trade name. Be sure to avoid the very thin plastic films, as they usually have many small pin-holes which will make for many leaks in the final layup.

SEALING TAPE can be any double-faced self-stick tape, as long as care is used in keeping out wrinkles where the tape touches the film. An even better bet is ordinary caulking compound (the cheap stuff), sold in tubes for use in a hand-operated caulking tool, available at hardware and builders supply stores.

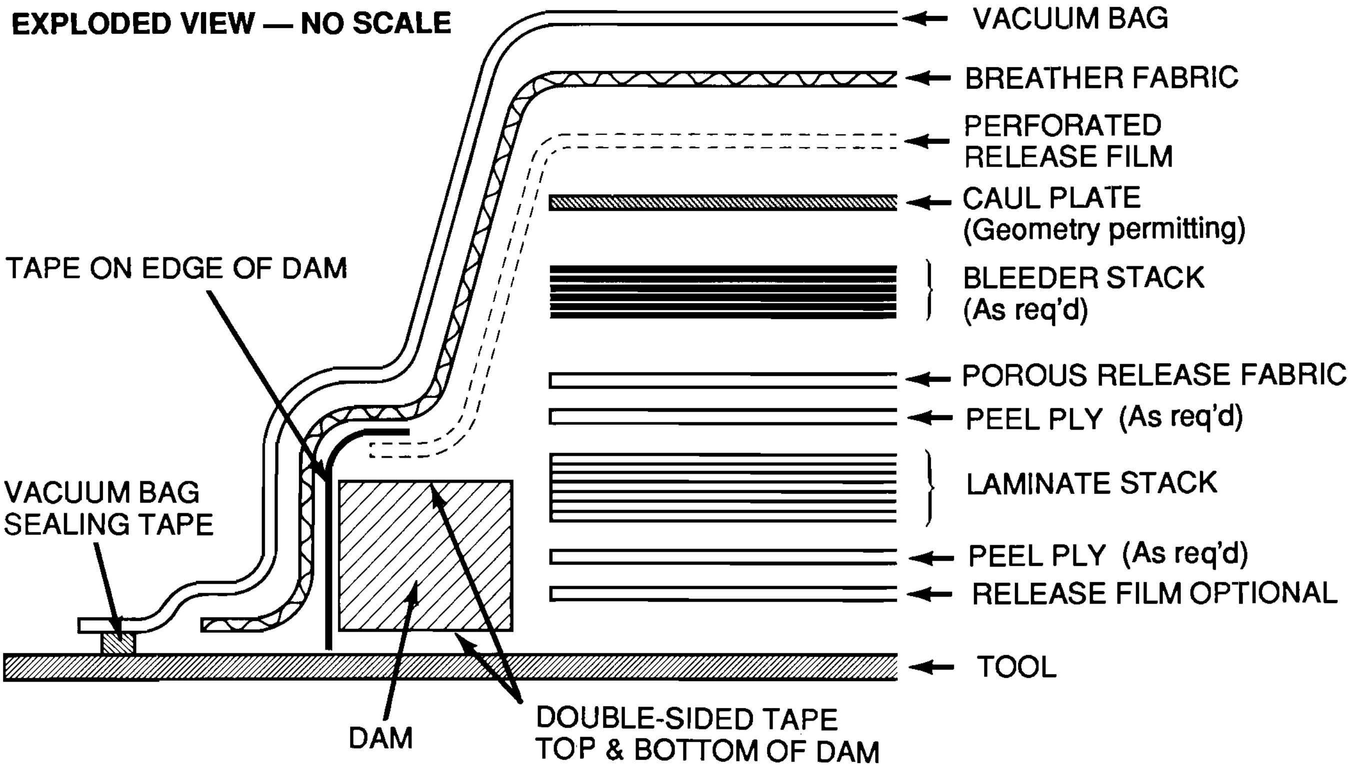

Figure 7-6. Typical layup used for a complex carbon fiber-based part.

RELEASE COMPOUND can be any good floor wax or paste wax, particularly those intended for automobiles or boats. Be sure, however, that it completely covers the mold and that it is buffed and polished. Often, layup instructions will call for as many as four coats, each buffed and polished prior to application of the next coat.

RELEASE FILM may be made of cellophane or of any of the same films as the bag. If you are using it between the part and a breather or bleeder ply, punch a zillion small holes in it, or it will seal off areas of the part and prevent the vacuum from covering the whole part. Also, check the film with your resin system to be sure it can be removed easily from the cured resin surface. (Cellophane tends to stick like crazy to some resins.) Commercially available perforated release films save a lot of time, and usually work better than the homemade variety.

A TEAR PLY is sometimes used between the layup and the bleeder ply, so that the resin soaked bleeder plies can be simply torn off the finished part after cure. Again, this material can be a nylon shirting material, or, better yet, one of the several fabrics made for this purpose and sold by the supply houses.

BREATHER PLY can be any fabric you are willing to throw away. Use enough of it so that air can freely pass along the surface of the entire part inside the bag.

BLEEDER MATERIAL can be the same as the breather, but you will need a lot more so that it can soak up the excess resin as it comes through the perforated release ply or tear ply. The thick, batting material sold by the commercial suppliers can be approximated by using the synthetic quilting that is sold at dry-goods stores. Be sure that it hasn't been treated with a non-stain material, as this will prevent it from soaking up resin.

THE VACUUM CONNECTION can be a length of copper or aluminum tubing going through the edge seal of the bag. Be sure to use plenty of sealant around the tube, as this is a common source of bag leakage. A better method of attaching the vacuum line is to use a flanged fitting, like that shown in Figure 7-7.

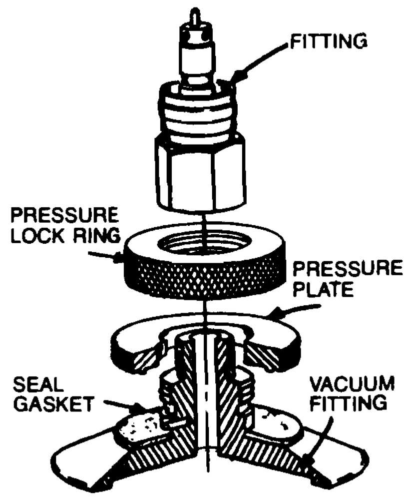

Figure 7-7. Vacuum fitting assembly (thru bag)
(Courtesy Hawkeye Enterprises)

In all of these examples of substitutions for readily available material that the industry would get from one of the specialty suppliers, be sure you test the material before using it. Sometimes the material that initially seems workable turns out to have some surface treatment or missing ingredient that causes problems in actual usage. For example, Hawkeye offers five or six different versions of the same material for some applications because of the small differences between resin systems.

One last tip on setting up a vacuum molding operation:

Allow plenty of excess material in the bag as it is being sealed in place over the part. About 6 inches folded into a 3-inch flap every three feet or so around the entire part is about right.

Figure 7-8 shows the way the bag should look. Even when using zinc chromate tape in several layers, the out-the-edge vacuum tap often leaks, especially after you bump it a couple of times while walking around the layup. You will be well advised to buy one of the special "through-the-bag" fittings designed for this purpose.

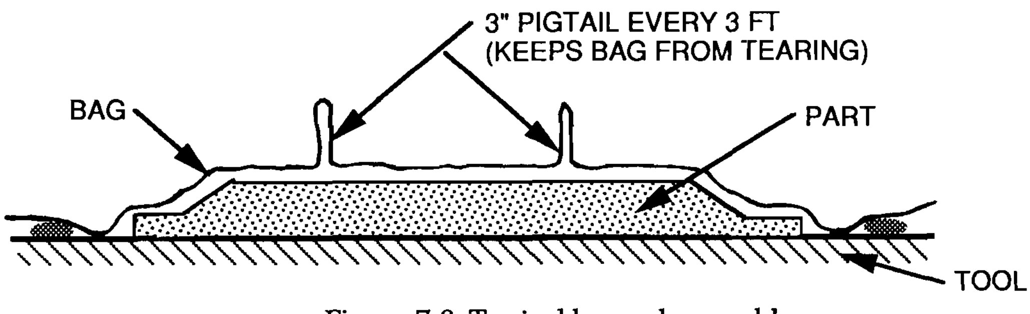

Figure 7-8. Typical bagged assembly.

CHECKING THE LAYUP

When all of the fittings are attached to the bag, and the part is ready for cure, check for vacuum tightness. If you have installed the extra vacuum gauge, this check is made by simply pulling a vacuum with the pump, closing the shutoff valve in the vacuum line, turning off the pump and observing the loss of vacuum with time in the layup. A well-sealed system will show a negligible loss of vacuum over a five or ten minute period. A poorly sealed bag (or a bad leak in the tool) will show a loss of about half the vacuum in as little as a minute.

For large parts, those having one or both of the plan dimensions more than three or four feet, it is a good idea to use more than one vacuum gage on the layup. This will show if all portions of the part are holding the vacuum, or if a leak in the tool is letting air into the layup at some unsuspected location.

A handy device to have when tracking down the vacuum leaks in your layup is a stethoscope. This doctor's listening device can easily and quickly pinpoint a leak, even with a fairly high noise level in your shop. Keep on looking for leaks, even if the resin has already started to set up, as lack of vacuum will always give an understrength part, compared to the part you will get under good continuous vacuum pressure.

TOOL LEAKS

One nasty source of bag leaks is not the bag at all, but the tool or mold, in which the part is laid up. It is obvious that a porous area in a fiberglass tool, or a crack in either a plaster or composite tool can leak outside air into the bag. That leak relieves the bag pressure in the area of the leak, and often will cause a defective part. These leaks are particularly hard to find when the layup is formed of a solid impervious core, and the facings are wet or viscous and tacky. In this situation, the area of the leak seals itself off from the rest of the part, and may be very hard to detect.

Be sure to check your tool with a blank layup (no part in the tool, but fully bagged as if there were one) to see if the tool is really sealed. If there is a problem with the tool, you can either repair the leak, or just bag the **entire tool**, backside and all. Remember that solvent or water picked up by the structure of the tool may out-gas under vacuum, and will act just like a leak with a very mysterious source.

HOW MUCH VACUUM DO YOU NEED?

The amount of vacuum pressure required to produce good parts will depend upon several things. The most important variable is the fit of the parts in the assembly before the bag is applied. If all of the pieces go into the mold without any appreciable misfit or warpage, only a few pounds per square inch of vacuum pressure will make good parts. Where the pieces in the assembly do not fit together well, particularly in tightly curved assemblies, or when bagging cores into female tooling, you will need much more pressure from your vacuum pump.

Make a dry layup on the mold(no resin), bag it with a transparent bag, and carefully inspect it under the actual pressure that your pump is providing. If the parts do not conform to the mold and to each other perfectly, you do not have enough pressure to make a good part. The pressure can be increased by using a better vacuum pump, but can only reach about 14.7 psi, even if you have a perfect vacuum and are at sea level. Practical shop maximum at sea level is about 13 psi, or 26 inches of mercury.

The easiest solution, if you already have a good vacuum source, is to make a better pre-fit assembly so that conformity to the tool is essentially perfect. Where this is not possible, the part must be made in an autoclave, which works just like a vacuum bag, except that additional pressure is provided, up to as high as 700 psi and more. As a poor second alternative, you can use an excess of a gap-filling resin, just like a hand layup. The part will then be heavier, but satisfactory parts can still be made, even with misfitting sub-assemblies under an inadequate vacuum pressure.

THE VACUUM PUMP

All of the above discussion assumes that a suitable source of vacuum is available, a convenience found in few home shops. In order to provide the vacuum, you can employ any of several devices. The handiest is your vacuum cleaner. If you use this method, be sure to allow sufficient bypass air (leakage), at the hose attachment, to permit adequate cooling of the motor, as the pump must run continuously during the **entire** cure cycle of the resin system, or about 4 to 10 hours for most room-temperature curing resins. If you use a standard four inch venturi from an old airplane's vacuum-driven gyro system, you will probably obtain both adequate cooling air and a substantially higher vacuum pressure than the unaided vacuum cleaner will provide. Either way, this source will only be sufficient for very limp or nearly flat assemblies, as it will provide 3 to 8 psi at best.

Another low-cost source is a device almost the same as an aircraft venturi, except that it is much smaller and fits on a garden hose, using water instead of air as the driving force. They are sold in hardware stores for use in draining flooded basements using city water pressure. Although it sounds terribly wasteful, they really do not use much water, as the venturi opening is quite small.

Most shops end up with a dedicated vacuum pump because they are so much more dependable. The cheapest pump is a junk air compressor. Even those in bad shape can work well, as the maximum pressure they will see in this service is only 14.7 psi, which is far less than the 50 to 100 psi that the typical compressor is expected to deliver. An excellent source is your local garbage dump, where fine compressors can be found in old refrigerators, discarded because the Freon system leaked. Any of these devices can be expected to deliver at least 10 to 12 psi of vacuum, enough for most purposes, and far more than the 3 to 5 psi of a vacuum cleaner. If you plan to get a first-class pump, they cost about $700 for the low-cost laboratory units, up to about $15,000 or higher for the units typically used in aircraft production shops.

If you plan to get a real vacuum pump, or even just an old compressor, you should also plan to plumb your shop with vacuum lines, so that you can locate the compressor far away from the working area. Most of them are very noisy, and represent a serious distraction if you must work close by. When running the vacuum line, locate several quick disconnect fittings at several appropriate locations in your shop, so that you can simply plug into the system when you wish to start the cure of another part. Remember to seal all of the joints in the vacuum line, as vacuum will find a very, very tiny leak in a joint. Even if your pump has sufficient capacity to allow such small leaks, the noise produced by a line leak can be terrible!

One additional unit is also a good idea. If you are to prevent the vacuum pump from constantly turning on and off every time you touch a hose connector, you should also include a plenum in the system. A perfectly good answer is an old compressed air tank from a shop compressed air system. The vacuum pressure load on the tank is much lower than the original load of compressed air that the tank was designed for, so it is still quite safe to use, even if it has a lot of rust and pits on the outside. If it actually has a hole in it, it still can be used, if you can plug the hole with some epoxy.

If you are interested in further exploring the typical vacuum bagging processes used by commercial shops, request a copy of a booklet, *Handbook of Layup and Bagging* written by William McCracken, published by Mar Mac Engineering & Graphics and distributed without cost by National Aerospace Supply Co., at the address listed in Appendix 1.

RTM MOLDING

Although open layup and vacuum bag molding are probably the most commonly used molding methods, many other methods are also used. In the case of relatively simple shapes and a large number of pieces to be made, a method of closed die molding called, "Resin Transfer Molding", or "RTM", has found rather broad acceptance. When a vacuum is used to assist the flow of the resin through the dry reinforcing fibers, the method is called, "Vacuum Assisted Resin Transfer Molding", or "VARTM".

RTM is a process in which the part is contained in a matched closed mold, which has been filled up with a Preform which consists of all the reinforcing fibers intended to be contained in the finished part. This mold full of dry fiber is then infiltrated by a liquid resin which is pumped into the cavity full of dry fibers, displacing all of the air which was originally in the open spaces between the fibers. At the time of first use of the method, some fifty years ago, most of the parts were both small and of simple shape.

As the use of RTM became more widespread, much more complex and larger parts have proven to be quite successful in production situations. The largest part yet produced is believed to be the nose radome of the British-French Concorde supersonic jet transport, which was first flown in the 1960's. This part is more than sixteen feet long, and quite consistent in its control of critical dimensions.

In addition to success on larger parts, the method has also been quite successful on such complex parts as a complete thrust reverser assembly for the Boeing 757. Also, the blocker doors in the thrust reverser for all three engine installations have been made by this molding method. These parts were made with carbon fiber reinforcement, and then molded as a complete part in a single cycle. Many other large and complex parts can be found in current production.

Obviously several conditions must be met to be able to make successful parts using this method:

1. The value of the part to be produced must justify both the substantial mold cost and the often lengthy process development needed to assure success for any specific part.