AFWAL-TM-80-101-FIMS

INVESTIGATION OF LOW COST FOAM TECHNIQUES FOR FABRICATION OF MINI-RPV'S

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ABSTRACT

This memorandum describes and reports the results from a development program conducted by the Mini-RPV Group of the Aeromechanics Division of the Flight Dynamics Laboratory to define techniques for the low-cost production of mini-RPV's. Areas covered include the applicability of very low-density structural foams, and reinforced plastics, exploration of methods and parameters relating to structural foam, fabrication of usable mini-RPV component parts, and an initial assessment of alternate and complementary materials and techniques. Conclusions and recommendations are also presented.

This effort was accomplished by Centro Corporation, Dayton, Ohio, under contract F33615-77-C-3048.

This Technical Memorandum has been reviewed and is approved.

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I. SUMMARY

An investigative program has been conducted into the application of low-density rigid urethane foams and other plastics to the production of low-cost mini RPV's. Several trials were conducted to explore the feasibility and process parameters of molding various aircraft parts from urethane foams. Mold design requirements, mold temperatures, venting, mold filling, and resin component temperatures were investigated. The introduction of auxiliary skins, both structural and cosmetic, was also explored. Problem areas were identified and solutions arrived at to the point that several aircraft component parts were fabricated and flown. These included ailerons, stabilators, rudders, wing and vertical fin tips, servo boxes, side force fin thrust bushings, side force fins, rudder subfins, and bulkheads. These parts have been successful and have generally shown improved weight and performance characteristics while requiring much less time to produce.

Structural components, such as motor mounts, spar caps, structural bulkheads, and vertical fin ribs, have been fabricated using the elastic reservoir molding technique using epoxy resin reinforced with glass and Kevlar. These parts can be made with this technique with a drastic reduction in manhours, have good surfaces on both sides, controlled thickness and strength properties, and with lower weight than the equivalent hand lay-up parts.

I. SUMMARY - Cont'd

The methods and results are discussed in this report for the work to date. Further studies are to be conducted to develop the fabrication of wing and fuselage parts.

II. INTRODUCTION

Small, remotely-piloted vehicles (mini-RPV's) are generating considerable interest for use as flying test beds, sampling and surveillance vehicles, and weapons for defense and harassment. These vehicles have always been carefully handcrafted to suit the intended mission and have carried large price tags. This increased interest has created the need for techniques for producing mini-RPV's in greater quantity at lower cost. Traditional methods of construction do not lend themselves readily to low-cost quantity production.

A search for alternatives has turned up a group of materials, called structural foams, which seem to hold promise for low-cost production techniques. These foams are made by blowing any of several plastic materials into a rigid, loadbearing, lightweight material. One of these plastic materials, polyurethane, can be formulated so that it can be mixed (by hand or by machine), poured, and foamed directly into a mold to yield a finished part that is strong, lightweight, has any desired surface texture, and is resistant to most fuels, oils, and solvents.

The furniture and automotive industries have been using structural urethane foams in the production of commercial product components for several years and the technology of lightweight structural foams is well developed for these industries. However, lightweight in industrial use means densities of from 25 to 60 pounds per cubic foot. When considered for small remotely piloted vehicles, these densitites are much too high. Mini-RPV's

II. INTRODUCTION - Cont'd

need foam densities in the range of from 2 to 12 pounds per cubic foot. The problem is that the only application area that has ever used rigid urethane foam in these densities is the area of insulation. Virtually no technology has ever been developed for the structural application of rigid urethane foams in this density range. This project has the objective of developing this technology as applicable to mini-RPV's.

Some preliminary work had been done in FDL prior to the start of this project. A foam machine had been leased, some molds made, and several trials made with some successes and enough failures to start showing some of the problem areas. The foam machine was returned to its owners and is no longer available, so, for this project, a new foam machine has been selected for purchase. In the meantime development work was started using hand mix procedures.

III. EXPERIMENTAL PROGRAM

The foam components on hand when this effort started were the remains of two (2) 55 gallon drums of components for a 4 lb/ft^3 foam left over from the previous work with the leased foam machine. Exposure to high temperatures and humidity had deteriorated these components so that the usual 1:1 mixing ratio no longer produced good parts. The isocyanate component had partially reacted with atmospheric moisture requiring 5% excess of this component to produce proper rigidity in the foam.

The flurocarbon blowing agent in the polyol component had partially volatilized, due to excessive temperatures, resulting in decreased blowing action. A small amount of methylene chloride added to this component, before mixing with isocyanate, improved the blowing action considerably. Methylene chloride will affect the physical properties of the foam if too much is used, making this a high risk way of improving blowing of the foam.

Fresh 3 gallon samples of each component were obtained from General Latex and Chemical. This material was used for trial production of wing tips, stabilator tips, servo boxes, side force thrust fin spar bushings, ailerons, rudder, stabilators, vertical fin tips, ventral fins, sideforce fins, fuselage bulkheads, and vertical fin ribs. All of these parts have been made successfully and used in aircraft produced in the shop. The ailerons, rudders, and stabilators are made with 2 oz-fiberglass/ epoxy skins. The sideforce fins have been made both with and without skins. All other parts are currently made with foam alone.

It has been impossible to make larger parts, such as wings, because it is not possible to hand mix enough foam for these large pieces within the cream time of the foams. A foam machine is required for the production of large pieces.

During the trials which led to successful production of aircraft parts, several aspects of the foaming and molding processes were examined to determine the effects of such factors as direction of rise, mold temperatures, venting, and mold surfaces.

As the reaction between the isocyanate and polyol proceeds, the reaction mass heats up and the reaction is accelerated as more heat is developed. A polymeric structure is being formed and the heat of reaction volatilizes the flurocarbon blowing agent which expands the structure into a foam. This expansion occurs until all of the blowing agent is released and the polymeric structure becomes rigid.

A cold mold surface will remove some of the heat of reaction from the foam material next to the surface and reduce the blowing action thus giving a layer of higher density material at the surface of the foamed part.

Figure 1 shows the density profile of a cross-section of urethane foam molded between two flat surfaces, such as a panel mold. The center core has a relatively uniform density but, as the mold surfaces are approached, the density increases significantly. This dense "skin" accounts for a large portion of the total weight of the foam part even though it represents a small portion of the overall thickness of the part.

In any molding operation, the weight of skin that can be tolerated must be carefully considered. In some cases, heavy skins are desirable for added strength or durability. In other cases, they are of little value and efforts may be made to minimize their thickness and weight. Several factors influence skin thickness: mold temperature, part thickness, the way the mold is filled (vertical or horizontal pour) as shown in Figure 2, and the use of frothed or non-frothed systems.

In a mold where the foamed part is very thin, there may be almost no blowing at all if the mold is cold. The temperature of the mold is important in maintaining desired densities in part surfaces, thinner sections requiring higher mold temperatures than thicker sections. During the trials it was found that for pieces such as ailerons, rudders, and stabilators, which have reasonable thickness, that mold temperatures should be between 95°F and 110°F depending on the particular configuration. The temperatures of the mold for the thin-walled servo boxes should be higher to prevent excessively dense parts, perhaps 125° to 150°F. Care must be exercised to avoid overly high mold temperatures because premature gel might occur or the surface might blow too much and produce a bad part.

As foam rises in the mold, the foam tends to stick to the surface of the mold while the foam away from the mold surface keeps moving. This introduces a shear into the foaming mass which increases with higher rise and smaller cross section. The cell structure in the shear zone tends to break down which increases the density of the skin and the overall density of the molded part. The lower density foams are more sensitive to the effect of thin section, high rise shear than the higher density foams and so suffer a greater relative densification.

If foam is still rising in the mold when gel starts to take place, the increased viscosity of the material increases the shearing and turbulence in the foam such that tearing at the mold surface and localized collapse of the cell structure can take place causing parts to have poor surface characteristics and poor structural properties. It is, therefore, important to fill the mold before gel occurs. In some cases of high-rise, thin-sectioned parts, the best way to assure filling the mold completely before gel is to use the frothing method in which the foam is blown with a flurocarbon with a low boiling point to fill the mold quickly and then the regular blowing agent develops the final molding pressure.

Tearing is much less pronounced when the foam is against a surface, such as a layer of paint or a skin, which does not have a parting agent on it. This is because the foam can adhere to the surface better. However, the localized cell collapse can still occur due to internal turbulence but, unless excessive, does not effect the serviceability of the part.

The time required for the foam to cure after foaming has stopped is heat dependent. In thick sections the heat of reaction is enough to give rapid cure. In thinner sections mold temperature can influence the cure time or mold residence time.

At room termperature, mold times of one-half hour to three hours are common. If the mold temperature is increased to $120^{o}F$, mold time may decrease to 10 to 20 minutes. Again the importance of mold temperature control is shown.

Density, temperature, blowing agents, foaming systems, and polyols all have an effect on the dimensional stability of a foam. A properly formulated rigid foam of a 2 lb/ft^3 density or higher will be very stable for application between $-100^{o}F$ and $225^{o}F$ on a continuous basis and up to $250^{o}F$ for short periods.

Many usable parts have been successfully foamed and incorporated into finished airframes. In making these parts, it has been found that two factors helped produce foamed parts with good surface finish; first is increased density and second (and most important) is filling the mold completely before any gel can develop. Very low density foams present problems with surface finish when handmixing because it is extremely difficult to mix the foam, pour it into the mold, wet the surfaces of the mold, clamp the mold shut and position it for proper venting, all before gel formation has begun. Increasing the density by overfilling the mold allows the mold to be filled (all surfaces wetted and little movement of foam required) before gel starts and produced parts with very good surface properties. However, the parts are then too heavy. One solution to this would be to incorporate cores into the molds so that the finished parts would have walls of higher density foam, caused by overfill, and hollow areas in the center. This way the mold could be filled quickly with handmixed foam to get a good surface but still keep the overall weight at an acceptable level.

A second solution to the problem is to use a foam machine with frothing capability which will allow the mold to be completely filled before gel can occur without overfilling the mold and without the increase in density. If the two techniques, coring and frothing, were used together, parts with good surface characteristics and very light weight would result, but to do so would require a foam machine with froth capability.

The possibilities of including a finish coat, primer coat or load bearing skin in the initial molding step were explored. After the mold had been coated with release agent, a layer of paint was sprayed into the mold and allowed to dry. The usual foaming process was then performed. Several trials, using this technique, were conducted to explore the feasibility of spray coatings. It was shown that primer and/or color coats can be included in the molding operation provided:

a. the coating material is compatible with the urethane foam - Teflon, silicone or oil based coatings will not bond satisfactorily with the foam. Water-based paints or polymeric coatings, other than silicons or Teflon, will bond very well and provide virtually any desired finish for the foamed parts.

b. any solvents or water in the coating material is completely evaporated and dissipated prior to foaming. Water remaining in the coating will react with the insocyanate component of the foam upsetting the ratio between isocyanate and polyol groups and altering the properties of the foam at the coating/foam interface. Solvents remaining in the coating may either volatilize causing gas pockets between the foam and the coating or they may attack the foam at the interface. In either case the integrity of the foam/coating bond will be compromised.

c. the coating material is formulated to give a matte or satin interior finish rather than gloss. Urethane foams will not reliably bond to very smooth or high gloss surfaces so any potential coating material with a smooth surface should be thoroughly tested for adequate bonding before it is specified for regular use as a foam coating.

Several approaches were explored to provide load-bearing skins for foamed parts or skins which would take considerable handling abuse while protecting the integrity of the foamed part. One material which was tried was a stretchable fabric coated with a pigmented rubber compound. Pieces of this material were cut to size, laid into the aileron mold, and held in place by doublesided tape. In a production situation vacuum would be used to hold the pieces in position. The part was foamed against the fabric side of the skin material and produced a part with excellent skin bonding, built in surface finish, and with an acceptable weight. In this method it is extremely important that the skin material not have any oils or waxes or other bond inhibiting substances on the surface which is to be next to the foam core and that the material itself be compatible with the foam components.

A load bearing or structural skin can contribute significantly to the stiffness of a foam part in both the bending and torsional modes and enhance its ability to carry high flight loads. Skins of this type were fabricated of glass reinforced epoxy using 2 ounce glass cloth with Epon 815 epoxy for both gel coat and cloth saturation. These skins were laid up in the molds and left in place during the foaming operation. Urethane foam bonds very well to the epoxy in these skins and the finished part exhibits excellent surface finish and strength properties. Removal of parting agent from the surface and clean up at the parting line are all that is required to produce a part ready for painting. Again, the surface of the skins must be free of any oil or waxy materials. Some skin delamination has occurred on parts made with epoxies with a high wax content. Pigmenting the gel coat and laminating resin could eliminate the need for painting. Ailerons and rudders were produced by this technique for use on several airplanes. Two sets of stabilators were also produced this way which were flown on two of the planes. Larger parts, such as wings and fuselage sections, can be produced the same way with the skin lamination being engineered to suit the strength requirements of these parts.

Hand layup of glass/epoxy skins allows a reduction in manhours of about 50% compared to the original balsa skins while giving greater strength and durability. The surfaces of the glass/epoxy skins are very true to the mold which significantly reduces the labor time involved in finishing completed parts. However, this method is still more labor intensive than is desirable and the cure time of the epoxy greatly reduces the production rate of these skins. This latter problem can be alleviated considerably by heat curing the epoxy but production rates would still be somewhat restricted. Ideally, a method must be found which reduces labor to an absolute minimum and eliminates cure time.

The method which looks most promising at this time is the thermoforming of the skins using a high performance thermoplastic. The skins for several parts could be formed simultaneously, trimmed, and dropped into the molds where the foam operation would be carried out directly in the skins. Whereas the fabrication of balsa skins (old method of construction) took an estimated 20 hours for wings and tail, and the layup of fiberglass/epoxy skins (current method) takes about 10 hours of actual labor, the skins could be produced by thermoforming in approximately 1-2 hours.

Materials available for thermoforming do not have physical properties matching fiberglass but are good enough that, with proper engineering of the total structure of the parts, an adequate skin could be produced.

Several methods of forming skins in the molds, other than hand lay-up, are available. Briefly, some of these are:

a. Vacuum bag molding - cut-to-shape plies of cloth are placed into the mold, resin poured in, the mold covered with a membrane and sealed, vacuum drawn in the mold allowing atmospheric pressure to force the membrane and cloth plies into the mold. The flow of resin to all parts of the mold is assisted by hand. Tooling and equipment costs for this method are low but production rate is restricted by cure time of the resin and by the labor involved.

b. Pressure bag molding - similar to vacuum bag molding except that a bag pressurized with compressed air does the molding instead of vacuum/atmospheric pressure. Some means must be provided to clamp the mold closed during pressure molding so equipment costs are somewhat higher with this method and resin cure time still restricts production rates.

c. Matched die molding - cut-to-shape pieces of reinforcement/resin prepreg or sheet molding compound (special resin compound reinforced with chopped glass) are placed into matched metal dies, the dies closed and clamped at high pressure, and heat applied to cure the resin. This method can give good skins with fairly high production rates. Tooling and equipment costs are quite high and would require large quantity production to amortize costs over a large number of units.

d. Elastic reservoir molding - flexible, porous foam is charged with resin, the foam is sandwiched between plies of dry reinforcement (glass, graphite, Kevlar, etc.), placed in matched dies, the dies clamped and heated to cure the resin. Pressures required are lower than with other matched die molding techniques so equipment and tooling costs can be lower. This is a very versatile method since additional strength and thickness can be planned into the part where needed and wide variations can be produced in one molding operation. The minimum thicknesses possible with this technique might be great enough to make skins too heavy for mini RPV's but the method appears to be very good for molding structural carry-through parts for wing and engine loads.

Several sample pieces were made with this method and exhibited good homogeneity, uniform thickness, and good surfaces on both sides. Spar caps were made with seven layers of reinforcement (2 with 7 oz. fiberglass and 1 with 5 oz. Kevlar) sandwiched around 1 inch foam. These caps had complete saturation of the reinforcement, a thickness of 0.100 inches, and a reinforcement-to-resin ratio of 60:40. A motor mount was molded the same way with extra thick bosses for the spar clamp area molded in. Again a very high quality composite resulted. Ribs for the vertical tail were molded using ¼ inch foam with a layer of 2 oz. fiberglass on each side. This was an intricate part with lightening holes and stiffening flanges but good saturation, good surface finish, and a uniform 0.032 inch thickness were achieved. The main structural bulkhead was molded with 1 inch foam and 4 layers of 7 oz. glass cloth. This piece was also very high quality. All these parts were lighter than the hand layup parts previously used while being higher quality with better cloth to resin ratios.

Some trials were made placing dry 2 ounce glass cloth in the mold and foaming into that. The thinking was that as the foam expanded against the cloth it would penetrate the cloth and densify giving a glass reinforced urethane skin over the foam core. Over most of the surface of the foamed parts this worked quite well but due to the curving convergence of the mold surfaces, combined with the turbulence in the foam, the air in the cloth was trapped in some areas near the top of the mold causing some unsaturated areas of cloth. No practical way has been found, so far, to prevent these trapped air pockets and so no more trials are being made at present.

The ability of urethane foam to bond to other materials was investigated and it was found that bonds are possible with most plastic materials, as long as they are oil-free and satin finished, except for the self-lubricating polymers such as polyethylene, Delrin, Teflon and nylon. In some cases the formulation of the foam might have to be adjusted to promote better bonding but this is not a serious problem. This would make it possible to thermoform skins from materials such as ABS or urethane thermoplastics which have high forming temperatures and good strength properties at normal service temperatures. If these skins are pigmented to eliminate painting, finished parts could be produced by only moderately skilled workers with low total labor costs per unit. No parts have been made this way, yet, because we do not have thermoforming capabilities. However, it has been done with some automotive parts and has been suggested in the literature for other applications.

Tooling costs for thermoforming skins are relatively low. Wood can be used for tooling for low production and prototype work while high-temperature filled epoxies would serve for larger production runs.

The machine for thermoforming consists of a movable frame to hold the plastic sheet, an oven capable of heating the plastic to a maximum of about 400°F, a means of positioning the plastic in the tools, and a vacuum source. Such a machine is available for use at Wright-Patterson AFB for prototype and limited production work.

Successful production of small parts has been achieved. Strong load-carrying flight surfaces (ailerons and stabilators) have been produced with skins of fiberglass. Most of the problems of applying very low density/structural foams to mass production of mini-RPV components have been identified and solutions appear to be in hand. The next step is to start producing larger component parts, such as wings and fuselages, and trying short production runs at "high rate". This will be attempted when the foam machine is received.

IV. CONCLUSIONS

Low-density rigid urethane foams, reinforced plastics, thermoformed plastics, and polymeric barrier coats, used individually or in various combinations, provide a viable means of producing low-cost mini RPV's. The cost savings stem largely from two considerations: the time required to produce the airframe can be reduced by a factor of from 5 to 10 and the skill level of the workers is much lower than for the hand-crafted vehicles previously produced. In addition, these materials allow much more design freedom since form possibilities are virtually unlimited and strength can be engineered exactly where and when needed.

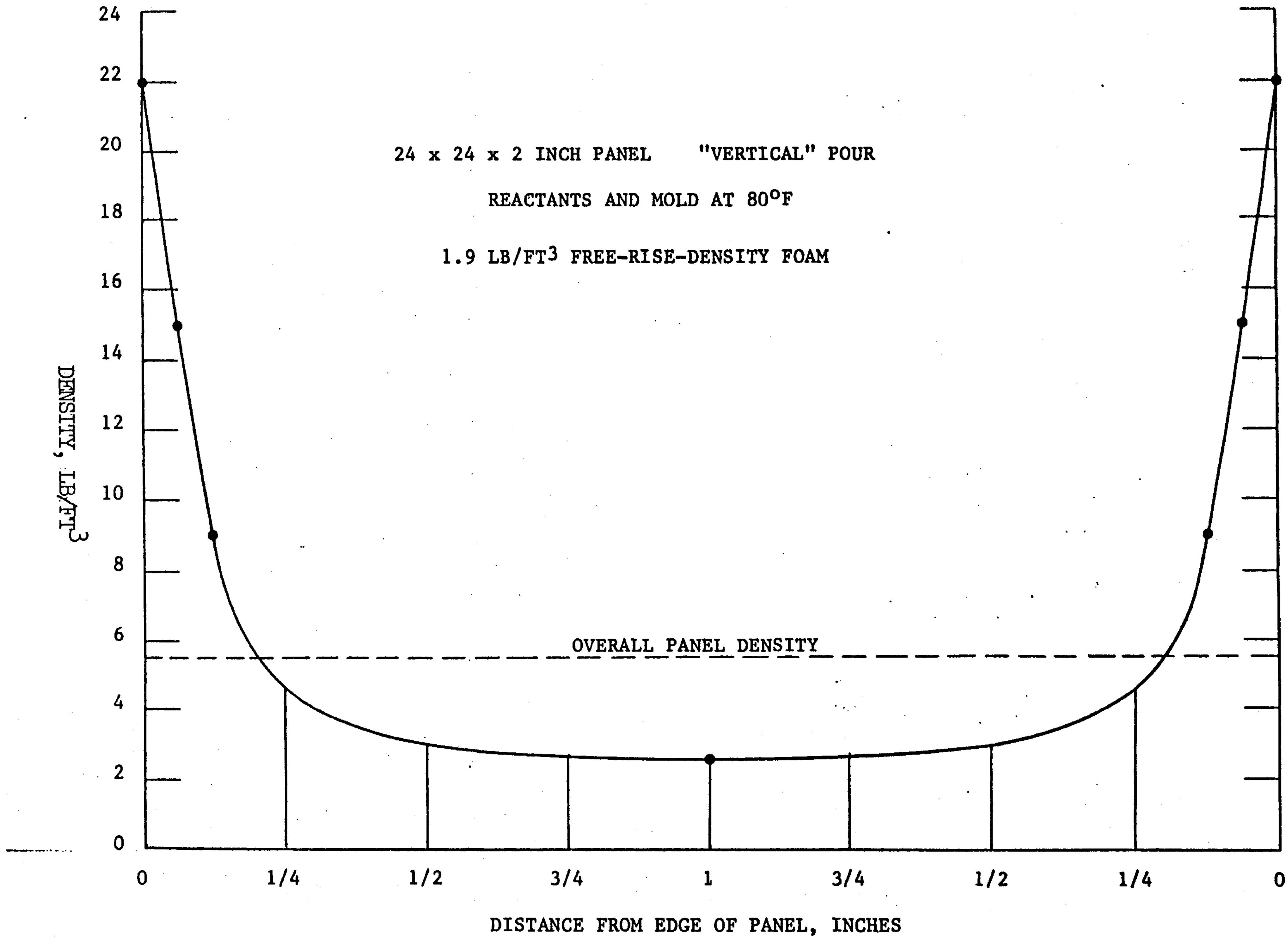

FIG 1. DENSITY PROFILE OF MOLDED RIGID FOAM PANEL

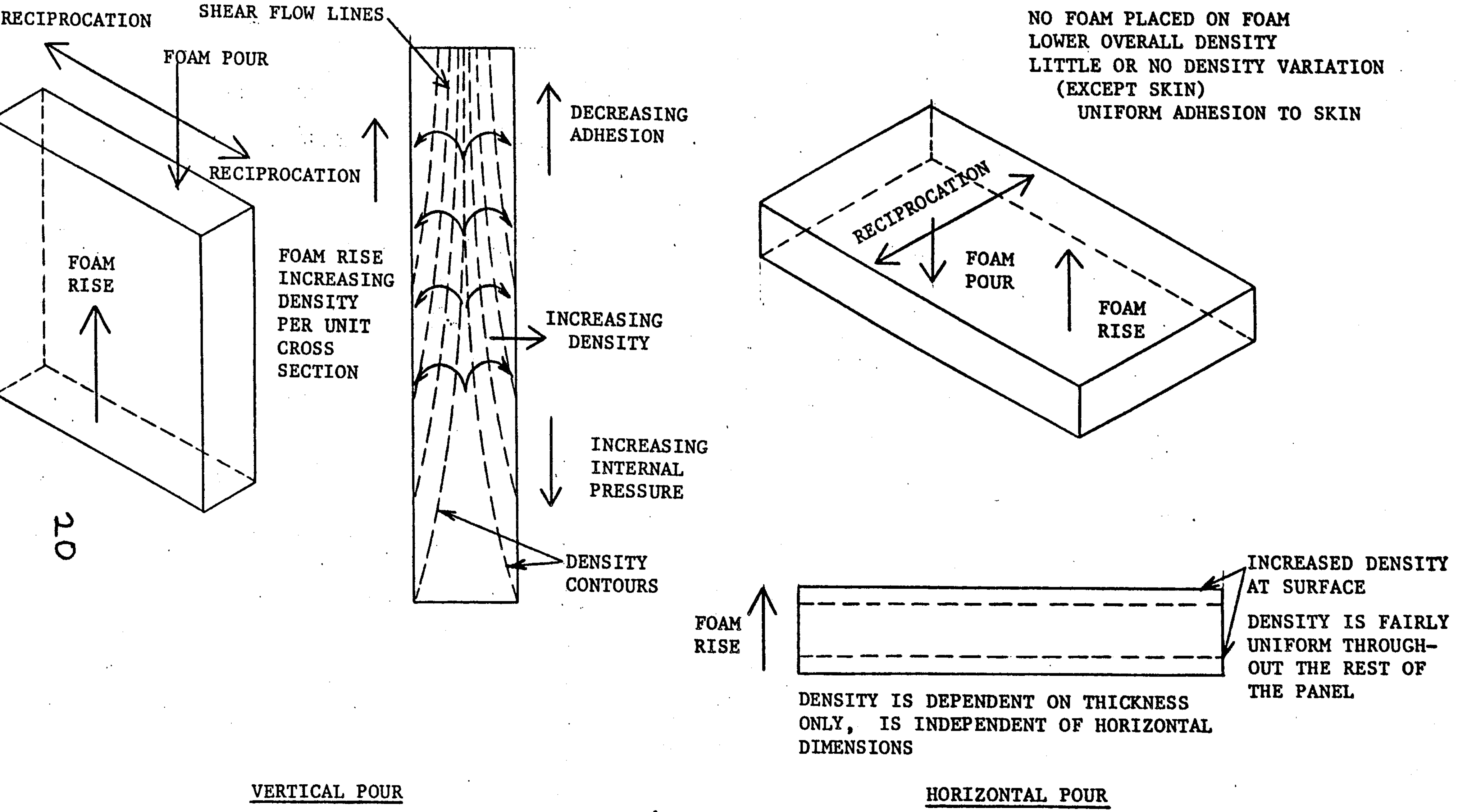

FIG 2. VERTICAL AND HORIZONTAL MOLD FILLING