DEVELOPMENT OF TOOLING AND PROCESSES FOR FABRICATING LARGE HIGH-ACCURACY RADOMES

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I. INTRODUCTION

Radomes that are under development for use with certain fire control systems must meet critical boresighting requirements, and they must maintain this required accuracy under the high temperatures and aerodynamic loads encountered during operation of the high-velocity interceptor aircraft on which they will be mounted. Although radomes of the large size necessary for these systems can be fabricated commercially, radomes so produced do not meet these requirements. Therefore, a die-development program, initiated in 1952, was pursued concurrently with the development of radome-molding procedures and processes.

Theory and past experience both indicate that a radome of streamlined shape achieves the best electrical performance if it is of half-wave-wall configuration. In this type of radome, undesirable reflections from the radome surfaces can be almost completely cancelled if very close tolerances on the thickness and dielectric properties of the radome wall are carefully maintained. Experience with smaller radomes has shown that close tolerances can best be met by radomes that are molded under high pressure between matched, hardened steel dies. Although this method of radome fabrication requires a relatively high initial expenditure for equipment and tooling, the exceptional quality and reproducibility of the product more than offset these costs.

A program that was undertaken to develop such a set of matched dies is described in this paper. Early in this program it became apparent that no dies for plastics molding that even approached the required size and tolerances had ever been built before and that the accuracy necessary between surfaces had, in the past, been limited to dies that were only a fraction of the size required. Because of this lack of experience it was therefore decided that the final set of dies would be designed from the data obtained by the design, fabrication, and tryout of a scale model of these dies. The die-development program that resulted is discussed herein.

II. PURCHASE OF EQUIPMENT

After the first rough sketches of the dies were completed, it was necessary to initiate the purchase of the equipment required in using these dies. This seemingly premature action was necessary because of the long time needed to approve funds, to design and fabricate the equipment, and to ship, assemble, and test it. Among the equipment purchased were the following large items.

1. Hydraulic Press

After calculations had established that a rigid and very accurate press having a 2500-ton capacity was required for use with the final dies, the standard presses of this size available from various commercial press builders were studied. Although none of the standard presses had the rigidity and accuracy of movement desired, several companies thought these qualities could be attained. Rigidity could be achieved by housing the four press posts in built-up slab sides and then bracing these sides with cross-rails. The daylight and stroke of the available presses were much too short for the anticipated application but to increase them would be to sacrifice accuracy and rigidity. It was therefore decided to purchase a press with 10-foot daylight and to move the die in and out of the press after each molding cycle. This was possible because of the developmental nature of the program. ??? ???

The press that was purchased (see Figure 1*) was built by Williams White and Company.

Its specifications are as follows:

Capacity:	100 to 2500 tons adjustable compression, moving down
Platen area:	78 inches by 66 inches
Bed-face size:	88 inches by 66 inches
Daylight: ?	120 inches maximum
Stroke:	72 inches maximum
Stripping:	140 tons with "kicker" cylinders only 750 tons with stripper cylinders included
Stripper-ram stroke:	18 inches maximum
Total weight:	363,000 pounds (supported by twelve 20-ton piles)
Height above floor:	29-1/2 feet
Total height:	35 feet, 3 inches
Size of pit:	11 feet by 20 feet by 5-3/4 feet deep

After the press was installed and the gibs adjusted, the following characteristics were measured and found to be within the stipulated tolerances:

Parallelism between the face of the moving platen and the face of the base is within 0.0015 inch over the entire stroke.
Change of parallelism is 0.002 inch over the entire stroke.
Horizontal movement of the moving platen through the entire stroke is 0.001 inch with smooth travel and 0.002 inch with jogging.
Deflection of the base under a uniformly distributed load of 2500 tons is 0.006 inch in a span of 64 inches.

2. Vertical Boring and Turning Mill

A survey of facilities throughout this country revealed that there was no lathe or vertical boring mill that could be made available for machining the mold surfaces of these large dies to the accuracies demanded. As a consequence, it was necessary to purchase such a machine tool. Conferences with those using this kind of equipment revealed that a vertical boring mill with an electronic tracer was the most accurate machine for the purpose.

Accordingly, a modified, 6-foot, heavy Cincinnati Hypro vertical boring and turning mill was purchased (see Figure 2*). This machine includes a General Electric electronic duplicating attachment on the left rail head.

Specifications for this machine are as follows:

One right-hand turret head, one left-hand ram-type swiveling rail head, one right-hand side head

Swing:	76 inches
Height under rail:	101 inches
Travel of left-hand ram:	72 inches
Vertical travel of rail:	90-1/2 inches
Speed of table:	0.96 rpm to 75 rpm
Diameter of table:	72 inches
Feeds:	0.004 inch to 0.750 inch per revolution
Weight:	91,500 pounds
Support:	Nine 20-ton piles under a concrete pad 17 inches thick
Accuracy of duplicating:	±0.002 inch
Finish of work:	27 micro-inches possible under favorable conditions; 50 to 60 micro-inches expected under normal conditions.

A series of measurements made while machining various dies on this mill show that the accuracy in duplicating a large die can be within ±0.0003 inch. The finish on forged tool steels has been in the region of 100 micro-inches, but this finish can be improved to a finish as fine as one micro-inch by using a grinder on the ram and then polishing the surface.

3. Curing Oven

A large oven is required for postcure of the radome after its removal from the die. A suitable oven was purchased.

Its specifications are as follows:

Gas-fired, floor-type, vented; equipped with Partlow temperature programming and control

Heating capacity:	600,000 Btu
Maximum operating temperature:	550°F
Exhaust fan:	675 cubic feet per minute
Circulating fan:	6000 cubic feet per minute
Outside dimensions:	9 feet wide, 9 feet long, 14-1/2 feet high
Inside working area:	6-1/2 feet wide, 8 feet long, 10 feet high
Door opening:	6-1/2 feet by 10 feet.

The oven was installed in such a position relative to the large press that either the layup fixture or the dies could be rolled into the oven for precuring or postcuring on the tooling, thus eliminating a considerable amount of distortion in the part.

4. Fifteen-Ton Crane

A crane was necessary to assist in the erection of equipment and to move the tooling and finished products. Although a larger crane would have provided more lifting power, one having a 15-ton capacity was decided upon in order to obtain the greatest coverage of floor area. This crane has a 30-foot span and an 80-foot craneway. It is mounted on separated columns, which are supported by 35,000-pound capacity piles. The maximum distance from the bottom of the hook to the floor is 32 feet; the floor area covered by this crane, measured from the center of the hook, is 22 by 69 feet.

5. Housing for Equipment and Facilities

The equipment already mentioned is installed in a building having a high bay area approximately 32 by 80 feet. This building is supplied with steam, water, electric power, gas, telephone, and air. The steam line is a 6-inch insulated pipe carrying saturated steam at 140 psi with a temperature of 360°F; a 3-inch condensate return line is parallel to it. There is a flash tank in the building for condensing the spent steam and a pump to return the condensate to the boilers of the central heating plant.

Cold water is piped in from a nearby building; hot water is provided by a heater within the building. Hot water at various temperatures for layup-fixture heating is obtained from a steam-and-water mixer. Two towers mounted on the roof of the building furnish a cooling system for the dies in the presses and for the heat exchangers in the press hydraulic systems. Vacuum is obtained by the use of vacuum pumps that are located in the building.

III. DESCRIPTION OF THE DIES

Five sets of large, matched dies for the high-pressure molding of laminated fiberglass radomes have been completely designed and have the characteristics shown in Table I. All are designed for use in the 2500-ton hydraulic press, and the molding surfaces are to be contoured in the vertical boring mill.

The designs were completed in the order shown in the table; the "D" dies were the first to be fabricated. Equipment was purchased on the basis of a rough design of the "C" dies. The main parts of each set of dies are the punch (hereafter called the male die) and the cavity (referred to as the female die). Each male die includes a ring around its base that is used for stripping the part from the male die. Also, each male die is mounted on a base that holds it to the bottom platen of the press. The four guide pins and bushings are standard items in most dies. In the first four sets of dies, the lower (wide) end of the female die is divided and has a collar that serves as the guidance area for the female die.

IV. DESIGN PARAMETERS AND LIMITATIONS

These five sets of dies can be divided into two groups according to their design parameters, which were determined by the intended application. The first three sets ("A," "B," and "C" dies) were to be used under most extreme molding conditions — the use of very high and rapidly applied pressures, with preforms of relatively poor quality made from many types of materials having a large bulk factor when preformed, and with a rapid increase of molding temperature. The "D" and "E" dies were to be used under more controlled conditions — a maximum of 1000 psi uniform molding pressure, a slow increase of molding pressure, carefully made preforms from only one kind of material with minor variations, a very low bulk factor on the preform, and gradual, controlled die heating.

In addition to these parameters there were the limitations imposed by the size of the existing equipment; these were:

1. The weight of any component could not exceed approximately 20 tons.
2. The total height of the assembled die could not exceed 110 inches.
3. The outside diameter of any die part could not exceed 75 inches.
4. The height of any part (including the clamping device) could not exceed 102 inches unless the part cleared the boring-mill rail.
5. The maximum depth of contour that could be accurately cut in the female die was 66 inches.
6. The amount of saturated steam available at 360°F and 140 psi was about 60,000 pounds per hour, which was available only for short periods.
7. The crane hook was 32 feet from the floor.

V. DIE DESIGN

The drawings of the dies were made by a small group of die designers, each of whom contributed a certain amount of basic knowledge to the program. One designer had several years of experience in the design of small plastics dies, another had machine-design experience with various job shops, while a third had a little shop experience, and so on. The basic die design, however, was done by the writer, with the help of many others, as discussed in a later section.

As soon as a drawing of the largest radome (the "C" radome configuration) was available, a rough die design was made for this configuration, which was to be molded under fairly severe conditions. With this basic design in mind, the required equipment was purchased.

The first set of dies to reach the final design stage was the smallest set, designated the "A" dies in Table I. In addition to molding finished radomes 24 inches in diameter and 37 inches long, these dies were to serve in testing several mechanisms and in measuring several molding conditions.

An automatic stripping device was incorporated into the design of this set of dies so that the molded part could be easily removed when the dies were opened. This device consisted of a set of cams in the male die that operated a set of fingers in the female die; the fingers protruded under a stripper ring and moved it up with the female die. The stripper ring then lifted the part from the male die. In order to ensure that the part stayed on the male die and separated from the female die when the dies were opened, two grooves were machined in the male die.

The design of the first set of dies included three types of guidance between the male and female for accurate alignment; each type could be removed so that the usefulness of the others could be tested. The types of guidance were:

1. Four standard die guide pins and bushings
2. A guide pin through the nose of the part
3. Guidance between the base of the male die and the open end of the female die.

These guidance devices were considered very necessary because the use of preforms of poor quality imposed severe eccentric loading conditions on this set of dies.

This set of dies also incorporated a device for clamping the nose of the preform to the male die. Such clamping is necessary because of the shape of the finished part and the bulk factor. As the dies close, the first contact between them, through the part, is at the open end of the radome. The movement of the dies is then almost normal to the thickness of the part so that the force exerted by the press may tear the cloth or pull the preform down the nose of the male die. The nose clamp is intended to eliminate the latter problem.

It was expected that the first three sets of dies ("A," "B," and "C" in Table I) would be nitrided on the molding and wear surfaces and then chrome-plated. (These operations are discussed in detail in another section.) A check-out of the equipment for performing these operations was to be accomplished by nitriding and chrome-plating the "A" dies; these dies would also be used in testing the heating system that would be employed with the first three sets of dies.

The second and third sets of dies were to incorporate almost the same features as the first set. They would have an automatic stripping device, the three guidance systems, the nose clamp, nitrided and chrome-plated molding and wear surfaces, and a high-velocity-steam heating system. In addition, the female die in each set was to be made in two pieces, with a joint along the mold surface.

The fourth set of dies ("D" in the Table) was to follow in general the design of the first set. It would include the automatic stripping device and the three guidance systems. However, the nose clamp to be used was of a different type. The clamping plug had a larger diameter and fitted the flat part of the nose in addition to a portion of the conical part of the radome. This plug fitted into the female die in such a manner that, as the female closed under pressure and molded the nose of the part, the shear pin started to fail in shear. When the dies opened and the part was stripped from the male die, very little stripping force was necessary to shear the pin in the opposite direction.

In addition, this fourth set of dies was to have much softer molding and wear surfaces than the first three sets. The heat treatment was not as severe as that used for the first three sets, and the nitriding and chrome-plating were eliminated. Also, the high-velocity-steam heating system was replaced by a chambered-steam system.

The fifth set of dies ("E" in the Table) closely resembled the fourth set in general construction except that a simple stripping mechanism with manually operated fingers replaced the automatic stripping device.

VI. PROBLEMS CONNECTED WITH THE DIE DESIGNS

In designing each of the five sets of dies, the first problem encountered was the scarcity of experienced die designers. It was soon realized that the design of plastics dies is a field quite different from other types of design. Since no designers with experience in designing large plastics dies were available, it was decided to design the dies to be like some smaller ones (with which we have had considerable experience), except that all dimensions had to be larger; the tolerances, however, had to be held as close as those found in very small dies.

In "blowing up" the design of a small die, the problem of weight had to be considered because only limited space and handling equipment were available. It was definitely necessary to analyze the dies structurally in order that excessive weight could be reduced. In fact, for the largest dies, (called "C" in the Table), the stress analysis resembled that for a major airplane component, with even more consideration given to rigidity and deflections. The services of several experienced aircraft stress engineers were used in making these analyses.

The problem of heating the dies came up next. The usual practice of heating dies by means of a chamber around the female die and a hollow male die was acceptable for the last two ("D" and "E") sets and was adapted from the small die design. However, in heating by this method, uniform wall thickness was much more important on the molding surfaces of the large dies than on those of smaller dies.

To obtain the fast heating rate required with the first three sets, the chamber method of heating was inadequate because the transfer of heat from practically quiet steam through a water film into a steel surface is very slow. In the design of these dies, then, a system of high-velocity steam was used. Saturated steam was introduced into tubes wrapped around the female die and into grooves cored into the male die. To reduce the accumulation of condensed water, a specially developed water trap was installed along the walls, every ten or twelve feet of tube length. For the calculation of the quantity, pressure, and temperature of the steam in these heating systems, the services of a thermodynamicist were employed.

In order to obtain hard molding surfaces on the first three dies, a form of surface treatment was necessary. The common methods of case hardening (pack carburizing, gas carburizing, cyaniding, and carbo-nitriding) require a quench from 1375°F or higher, which produces considerable distortion. Since a large amount of contour grinding would be required to clean up this distortion, these methods were eliminated from further consideration. Contour grinding was not desirable because:

1. Wheel wear would make it difficult to obtain the necessary accuracy.
2. Grinding would not result in uniform surface hardness due to the varying depths of stock to be removed.

3. A considerable amount of grinding in the boring mill would tend to wear the ways of the mill and thereby reduce its accuracy.

Flame-hardening was another method of surface hardening considered. However, this method, which is essentially a two-dimensional process, could not be easily adapted for use with dies of the shape required. To design a flame-hardening fixture for each die would be costly and the result would not be satisfactory. Hard chrome-plating was eliminated because it is porous and uneven in thickness.

The metallurgists that were consulted agreed that a form of heat treating known as nitriding would be the most suitable method. Because only a relatively low temperature (usually 975°F) is required for this process and no quench is needed, the amount of distortion would be minimum. By the use of the Floe process, the thickness of the white layer could be controlled to less than 0.0005 inch and could be removed by only a hand polish. With nitriding, the steel dies could be heat treated, finish machined, and case hardened, so that only a small amount of polishing would then be necessary.

The nitriding operation, especially the Floe process, is relatively new; therefore, the advice of an expert in this field was obtained, and a nitriding facility was designed under his direction. This facility has yet to be built and tested, and the exact process required for specific die parts to be determined. It is definitely needed because none of the heat-treating companies in this area has a furnace large enough to nitride the largest parts.

After the required strength of the die steel had been determined by structural analysis and the method of surface treating was decided upon, the proper material for making the dies was selected. After it was decided that the male and female die parts for high-pressure plastics molding should be fabricated of forged steel, a modified 3-1/2 percent chrome, air-hardening, tool steel was selected for the two smaller sets ("A" and "D" in Table I). This steel is in common use in England, but does not have an SAE designation. For the last die ("E" in Table I), SAE 4140 steel was chosen because no nitriding was necessary nor was the desired core strength unusually high.

The choice of material for several smaller die parts also presented problems. For instance, the steel selected for the nose guide pin of each die had to allow considerable bending deflection without breaking and yet retain a high resistance to bending and wear as well as good hardenability. For the smaller dies ("A," "B," and "D"), SAE 1095 bar stock was the material selected for the nose guide pin. For the larger dies, this part was too thick to respond to the heat treatment suitable for SAE 1095 so it was made of Gordon tool steel.

Deep hardenability, toughness, and resistance to wear were also required for the die guide pins. For the smaller dies, these guide pins were made of SAE 4340 bar stock and were heat treated to a hardness of 55 to 56 on the Rockwell C scale. For the larger dies, the material specified was ASM class II-B-1, air-hardened and drawn to Rockwell C 58 to 61.

The guide bushings and nose clamp for all the dies were made of Carpenter's Super Samson bar and were gas carburized to give a wear-resistant surface. The stripper rings, stripper cams, and stripper slides were fabricated of ASM class II-B-2, heat treated to Rockwell C 57 to 59. Most of the other parts were made of materials that are in relatively common use for these applications.

In order to ensure that the dies would undergo little or no distortion during the nitriding process, metallurgists recommended that a stress-relieving operation in a controlled atmosphere be carried out after each contour-turning cut. Since there seemed to be no controlled-atmosphere furnace of sufficient size available and since the limited use to which such a furnace could be put did not warrant building one, the nitriding furnace was to be used for stress-relieving operations. The design of the nitriding furnace, therefore, made provisions for these operations.

The three dies that were to be nitrided were also to be polished to a high luster and then flash chrome-plated with 0.0003 to 0.0005 inch of chromium. Past experience had shown that a flash chrome-plating acts as a lubricant on the molding surfaces, a desirable feature on these dies that were to be used under severe molding conditions. However, very few platers will try to plate over nitrided steel because all of the "white layer" must first be removed from the nitrided surfaces.

Although no facility for plating a piece of steel as large as the "C" female die was available in the Los Angeles area, a concern was found that was planning just such a facility, which would be completed in time to handle this job.

The selection of suitable machine shops in which to fabricate these dies was not too difficult. An investigation of forging facilities in this country revealed that only two companies had electric furnaces, ingot molds, and forging presses that were sufficiently large to process the larger dies ("C" and "E"). A slight modification in the design of the "E" dies made it possible for a local company to pour and forge this set. By a fortunate coincidence this was the only local company that also had machine tools sufficiently large for machining these dies. Thus, it was possible to place just one order with a local concern for the complete manufacture of the "E" dies (except for the contouring of the mold surfaces).

A thermodynamicist determined the requirements of the steam for heating the dies; an outside consulting firm designed the heating-control system. These controls were necessary in order to maintain the temperature of the dies at the desired value until the preform was loaded, to raise the temperature at a specified rate until the molding temperature was reached, and then to maintain this temperature during the curing cycle. The controls also included the necessary plumbing and valves for cooling.

A safety engineer checked these dies in relation to safety, insurance, and health. His approval of the design of all the dies as well as of many of the items of auxiliary equipment was obtained before fabrication was started. Among the reasons for this concern were the following:

1. The resin in the material of which the part is made contains a certain amount of volatiles.
2. The preform is made on a fixture that is heated to 190°F, and the material is heated to a temperature as high as 130°F during the

layup operation.

3. The female-cavity detail part of one of the dies weighs over 14 tons, and the female die assembly weighs over 24 tons.
4. Three sets of dies were to be loaded into the press at temperatures of 190°F to 200°F.
5. The steam temperature is 360°F, and molding temperature is as high as 310°F.
6. The glass cloth used in making the radome is irritating to the skin of most people and some are allergic to it. Fine particles of the material can be carried in the air.

To design the auxiliary equipment needed in connection with the dies, a small machine-design group was set up. The results of their efforts are discussed in the following section.

VII. DESIGN OF DIE-HANDLING EQUIPMENT

The excessive weight of the main parts of these dies as well as the large number of different handling operations required adequate handling equipment. The design and fabrication of proper equipment was accomplished concurrently with that of the dies, so that it was available when these large pieces of steel were to be moved to a particular area in preparation for a certain operation.

To minimize repetition, the handling procedure followed for one set of dies will be explained here, and any additional items not typical will be added as the discussion proceeds. For various reasons it will be most convenient to describe the equipment that is to be used with the last set of dies ("E" in the Table); however, the illustrations will be those of the equipment for the "D" dies.

The large forging for the male die contained a cylindrical knob on the smaller end. This knob allowed adequate handling in the machine shop and also served as a means of chucking the male die into lathes and vertical boring mills for turning the face at the large end and boring the inside.

The first handling fixture (see Figure 3*) designed for the male plug served several purposes. The base was fastened to the male die so that it could be clamped into the vertical boring mill for contour machining. After the male form had been lifted onto the mill by the knob, which was then machined off, the nose-pin hole was drilled, counterbored, and tapped. An eyebolt fitting this hole was used for lifting the part from the mill, although the handling fixture also could have performed this operation. The eyebolt was primarily designed to be shipped with the male die when it was sent out for nitriding and chrome-plating (as in the case of the first three sets of dies). It provided a means of handling the detail part during these processes. The male handling fixture had two other uses: it provided a means for handling the detail male form for the layup fixture (which was either similar to, or the same as, the male die detail), and for moving the entire layup fixture after assembly. This is a desirable feature, because it is necessary to get the layup fixture out of the way when the die is moved into the oven.

The female die also had a large knob on its smaller end that facilitated handling in the machine shop and provided a means of attaching the die to the face plate of the lathes and boring mills. After heat treating and rough machining, the female cavity had a wide flange welded to this knob, and the holes for attaching the collar were drilled in the other end of this part. To handle the die after this stage of fabrication, a fixture was designed to grasp it at the nose end, and a set of eyebolts was purchased for the open end. A set of equalizing slings was also purchased so that the die could be moved in a level position. Because the female die required a large amount of handling in various positions (this was particularly true of the first three female dies), a rotation fixture was designed for turning it over. With this fixture the various shops could contour-machine with the open end up, nitride with the open end down, and then chrome-plate with the open end up again.

A simple, table-type fixture that could be used with all five female die assemblies was built to serve as a storage fixture as well as for the assembly of details into the die and the inspection and cleaning of the die assembly after use.

Additional equipment suitable for use with all five sets of dies is needed for the molding cycle. With each molding cycle, the "C" and "E" dies have to be moved into the press and then out again. A die-transfer truck that moves on roller skids is used for this purpose. Due to the limited height inside the press, it is only five inches high.

A pair of tracks was laid to guide the truck to the press, and a winch was installed to move it. A series of pulleys enables the operator to move the truck down the track in either direction. A turntable is used to turn the die and head it into the oven. The track from the press to the turntable constitutes the die-loading area; a track perpendicular to the first track and running from the turntable to the oven forms the layup area. Directly in front of the press is a steel plate covering the pit. Reinforcement was placed in the pit under this plate, and a temporary track was installed over it. The bed of the press has a bed plate with machined grooves that correspond to the track. This plate serves as a track inside the press and can be left in the press during the molding cycle.

The molding cycle is as follows: A preform (layup) is made on a layup fixture. It is then stripped from the fixture and loaded onto the heated male die, which rests on the transfer truck. The heated female die is lifted from the storage table by the use of the handling fixture, the equalizing slings, and the crane; it is leveled and then lowered over the male die until it bottoms. The handling equipment is uncoupled, and the assembly on the truck is pulled into the press by the winch. The truck is positioned on the grooved bed plate with pins provided for this purpose.

The dies are then rejoined with the control panel; the upper platen of the press is lowered until it contacts the die, and bolts are inserted to tie the die to the upper platen. After the male and female dies are joined, the upper platen is raised, and the truck is removed from the press. The bed plate can also be removed, but this is not necessary. The die assembly is then lowered until it contacts the press base platen (or bed plate). The lower bolts are inserted, the tie blocks removed, and the dies are closed under pressure as the controls are adjusted.

After the part is cured and the dies have cooled, the press is opened to break the part from the female; the part is then stripped from the male. The dies are then closed, the tie blocks are inserted, the lower bolts are removed, and the die assembly is raised. The truck is then moved in, the die is lowered to the truck, the upper bolts are removed, and finally the die is moved out in front of the press. The handling fixture is installed on the female die, the tie blocks are removed, and the female is lifted from the male with the crane and slings and is set on the storage table; the finished part is then removed from the male die.

For the "A," "B," and "D" dies, the procedure for loading the dies into the press needs to be followed only once; the dies can be opened after the mold cycle, and, because of the smaller size of the part, it can be removed from the open dies while they are still in the press.

VIII. DESIGN OF OTHER MISCELLANEOUS EQUIPMENT

In addition to the matched steel dies and their handling fixtures, various other items of tooling and equipment are necessary for the high-pressure molding of large radomes. The more important items are discussed below.

The layup fixture (see Figure 4*) mentioned previously is a very necessary piece of equipment in the molding of any laminated part. This fixture, on which are built up the preforms that go into the dies, is essentially a male die with a stripping mechanism and is mounted on a base having casters. It enables the technicians to build up pieces of impregnated glass cloth into the rough radome shape. This form must be steam-heated and the fixture must provide easy access to all parts of the form for ironing, trimming, pressing, etc.

Due to the thickness of the part (approximately one quarter of an inch), it becomes increasingly difficult to heat each successive layer of cloth in the preform because of the insulation offered by the previous layers. Proper heating of these layers is accomplished with unit electric heaters. To ensure that the temperature is uniform and stable, an enclosure was built around the layup area. It consists of a metal framework covered with canvas and has lights and an exhaust fan on the ceiling. The entire assembly is suspended from one column of the building; it can be raised out of the way, or it can be lifted by the crane and stored in another area.

To handle the largest preforms (those for the "C" and "E" radomes weigh over 100 pounds each) a clutch device is used to reach inside the molded-in insert, grasp it, and lift the preform over to the male die.

A set of adapter plates was built for mounting the "B" dies in the press. These plates contain bolt holes that match the bolt pattern in the press platens as well as those in the base and upper flange of this set of dies. The plates also contain bolt patterns for other dies that were used in molding parts other than the large radomes.

Stripper posts of various lengths and designed to fit the ways of the press were used for breaking the dies apart. These posts are used in pairs and fit vertically between the stripper cylinders in the press base and the upper platen.

It was necessary to machine some of the radomes molded on the "D" dies to various thicknesses for electrical testing. The initial machining was accomplished on the male die before stripping. The radome, still on the male die, was removed from the press and, by means of the handling fixture, was mounted on the boring mill for contour machining. It was then stripped from the die by means of a special fixture. The main advantage of machining a part on the male die is the accuracy that can be obtained.

For additional machining of the above parts, for machining parts already stripped from the male, and for trimming the radomes to length (both ends), a machining mandrel was built (see Figure 5*). In order to duplicate the male die as closely as possible, the contour of the mandrel was turned on the boring mill using the same template that had been used for turning the contour of the male die. An abrasive-wheel cutoff mechanism was used to trim the radomes to length.

A template and template mount were other necessary items of tooling. The template mount was used for locating and holding the template on the boring mill during the contour-machining operation. With the use of a compensating tracer stylus and a micrometer-adjustment device on the tracer head, both of which were designed by the development group, it was possible to machine both the male and female dies of each set with only one template, a unique accomplishment.

A gage was developed to check the thickness of the "D" radome as it was being machined on the mandrel. This gage, which fits over either the male die or the machining mandrel, gives the thickness reading directly for any point on the radome. It also serves to check tool wear during the machining operation and indicates if the radome has slipped from the die or mandrel (see Figure 5*).

The thickness of the finished radomes is measured by a mechanical thickness gage. The radome is suspended by its nose and the instrument enables a direct reading to be made of the thickness at any point by raising (or lowering) and rotating the radome. Although considerable work was done on electronic thickness gages, a satisfactory gage has not yet been developed.

The "E" radome has a metal ring assembly spliced to the aft end for mounting the radome on an airplane. To machine this splice joint in the radome, an automatic thickness router is used in connection with simple jig that holds the work. Then the radome and ring are loaded on an assembly fixture for locating the parts and drilling rivet holes and for riveting the parts together.

Several other items of tooling were designed for this program, such as test fixtures, inspection tools, and a bulk-reducing fixture; however, they will not be discussed since they have little direct bearing on the actual die program.

IX. FABRICATION OF TOOLING

The "D" dies were the first set to go to the shop for fabrication and are the only dies that have been completed (see Figures 6 and 7*). The following discussion of fabrication problems will therefore be concerned with this set.

The most difficult problem, in the opinion of the writer, was that involving the use of the boring mill in machining the contour of the molding surface of the dies. Because of the accuracy which can obviously be obtained by the use of only one template for contour-machining both male and female dies, our engineering group developed a method that would make this possible. This operation involved the design and tryout of the micrometer adjustment and compensating tracer stylus mentioned previously. The method is an improvement over the tried-and-true method of using matched templates to machine matched dies — a male template for the male die and a female template for the female die, the set varying by the thickness of the finished part.

Another problem that came up in connection with the "D" dies was the alignment of holes for the automatic stripping mechanism in the female collar. It was found that jig boring was the only sure way of attaining the alignment between the horizontal and vertical holes for the 12 sets of cams and slides. This was an expensive and difficult operation because of the hardness of the heat-treated forging.

Hardening the wear surface of the female collar was also difficult. The drawing stated merely that it should be of a certain hardness and the procedure was left to the machine shop. The choice of flame-hardening was eventually made because the machine shop that was building the dies had developed that process to a high quality. There was considerable reservation in this choice because of the possibility of cracking around the jig-bored holes. However, the final results justified the decision.

Another problem encountered was that of sampling from the forging. Several tensile-test specimens cut from the excess stock of the female die were tested to determine core strength and hardness. In addition, specimens were cut from the knob of the male die for hardness measurements. These two areas were not truly typical of the forging, but they were the only ones from which specimens could be taken.

One of the hardness specimens showed a banded structure, with bands about 0.040 inch apart, and its hardness varied as much as 11 points on the Rockwell C scale. The boring-mill operator had complained of "hard spots" while contouring, so additional samples were cut. Since it was not possible to obtain this banded structure elsewhere, it was written off as only a local characteristic at the most-necked-down area of this particular forging.

To seal the steam chambers, a material was required that would repeatedly withstand the temperature and pressure of the molding cycle. However, because seals of teflon were used, great difficulty was encountered in compressing a large area of this material when assembling the steam chambers.

Delivery dates proved a serious handicap. As a policy, most machine shops underestimate the time necessary to fabricate a piece of tooling. This practice makes it difficult to schedule an entire project.

X. CONCLUSIONS

The tool-development program discussed in this paper is only partially complete but progressing very rapidly. However, many months will pass before it is completed and a final report can be written. The results obtained thus far are available for the advancement of the art of large-radome development.

The experience gained from the molding and testing of these radomes, as well as similar smaller ones, has provided data that will be useful to others who are working on similar parts.

The large press, the very accurate boring mill, and the other equipment have contributed significantly to the successful development of large, highly accurate radomes. It was fortunate that procurement of this equipment was initiated early in the program, because it takes about a year to build machine tools the size of the press and mill, and it requires almost another year to put them into good running order in a particular plant.

The development of reliable sources for engineering, materials, machine work, and testing is another result of this program. The search for these services is very time-consuming when they are not readily available, and they are very often necessary before even the planning can be started.

The finished designs for five different sets of matched dies and their auxiliary tooling have provided the designers engaged in this program with a vast amount of information on which to base future designs. These five designs have been completely engineered and are ready for fabrication. In fact, much of the tooling has been fabricated and has been checked in actual operation.

Finally, the results obtained by the use of the tooling that has been fabricated and data on the parts that have been manufactured and tested, as well as on the equipment that has been proven by actual use, are contained in reports readily available to those interested. In addition, there are many other reports on the engineering studies that accompanied the design of this large tooling; all are available from the writer.

TABLE I

GENERAL CHARACTERISTICS OF FIVE SETS OF MATCHED DIES

DESCRIPTION	"A" DIES	"B" DIES	"C" DIES	"D" DIES	"E" DIES
Radome Diameter in Inches (Approximate)	24	23	38	24	37
Radome Length in Inches (Approximate)	37	50	83	37	78
Maximum Press Load (Tons)	500	900	2500	225	530
Maximum Average Molding Pressure (psi)	2200	4300	4300	1000	1000
Total Weight of Dies (Tons)	6	8	37	5	13

* Because of the format requirements of this publication, photographs can not be reproduced. Those figures not included here can be obtained by requesting them from the author. A list of these figures and their captions follows:

Figure 1.	2500-ton press	HAC Photo No. S11423
Figure 2.	Vertical boring and turning mill	HAC Photo No. S13336
Figure 3.	Male die detail in handling fixture	HAC Photo No. R34755
Figure 4.	Layup fixture with preform	HAC Photo No. R36157
Figure 5.	Thickness gage on machining mandrel	HAC Photo No. R38527
Figure 6.	Male die assembly	HAC Photo No. R38699
Figure 7.	Female die assembly	HAC Photo No. R38697