LARGE RIGID RADOME DESIGN

By

Hadley F. Morrison

Zenith Aircraft
Gardena, Calif.

Introduction:

It is becoming increasingly apparent that the field of large ground radomes encompasses requirements for rigid radomes. Because of this need, additional emphasis is being placed on the research, development, and evaluation of large rigid ground radomes. It might even be stated that the requirement for mobility which previously restricted the use of rigid radomes is in some instances no longer a serious bar to the use of the rigid radome.

The foremost intent of any radome is to provide protection to the radar antenna with a minimum attendant loss of transmission efficiency. This concept is no less applicable to large ground radomes than it is to airborne radomes. The design variables may differ; however, the net desired result is essentially the same. The evolution of the large rigid radome from preliminary design to final fabrication and test is based upon this prime consideration of high transmission efficiency. However, there are other important design factors which oftentimes are overlooked or are unduly minimized. A successful radome will reflect an honest evaluation and resolution of these many design variables and factors. In fact, it is a design responsibility to insure that the radome complies with these many factors which will result in an optimum design.

Discussion:

Among the factors which dictate optimum design of large rigid ground radomes are: (1) transmission efficiency, (2) service environmental operating conditions, (3) structural integrity, (4) safety of personnel involved, (5) field erection, (6) service operating life, (7) operational maintenance, (8) manufacturing and fabrication, (9) mobility, and (10) unit cost.

The feasibility of designing and manufacturing large rigid ground radomes per the above factors has been demonstrated by the Zenith Plastics Company, as well as various other commercial firms and military research and development centers. The research and development program which resulted in delivery of such a radome (hereafter called the Rome Dome) to the U.S. Air Force was sponsored by the Rome Air Development Center. The general requirements were for an anti-iceable rigid radome which was to be mountable on existing arctic towers. This radome was to be the cover housing for radar set AN/FPS-4 or for radar set AN/TPS-1D. In addition, it was required that the radome be transportable in a C-119 type aircraft. Because the many design factors are so inter-related, it is not possible to discuss them as separate entities. Thus, no attempt is made in this brief discussion to adhere to any specific numerical order such as appeared in the introduction.

The optimum configuration and size of the Rome Dome were selected on the basis of providing a radome which would lend itself to simplicity of design and ease of sectionalizing, transport, and erection. In addition, the radome must provide adequate inside clearances for the assembly of the antenna, must provide clearance between the edge of the antenna and the surface of the radome, and must be mountable on existing arctic towers. The radome configuration finally selected (Figure I) has a hemispherical dome of 10-foot spherical radius which is tangent to and continuous with a 20-foot diameter, five-foot high vertical cylindrical base segment. The resulting height (less lightning rod) is 15 feet. The surface was divided into eight identical peel-shaped side panels of approximately 8' x 18' and one 6-foot diameter circular top cap panel. It is well to note that no particular difficulty has been encountered by the fabricator in handling these panels during test erections.

The selection of materials for the Rome Dome, as with any radome, was dependent upon the integration and assimilation of the many varied design and operating conditions. The basic structural material selected was fiberglass reinforced plastics. This choice was made because of its desirable electrical properties and because it is now a well established fact that fiberglass is relatively maintenance-free. More specifically, the requirements per specification were that it should be fiberglass fabric (not mat) with suitable resins. Because of the anti-icing requirements of the radome and the consequent heat requirements which under certain conditions would render radome skin temperatures above normal, it was decided to use Selectron 5016 resin in combination with types 120, 181, and 182 glass fabric, RS-49 Garan finish. This combination of fabric and resin is relatively economical, is easy to work with, and is structurally reliable at the design heat versus load conditions.

In order to fully appreciate the panel construction it is necessary to note that the anti-icing means selected as best for this job was the use of ducted heated air. In this particular application the heated air flows through passages or channels which are integral with the radome sandwich panel and are adjacent to the outer surface. The final panel construction selected for the transmission area is shown in Figure II. This type of fabrication commonly known as the lost-wax process for radome construction is permitted under license from the Douglas Aircraft Company. The base of the side panels and the top cap panel being outside of the transmission area are respectively honeycomb sandwich construction and thin solid laminate construction as indicated in Figure III. All attach edges and field joints are built-up solid laminate. Typical construction of the vertical field joints is shown in Figure IV.

The final panel construction indicated in Figure II was that configuration deemed best from an electrical transmission standpoint which would still render the necessary structural properties and be functionally adequate from the anti-icing standpoint. Original electrical transmission target was 95%, which served as the basis for theoretical calculations resulting in the sandwich construction shown in Figure II. Recent tests indicate that a transmission efficiency in excess of 90% can be expected through the sandwich of the panels.

The vertical field joints of Figure IV are not desirable from an electrical transmission standpoint (60-70% predicted). Because of the low transmission inherent in this type of joint, studies are currently being directed toward a practical joint design which will allow a maximum transmission with a minimum pattern distortion.

The heat requirements were established by a conservative thermodynamic analysis based on data available at that time. This analysis indicated a net heat requirement of 480,000 BTU per hour. It has since become evident from additional data that the original concepts were probably over-conservative, and in future designs for anti-iceable rigid radomes the governing heat requirement criteria will be adjusted accordingly.

The anti-ice heating system designed for the Rome Dome consisted primarily of (1) an oil-fed burner which is to be located in the radar tower below the second floor, and (2) a circulating system for ducting the heated air to the radome panels and partial return for recirculation. The system is provided with controls for maintaining preset heated air temperature and has safety and limit switches. All exposed hot surfaces have been thermal insulated and moving parts have been provided with protective covers.

The requirement per specification was that this radome should be operable in tropical and desert locations as well as locations of extreme cold. Because of these requirements plus the fact that equipment within the radome should not be operated in ambient temperatures above 125°F, it was necessary to evaluate the potential temperatures within the radome. It was found that outside ambient air must be circulated through the radome walls (normally used for anti-icing air) in order to prevent the ambient air temperature in the radome chamber from exceeding 125°F. This fact was found to be applicable for both the extreme desert and tropical daytime conditions.

It goes without saying that the radome had to be structurally sound. A complete aerodynamic investigation was conducted to arrive at design pressure loads due to the 109-knot wind requirement. Thus with the configuration, loads, and design established a stress analysis was completed. This stress analysis revealed that certain portions of the radome side panels had negative margins of safety. However, in view of the conservative assumptions and method of analysis and of previous experience in radome design, it was the weighted engineering opinion that the radome would withstand the design loadings without failure. The validity of these assumptions and opinions was later substantiated with the successful completion of the static test.

The fabrication means and cost of fabrication are influential factors in making or breaking a radome design. These factors are too often overlooked in preliminary radome design and can result in a finalized production design which is not economically feasible to produce. The previously noted operational factors must in the final analysis be compatible with the means of construction. Among the most common differences existing between desired and practical application is the problem of close tolerances. It is definitely next to impossible to provide the theoretical close tolerances often requested. Or at best, it is not possible to consistently provide extreme close tolerances even with the most precision tooling. The net results often indicate that the closeness of tolerance originally requested was not mandatory for normal radome performance. Had these tolerances been less stringent and more practical, it would have been possible to produce a radome almost as operationally efficient and much more economically efficient. It can easily be seen that because of extreme close tolerances the cost of tooling rises, the actual cost of fabrication rises, the cost of quality control rises, and the rejection rate rises. In addition, all too often each acceptable radome produced has had to be a tailor-made and hand-fit operation. Thus the fabrication and economical factors cannot be discarded in radome design. This becomes especially true when the radome fabricator operates as a subcontractor and must remain competitive with others in the industry.

Specifically, the Rome Dome was developed from a research and development contract which was to reflect a successful radome and in addition was to reflect the development of production tooling. The evaluation of the tooling problem resulted in the selection of molds of cast phenolic tooling resin. This is an economical approach which renders good results over an extended quantity of parts. In the event of high quantity production the molds can easily be duplicated in cast phenolic tooling resin or in permanent metal molds. The type of radome construction was not difficult considering its anti-iceable functional intent. The materials selected for radome construction were easily handled and the tolerances required of parts and tooling were reasonable. The geometry of the radome also lent itself to reduced economics because all eight of the side panels are identical units which can be produced from the same mold.

The requirement for shipping the radome in C-119 type aircraft was beneficial in that the maximum panel size allowed was a size that could be easily handled from an erection standpoint. The only tool required for erection other than the ordinary hand tools and a stepladder was a lighweight erection pole. This erection pole is placed in a tripod-like support position when the first side panel is erected. This pole can be left in position while most of the remaining panels and the top cap panel are installed. Thus the basically monocoque structure is quite stable during the rapid erection.

It is a matter of necessity in any research and development program that the end product has proven itself testwise. Test of the Rome Dome, contractual and otherwise, consisted of electrical panel transmission tests, anti-icing air flow tests, static tests, complete erection tests, and anti-ice air heating equipment tests. The above listed tests were successfully completed at the contractor's facility prior to delivery of the complete radome and related heating equipment to the Air Force. Among the contractor's final recommendations was the recommendation that the radome and related heating equipment be operated under the severe service environmental conditions for which it was designed. It is felt that such operation would be conclusive proof of the feasibility and practicality of this design and, in addition, would render operating data of invaluable nature.

Since the overall program of rigid and non-rigid radome development and use indicates a continued and expanded field of effort, the Zenith Plastics Company has been conducting preliminary design studies resulting in proposals of rigid radomes of varying sizes and functional use. By functional use I intend to convey anti-iceable and non-anti-iceable types.

In studying and proposing these different designs the same basic design criteria have been used that were used in the complete design and fabrication of the original Rome Dome. The exception to this is, of necessity, that more emphasis must be placed on the handling and erection of the larger rigid radomes. This is understandable when one considers that the panel size cannot increase due to shipping limitations; therefore, the quantity of panels for one installation increases approximately as the square of the diameter. As well, erection becomes more of a problem because of the increased distances above the base. In addition to the same basic design criteria, an emphasis has been placed on providing a radome which would tend to be inherently stable throughout the erection period.

The importance of this can be realized when one considers that longer periods of time are quite naturally required to erect the larger radomes. During these longer erection periods the chances of unfavorable or destructive winds arising become more pronounced.

The existing Rome Dome design portends a successful application of the lost-wax process panel construction for ducting heated air in anti-iceable applications. Therefore, a similar approach has been used in the study and proposal of a rigid radome of 55-foot diameter.

The main emphasis relative to rigid radomes seems to be currently pointed toward the non-anti-iceable type; the reason for this being that data compiled by Rome Air Development Center, Lincoln Laboratory, Cambridge Research Center, and others reflects little icing occurring on large radomes. Because of this emphasis, studies have been completed resulting in proposals for 20-foot diameter, 35-foot diameter, and 55-foot diameter solid laminate rigid radomes. In addition, a study is currently being conducted for a 110-foot diameter solid laminate rigid radome. That emphasis is being directed toward the non-anti-iceable type of rigid radome is perhaps timely because of the trend toward larger antenna design. It is easy to see how the complexities of design and manufacture are reduced in the solid laminate type radome.

An additional fact of relative importance in the successful development and design of the larger rigid radomes is the amount of capital expenditure required. It is easy to understand how the complexities of the structural problems are multiplied many times as the size of the radome increases. It is difficult for the low-overhead subcontractor to theoretically evaluate and solve the intricate problems associated with large rigid radome development. Therefore, firm design and development will of necessity be slow unless it is underwritten with firm financial assistance.

Conclusion:

In summary and conclusion, the facts orient themselves in the following manner. The feasibility and practicality of rigid radomes has been established and proven by various fabricators. This contractor has successfully demonstrated this with the Rome Dome, a 20-foot diameter anti-iceable rigid radome.

Because of a continuing and increased need for rigid radomes, further study and development is being accomplished. The successful optimum radome designs as a result of these studies and developments will equitably encompass the many important design variables and requirements.

In addition to proposals by other fabricators, this contractor having successfully completed the full design of a 20-foot diameter anti-iceable radome, has completed the preliminary design of a 55-foot diameter anti-iceable radome. Other preliminary designs completed or near completion are non-anti-iceable rigid radomes of 20-foot diameter, 35-foot diameter, 55-foot diameter, and 110-foot diameter. Future designs will cover radomes of 150-foot diameter and 200-foot diameter. In order to develop these larger radomes it will be necessary to conduct extensive research and development programs aimed at determining methods of structural analysis, determining the electrical effects of various types of joints, and determining the most efficient structural designs without the sacrifice of rapid means of erection.

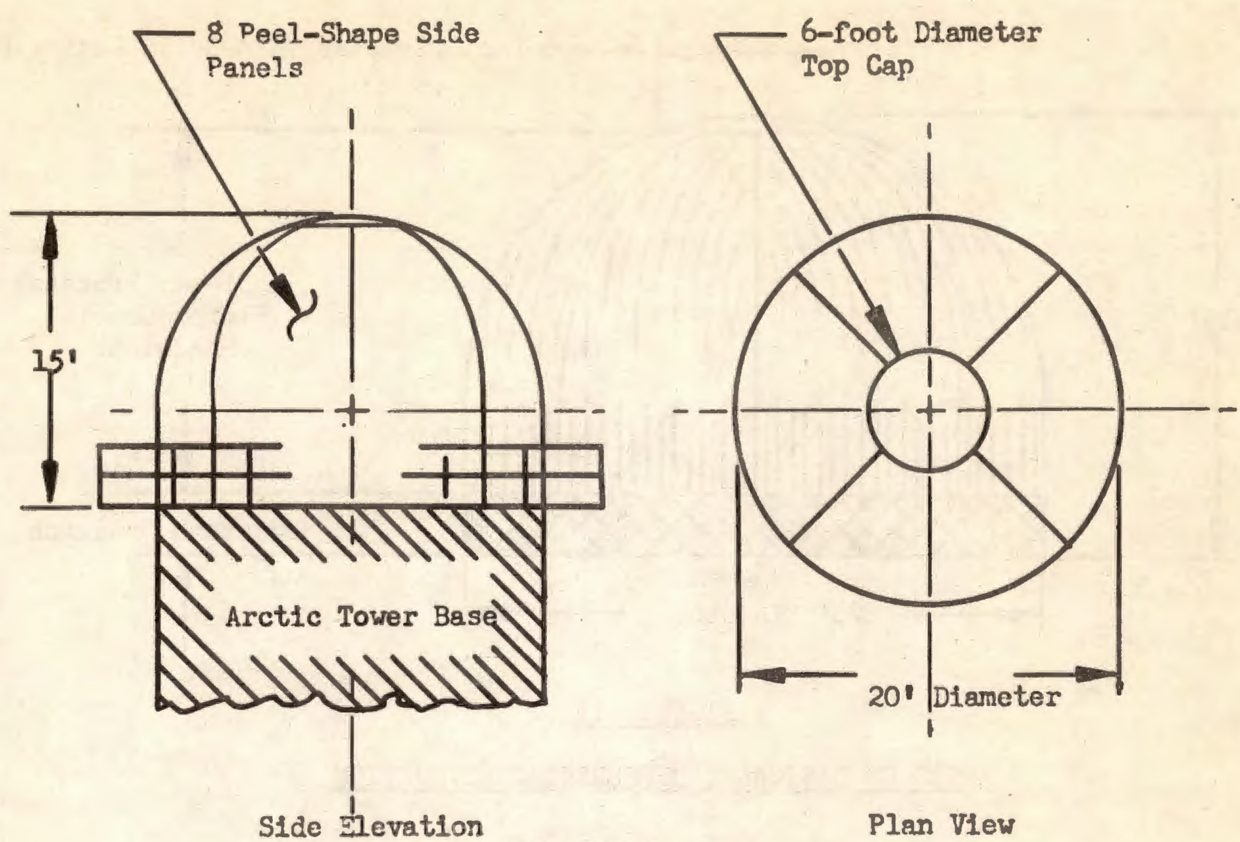

FIGURE I

RADOME CONFIGURATION

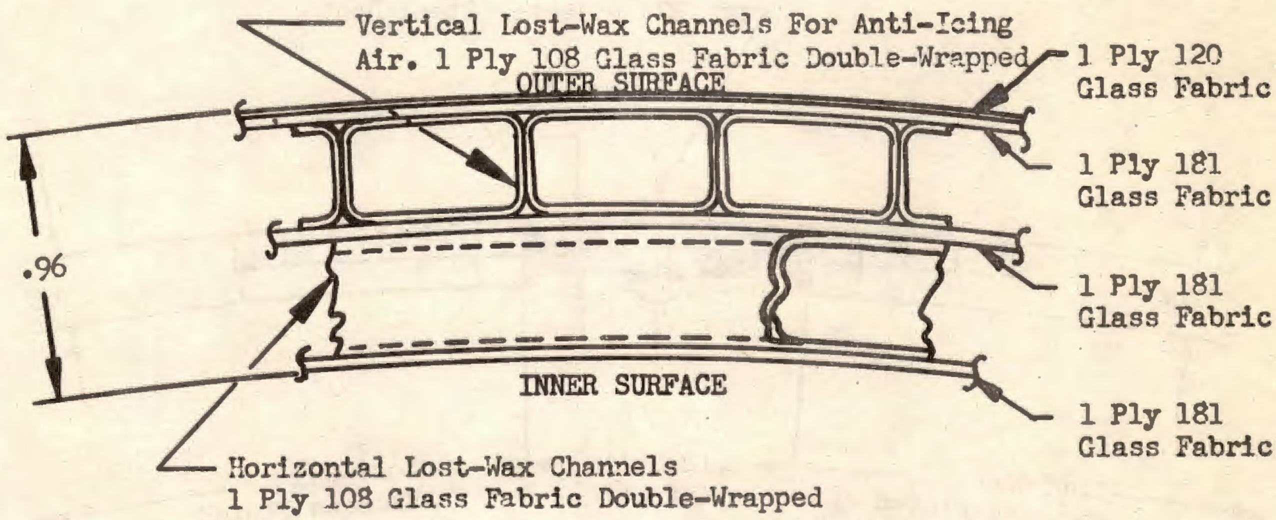

FIGURE II

SIDE PANEL CONSTRUCTION IN ANTI-ICED AREA

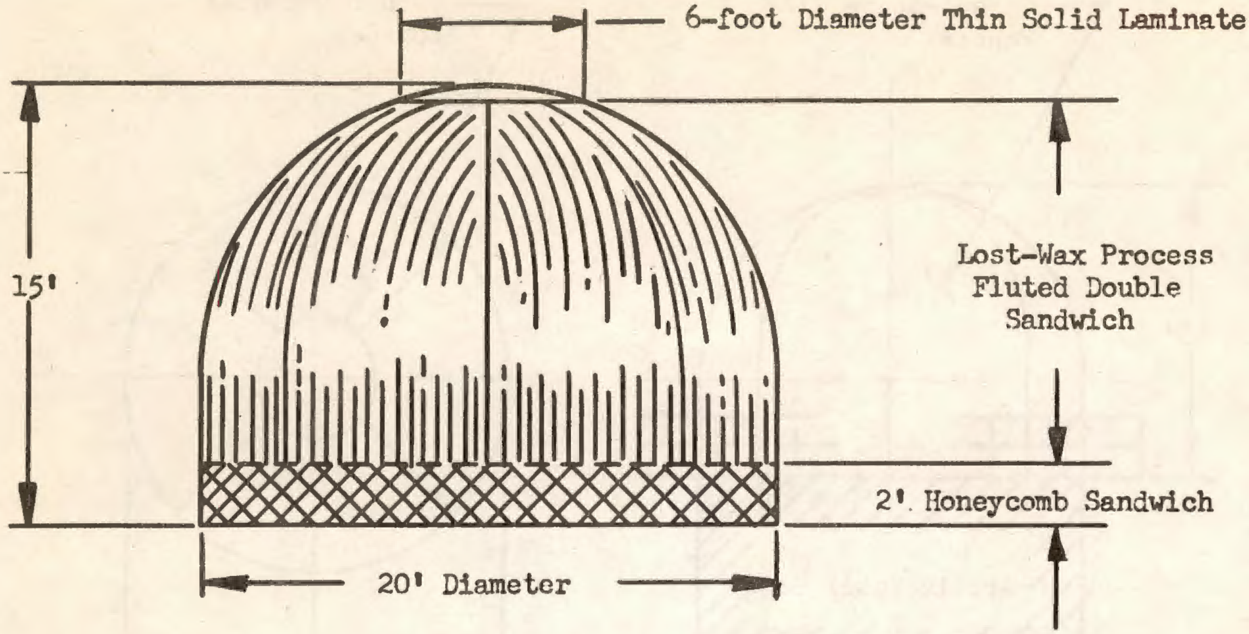

FIGURE III

AREAS OF BASICALLY DIFFERENT CONSTRUCTION

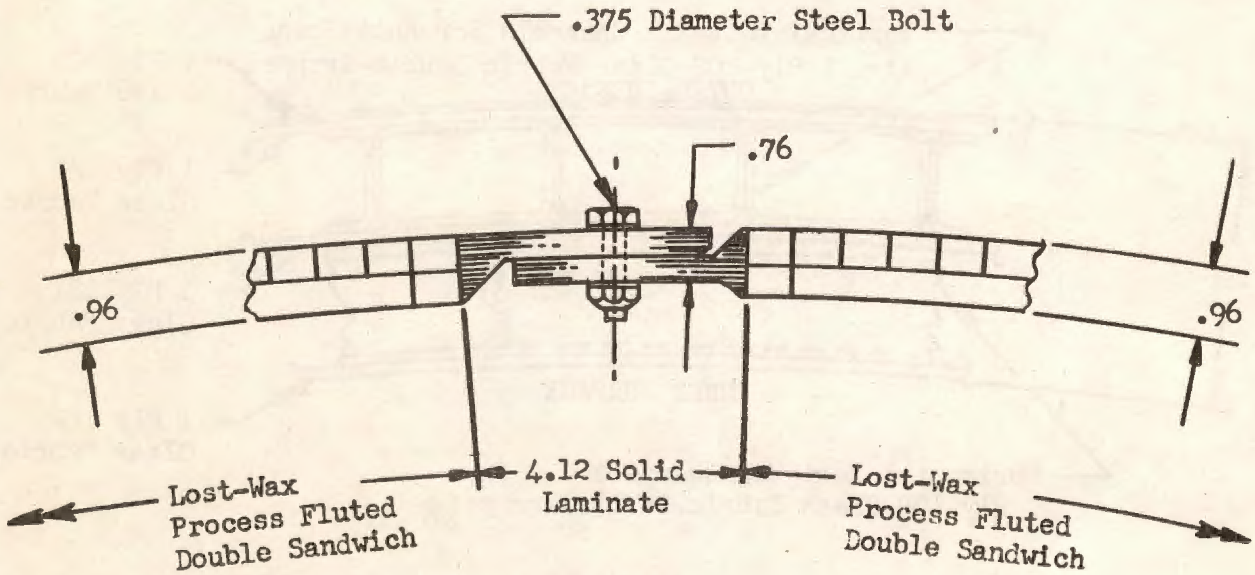

FIGURE IV

TYPICAL VERTICAL JOINT THROUGH TRANSMISSION AREA