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Unclassified

Quarterly Progress Report

*Division 7*

Engineering

15 April 1961

AFESD-TN-61-1010

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY



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*Lexington, Massachusetts*



## INTRODUCTION AND SUMMARY

The Engineering Division provides general engineering services to the Laboratory which include mechanical design, construction engineering and development engineering. In addition, centralized technical services are provided through the Division's drafting room, machine shop, electronics shop and photo laboratory. This report presents a summary of engineering accomplishments made in the first three months of 1961.

Part of the Division's engineering effort is devoted to providing service to other research divisions through the design of mechanical devices, the evaluation of the mechanical aspects of system proposals and the construction of facilities at the Laboratory's far-flung sites. However, a significant portion of the effort is also spent in developing independent programs, such as hardened radomes, and in advancing the state of the art in designing, fabricating, supporting and rotating large antennas. Each of these aspects will be reviewed in detail.

### GROUP 71

The Design Engineering Group has developed a number of small mechanical devices related to the high-power-tube program and to the Laboratory's mobile radiometer, but has spent most of its time on studies for, and the development of, components for large antenna systems.

A preliminary study is under way for the design of a large multielement phased-array instrumentation radar to be used for missile investigation.

Further progress has been made in a program to study metallurgical improvement of rolling element bearing components, and a summary is presented for a recently completed study of the support and rotation of large antenna systems.

### GROUP 75

The Construction Engineering Group's operations during the past quarter were primarily concerned with various portions of the Reentry Physics Program, implementation of the Haystack Hill (Tyngsboro, Massachusetts) field site, construction of several heat exchanger systems, and design of modifications to the Millstone Hill Radar Observatory (Westford, Massachusetts). Structural evaluation of the Haystack Hill antenna is continuing.

### GROUP 76

- Through the cooperative efforts of Groups 71, 75 and 76, the 150-foot-diameter metal space-frame radome for Haystack Hill is approaching its installation stage. This radome, which is the largest in the world, is scheduled for erection within the forthcoming quarter. ●

Basic loading and deflection studies in proportionately sized thin paraboloidal shell antennas are progressing. This computer-oriented investigation is now considering shells with circular boundaries which will typify actual designs.

In the radome hardening program, data reduction of the shock tube results on both foam and metal space-frame model radomes is in process. The objectives for this series of tests were to determine the threshold level and mode of failure, along with other effects on various design types.

The first phase of the TTR (Target Tracking Radar for the Nike-Zeus system) radome experimental feasibility study to provide preliminary data on optimum geometry has been completed. A choice of geometry has been made which is based on the results from antenna pattern tests and bore-sight shift measurements. Final test models are being constructed in which metal member cross section and dielectric membrane thickness will be consistent with the 2-psi overpressure structural requirement.

A 55-foot-diameter metal space-frame prototype radome is being procured and will be tested both structurally and electrically in order to correlate data with that from model test results. This structure should be erected by midsummer 1961.

In the materials and processing category, measurements of the density profiles are being continued for assistance in improving the uniformity of foam for use in radomes and interpreting foam model behavior from the shock tube tests.

15 May 1961

J.A. Vitale  
Division Head

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# PUBLISHED REPORTS OF AUTHORS FROM DIVISION 7

15 January 1960 through 15 April 1961

## Journal Articles\*

JA No.			
1616A	First Aid for a Giant Bearing	D. Regillo	Am. Machinist/Metalworking Mfg. (20 March 1961)
1685	Measuring REALLY Large Diameters	C. A. Pappas	Am. Machinist/Metalworking Mfg. (6 February 1961)
1703	The Lincoln Laboratory Antenna Test Range	A. Cohen A. W. Maltese	Microwave J. <u>4</u> , 57 (1961)

## UNPUBLISHED REPORTS

### Meeting Speeches†

MS No.			
48	Large Radomes for Wide Band Application	A. Cohen A. W. Maltese	OSU-WADC Symposium, Ohio State University, June 1960
68	Design and Fabrication of Large Foam Radomes	S. C. Nilo P. Davis	Soc. Plastic Eng., Bethpage, L. I., April 1960
153	Application of Thin Shell Theory to Antenna Design	P. Davis	ASME Meeting, New York, November 1960
181	Stoichiometry of Copper Bonding Using Copper Oxide	E. B. Murphy T. P. Turnbull	American Electroplater's Society, Boston, 18-23 June 1961
222	Ground Rigid Radomes	A. Cohen	Antennas & Propagation Meeting, M. I. T., 5 April 1961

\* Reprints available.

† Titles are listed for information only; no copies are available for distribution.

# DESIGN ENGINEERING GROUP 71

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# DESIGN ENGINEERING GROUP 71

## I. INTRODUCTION

The efforts of the Design Engineering Group during the past quarter have been extremely diversified, and range in scope from studies and development of components for large antenna systems to the design and development of small mechanical devices pertinent to the various Laboratory programs.

Continued interest is being shown in the operating life of various mechanical components at the Boston Hill (North Andover, Massachusetts) experimental radar Mark I, now under the jurisdiction of the MITRE Corporation. Also of particular interest is the mechanical operation of the AN/FPS-31 radar at Jug Handle Hill (MITRE Corporation site at Bath, Maine) and especially the effect of minor repairs on the azimuth bearing which were undertaken last fall.

A preliminary study is under way for the design of a large multielement phased-array instrumentation radar to be used for missile investigation.

Engineering liaison has been provided for the work at North American Aviation, Incorporated, Columbus Division, the designated contractor for the Haystack Hill antenna system, where fabrication of a 1/15-scale structural model is in the final stages.

Further progress has been made in the metallurgical improvement of rolling element bearing components, and a summary is presented for a recently completed study of the support and rotation of large antenna systems.

Assistance has been given to Group 76 in the modification of equipment at the antenna test range. Extensive design and development efforts on components for the mobile radiometer and for the high-power-tube program have been undertaken.

Detailed accounts of these and other activities follow.

## II. EXPERIMENTAL RADAR MARK I AT BOSTON HILL

Operating time for this quarter was only 74 hours and 17,023 revolutions, for a total of 1651 hours and 348,489 revolutions since the system was turned on in August 1958. During the winter, the antenna has been subjected to several snowstorms and winds up to 80 mph. Following each storm, the antenna has been thoroughly inspected and has been found in excellent condition.

Service and maintenance functions have been accomplished according to schedule, and have resulted in very satisfactory performance of the entire system, including all structural, mechanical and electromechanical components.

C. A. Pappas

## III. AN/FPS-31 RADAR AT JUG HANDLE HILL

Operation of the AN/FPS-31 radar at Jug Handle Hill was routine during the past quarter. Performance of the mechanical components of this radar, particularly the azimuth bearing, is of interest to the Design Engineering Group, which originally installed this bearing in 1956 as a support modification to the radar. A minor repair on the outer race of the bearing was accomplished last fall by MITRE Corporation personnel under Lincoln Laboratory supervision; periodic subsequent inspection of this area has disclosed no new deterioration. These same inspections reveal that satisfactory conditions prevail on the other previously repaired areas of the

ances. As of 10 March, the bearing had accumulated 7812 hours and 2,297,776 revolutions since the major repair and turn-on in January 1957, and is operating smoothly. In the past quarter, the bearing has averaged 45-hours/week running time.

D. A. Regillo

#### IV. PHASED-ARRAY INSTRUMENTATION RADAR

A preliminary study has been undertaken, in conjunction with the Special Radars Group, to ascertain basic parameters relative to the design of a phased-array instrumentation radar system. This system will ultimately be used to further investigate the multibody reentry problem.

Initial concepts indicated a land-based, multiple-element stationary array. Figure 71-1 shows a model of a partial section of this type of array. Basically, it comprises a large ground plane, possibly 40 to 60 feet square and inclined at a 45° angle, to the rear of which are mounted 4096 square boxes, 3 feet in length, arranged rectilinearly. Each of these boxes contains a removable electronic package complete with dipoles that protrude through the ground plane when in the installed position. All cabling and cooling hoses are attached at the rear of the packages to facilitate servicing and maintenance. A suitable structure is provided for the support of the above-mentioned components. For a complete system, two arrays are contemplated; one for transmitting, and one for receiving.



Fig. 71-1. Partial model of a typical phased-array antenna.

Although Fig. 71-1 shows an array that is fixed in position, it is highly possible that two steerable arrays might be considered for mounting on board ship.

E. A. Davidson

#### V. HAYSTACK HILL ANTENNA SYSTEM

The Haystack Hill antenna contract at North American Aviation, Incorporated, has proceeded in two areas: (a) engineering and design of the antenna system, and (b) design and fabrication of the 1/15-scale structural model.

The antenna system engineering and design effort has included the development of the reflector and its backup structure, the azimuth hydrostatic bearing assembly, and the azimuth and elevation drive assemblies. Specifications and control drawings were completed and forwarded to prospective vendors for fabrication of the azimuth hydrostatic bearing assembly and the gear boxes for the azimuth and elevation drives. The design effort is approximately 47 per cent complete.

IBM computer programs for space-frame structural analysis are just about complete for the face-up and face-side deflections of the reflector backup structure, using loads distributed over the structure to simulate the reflector surface weight. When this program has been completed, a final program describing the interaction of the integral shell and backup structure will be carried out. The design of the 1/15-scale structural model is finished and approximately 65 per cent of the parts have been fabricated. Plans call for completion during the first week in April, with testing to begin immediately thereafter.

F. A. Folino

## VI. SUPPORT AND ROTATION OF LARGE ANTENNA SYSTEMS

### A. Kaydon Engineering Corporation

The subcontract with Kaydon Engineering Corporation, on the study of the support and rotation of large antenna systems, expired last quarter with the acceptance of Kaydon's final report on the project. This report covers the entire program, which ran from May 1959 to November 1960, and consists of two parts: (1) theoretical analysis and (2) practical design procedures.

The theoretical portion of the program investigated a new approach to bearing load analysis. Heretofore, the usual analysis of bearings assumed rigid races and supports. On this premise, bearing load and life were based on the local Hertzian stresses at the most heavily loaded ball. Small bearings that are normally used on heavy, solid shafts and very stiff housings can utilize this approach, since the press fits with the races produce the effect of rigid races. However, very large bearings, on the order of 10 to 15 feet in diameter, are quite flexible and infinite rigidity of their housings cannot reasonably be assumed. The report attacks the problem of large bearing analysis by assuming elastic behavior of the races and their supports. A general set of equations for a thrust bearing analysis is derived. These equations can handle unequally spaced loads, balls and reactions. When elasticity is thus introduced in the load analysis, the critically stressed volume element in a race ring carries normal and shear stresses in addition to the localized compression (Hertz) stress. The report proposes a method that would involve the critical volume element in the region adjacent to the heaviest load ball, taking into account not only the usual Hertzian contact stresses but also the tensile, shear and torsional stresses present in the races due to their elastic behavior. Once the applied stress system on the critical volume element is calculated, appropriate failure criteria can be applied. Some of the theories considered are:

- (1) Maximum principal stress theory,
- (2) Maximum shear stress theory,
- (3) Maximum energy theory, etc.

The best corroboration of this theoretical analysis would be actual testing of large bearings. However, since these bearings are very costly and few in number, and their typical present installations in radar antennas do not necessarily require continuous running, some other test procedure should be devised.

The report then makes a comparison between several large bearings and Kaydon's line of Reali-Slim bearings. The "stiffness" of each group of bearings is calculated for the radial and transverse directions, and the comparison reveals that the large bearings have the same order of magnitude of stiffness as that of the Reali-Slim line. Consequently, life testing of Reali-Slim bearings may offer a practical verification of theoretical analyses on bearings that are considered sufficiently flexible to react as elastic bodies.

The theoretical portion of the report presents a good first approach to the field of elastic analysis of large bearings. Future work along these lines would expand the established equations to include other types of bearings, and combinations of load to include radial and moment forces.

The design procedures work of the subcontract was based on present knowledge concerning rolling element bearings. Typical procedures of bearing type selection and load analysis are computed and illustrated. The effects of load eccentricity, ball spacing, bearing type, race conformity, race segmenting, etc., on bearing static and dynamic life, are analyzed and finalized in equations and nomograms. In addition, one can determine the manufacturing tolerances that must be met for races and housings in order that the system satisfy a minimum requisite life. Included are surveys of manufacturers and their facilities which disclose the capacity of the industry to handle large bearings, and its ability to meet close tolerance requirements. It appears from these surveys that the existing know-how and equipment for fabricating, shipping and handling large bearings place a size limitation of about 25½ feet in diameter for one-piece ball and roller bearings. The limit for segmented-race ball bearings is about 55 feet, whereas roller bearings are practically unlimited. The greatest limiting factor for a one-piece ball or roller bearing is the manufacturers' capacity to produce continuous rings, whereas machining capacity limits the segmented-race sizes for ball bearings only with respect to the shaped ball path which requires special machines, as compared with the flat surface roller paths which can be handled with portable equipment and jigs.

The report is sufficiently comprehensive to allow a wide selection of bearing designs to meet the service demands of practically all types of loading encountered in large radar installations.

#### B. Alloy Corporation

Work continues on the study and test program for the specific materials used in rolling element bearings. Studies on the effects of a long, posttemper draw (120 hours in oil at 360°F) on the retained austenite content and hardness of 52-100 were completed. The temper employed was 385°F for one cycle of two hours. The draw showed a marked reduction in retained austenite with little drop in hardness. This new draw effect, however, applies only to 1-inch diameter and smaller balls (of 52-100) for which nearly uniform hardening seems possible. This technique can best be utilized in instrument bearings.

In the testing phase of the program, further tests on the 1½-inch-diameter balls of 52-100 content are being conducted. The delayed procurement of the M2 balls from Industrial Tectonics, Incorporated, has resulted in a much delayed start on the testing phase for M2 balls. The total order consists of 200 balls each of the ½-, 1- and 1½-inch-diameter sizes. Initial testing has begun on the six ½-inch M2 balls received. For this small statistical sample group, life tests have indicated a life of 5 to 10 times greater than similarly loaded ½-inch 52-100 balls. Further tests on a greater number of ½-inch M2 balls will supply more substantial data. The testing of 1-inch diameter M2 balls has also started.

D. A. Regillo

## VII. SEMIAUTOMATIC MAGNETIC FILM DEPOSITING DEVICE

The operation of this device, described in the Division 7 Quarterly Progress Report [U] of 15 July 1960 (ASTIA 221707), although limited at this writing, has proved quite satisfactory. Approximately ten complete runs have been undertaken and it appears that the yield of acceptable substrates is slightly better than 50 per cent. This is a normal figure for this type of operation. However, the main advantage of the machine is the improved production rate of substrates over previous methods, rather than improved quality.

Since this unit is still a research prototype, refinements are continually being made in an effort to increase the quantity of acceptable substrates per run. A new conical-shaped crucible and induction coil have greatly improved the characteristics of the deposit. Also, a magnet placed near the crucible area has decreased the amount of troublesome corona present. A new monitor is now being developed to permit a more precise indication of the amount of deposit on each substrate.

E. A. Davidson

## VIII. HIGH-POWER-TUBE PROGRAM

### A. High-Power and Bias Collector Tubes

As reported in the last quarterly progress report, Group 71 is assisting the Radar Transmitter Group (48) in mechanical component construction for the XT-455 tube and the bias collector tube. Photographs of parts for the bias collector tube are shown in Figs. 71-2 through 71-4. An electric bakeout oven shown in Fig. 71-5, originally purchased for the bias collector tube, is also being used to bake out the XT-455 tube. This oven, which is an assembly of five individual units, is capable of maintaining temperatures up to 450°C.

In order to clean parts for the bias collector tube, a dry hydrogen atmosphere at 1200°C is required. The task of building the deep pit oven 27 inches square and 32 inches deep was accomplished by the Vacuum Tube Engineering Group (24). This oven has attained temperatures of 1200°C and is currently used to clean components for the above tube. Each of the components is fired in the retort shown in Fig. 71-6.

The design of a magnet support and positioner for the omegatron of the XT-455 tube has been completed and is currently being constructed at the Laboratory. This support and positioner will enable an 80-lb magnet to be moved in the x-, y- and z-directions, and rotate about its own x-axis.

A. M. Rich

### B. L-Band Tuner for Resonant Ring

In this quarter, the L-band tuner was delivered to Group 46 for preliminary electrical testing. The tuner, shown in Fig. 71-7, is to be used in the resonant ring assembly.

The function of this unit is to adjust and maintain accurately the included volumes ahead of each plunger as shown in Fig. 71-8. This is accomplished by axially moving the four specially designed double plungers within the  $3\frac{1}{4} \times 6\frac{1}{2}$ -inch cast aluminum waveguide. Individual controls have been provided to move and adjust the plungers in three steps:

- (1) Plungers 1 and 2 move together and may be positioned within  $\pm 3\frac{1}{2}$ -inch limits of center position.
- (2) Plungers 3 and 4 move differentially and may be positioned within  $\pm 1\frac{3}{4}$ -inch limits of center position.
- (3) All four plungers are moved together and may be positioned within  $\pm 3\frac{1}{2}$  inches of center.

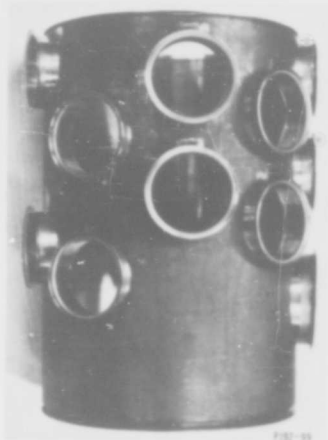


Fig. 71-2. Outer shell showing standoffs in position.

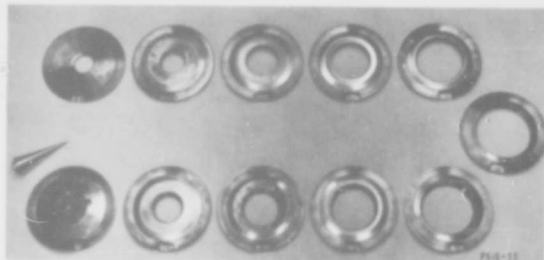


Fig. 71-3. Collector rings.

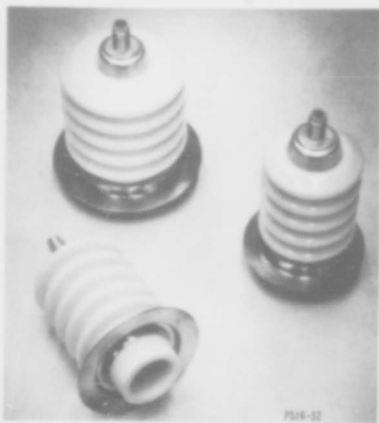


Fig. 71-4. Ceramic insulators for insertion in outer shell.

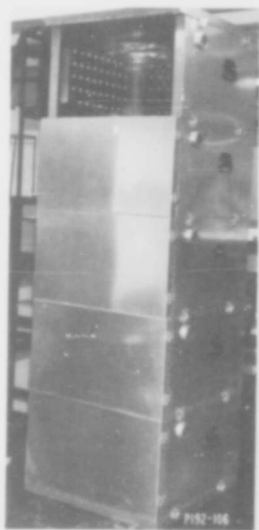


Fig. 71-5. Vertical oven for use in bakeout of high-power tubes.

Fig. 71-6. Retort for cleaning of components in deep pit furnace.

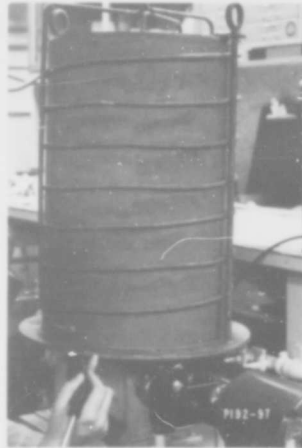


Fig. 71-7. L-band tuner.

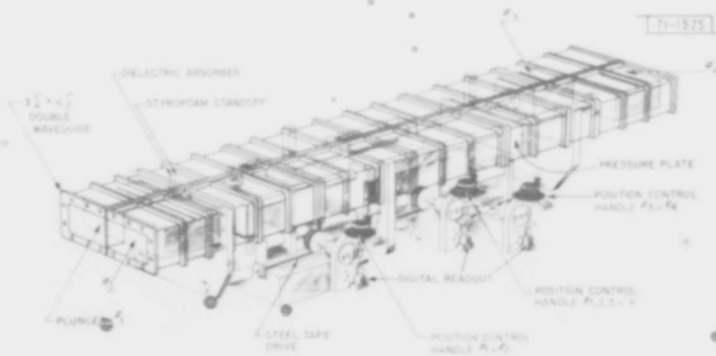
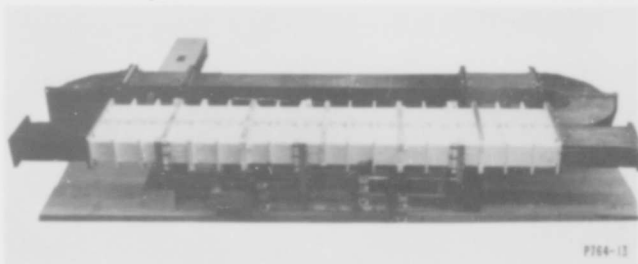


Fig. 71-8. L-band tuner (diagrammatic sketch).

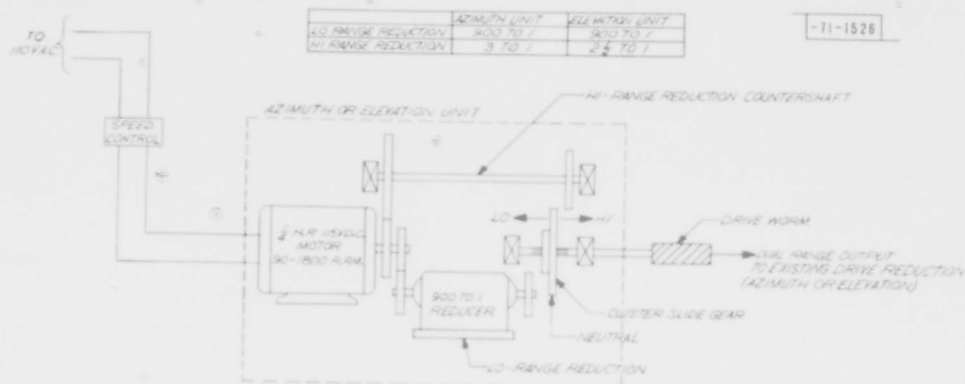


Fig. 71-9. Schematic of antenna drive modification (mobile radiometer).

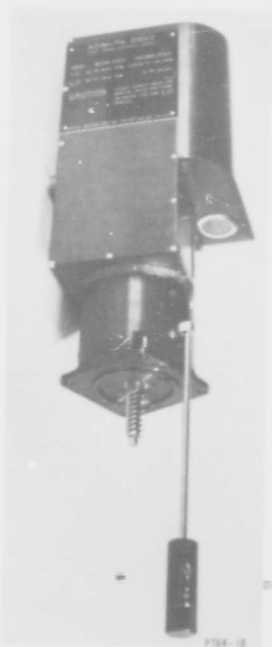
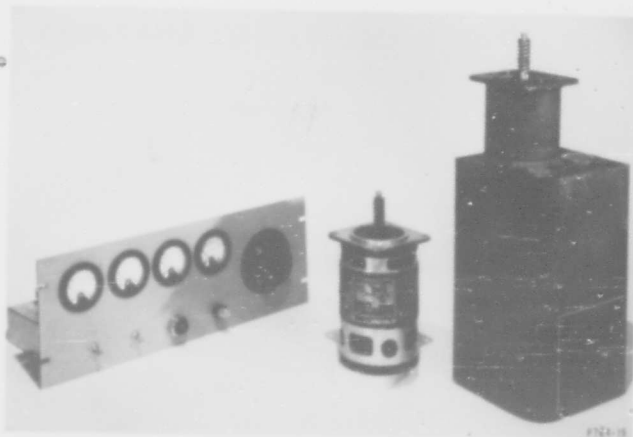


Fig. 71-10. Azimuth drive unit assembled prior to installation in drive turret. Rod at lower right switches between high and low ranges. Worm at output end engages existing turret azimuth drive reduction.

Fig. 71-11. Assembled elevation drive unit at right, original elevation drive motor to be replaced at center, and power supply for the new drive unit at left.



To provide the above linear motions, the design approach used was to cantilever the plungers from brackets and then mount the brackets on parallel rods.

The tuner was designed, manufactured and assembled to meet the following requirements:

- (1) During step 1 there is to be no relative motion between plungers 1 and 2; during step 2, the motion of plungers 3 and 4 must be precisely equal and opposite, with no "backlash" during reversal; and in step 3, there is to be no relative motion between plungers 1, 2, 3 and 4. The above was accomplished with a drive control arrangement by means of steel tapes.
- (2) A digital readout is used to indicate approximate plunger positions and to facilitate position repetition.
- (3) By using the digital readout, in any of the three steps, a turn of the control handle will move the plungers 0.050 inch.
- (4) Vertical orientation of the tuner in the system necessitated counterbalancing of the sliding assemblies. This was done with "Negator" constant force springs.
- (5) The plunger area within the waveguide may be pressurized to 30 psi.
- (6) The plungers are required to follow the actual center line of the waveguide within  $\pm 0.005$  inch with no rotation. This was done by maintaining very close tolerances and clearances during machining, alignment and assembly.

C. A. Pappas

## IX. MOBILE RADIOMETER

### A. Status of Cryogenic Components

At the inception of the radiometer trailer, plans were made for a cryostat to be incorporated in the receiver system. Changes in scope have eliminated the need for a closed-cycle cryostat in this particular application. However, work on the system did not cease, since there is a definite need for a closed system to furnish 4.2°K temperatures for maser component evaluation. On 1 March tests were conducted at Air Products, Incorporated, to prove that the unit adheres to the original specifications. Further system improvements are necessary and work is continuing at the vendor's plant.

A. M. Rich

### B. Status of Drive System Modification

Fabrication of the drive system modification units has been completed and the units assembled in the drive turret. The system modification comprises two separate drive units, one for the elevation drive and the other for the azimuth drive. Figure 71-9 illustrates the schematic layout of the basic parts of each unit. These units, when coupled to the existing reductions in the turret, provide the following system speeds.

Range	In Azimuth		In Elevation	
	Motor Speed	Antenna Speed	Motor Speed	Antenna Speed
HI	90 to 1800 rpm	0.069 to 1.39 rpm*	90 to 1800 rpm	0.055 to 1.4 rpm
LO	90 to 1800 rpm	5 to 100°/hour	90 to 1800 rpm	3.3 to 65.9°/hour

Figure 71-10 shows the assembled azimuth unit ready for mounting in the drive turret. The elevation drive unit is shown in Fig. 71-11. Next to it is the original elevation drive turret motor which it replaces. The control for the new unit is shown at the left.

\* Correction over previously published speeds.

The covers on both units are easily removed for periodic inspection and maintenance without removal of the units, thus allowing surveillance of the drive unit components under running conditions. Both elevation and azimuth manual drives are still retained.

D. A. Regillo

### C. Status of Mechanical and Structural Modifications

The program of redesigning and modifying the mechanical and structural portions of the mobile radiometer is continuing, with approximately 75 per cent of the work completed.

The following components have been redesigned and are being fabricated:

- (1) The Turret Support Structure is now a cylindrical configuration which provides a more rigid mount for the turret assembly. Close tolerance machined ends permit accurate alignment of the turret, azimuth bearing and drive gear. Changing from a rectangular support to the present configuration allowed a 10-inch shortening of the two reflector support rods, permitting a removal of 125 lb of counterweight.
- (2) The Reflector Support Structure is a rigid rectangular frame fabricated from 3-inch aluminum channels. The two reflector support rods, mounted on the turret gun slides, are made of solid aluminum alloy for stiffness.
- (3) The K-24 Camera is mounted to photograph over, but parallel to, the axis of the reflector. The camera and its mount are removable during transit of the trailer.
- (4) The Special Feed Horn and associate parts were adapted for mounting on the reflector. The design permits 90° rotation of the horn about the polarization axis.
- (5) The Turret Lift and Stow Mechanism has been completely revamped to provide improved stability and safety during operation and in the stow positions.
- (6) Floor Gratings are being installed on the trailer roof to provide firm footing and access to the reflector and camera for adjustment, service and maintenance.
- (7) Additional rework is being done to structurally reinforce the trailer, remount the data takeoff units and weatherproof the Plexiglas dome.

C. A. Pappas

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# CONSTRUCTION ENGINEERING

## GROUP 75

### I. INTRODUCTION

The major programs involving the Construction Engineering Group during the first quarter of 1961 were reentry physics and the Haystack Hill installation. In addition, a modification to the Millstone Hill Radar Observatory complex and several heat exchanger systems within the Laboratory at Lexington required significant staff effort.

The reentry physics work was the most extensive in number of jobs and in total dollar cost. During the quarter the optical testing laboratory at the Lexington Field Station was substantially completed, a camera house at the Arbuckle Neck field site was modified, and designs were prepared for a new camera house near Eastville, Virginia, and a building to house the 48-inch telescope at Arbuckle Neck.

Structural evaluation of the Haystack Hill radome is complete, the base plates are to be set early in April. Evaluation of the antenna design is continuing. Design of office and laboratory facilities has been started.

A new capacitor house has been designed for the Millstone Hill Radar Observatory, to permit adding a new L-band transmitter to the installation. Design studies are currently in progress for a 220-foot zenith-looking fixed antenna for ionospheric probe studies. This work will be reported in detail in the next quarterly progress report.

The design and installation of heat exchanger and controlled climate installations within the Laboratory has continued to occupy a major portion of the effort of the mechanical engineering section.

### II. REENTRY PHYSICS PROJECTS

Reports of progress in the Reentry Physics program are reported in detail separately to the Advanced Research Projects Agency. An outline of recent Group 75 work is given here to acquaint others with certain problems and their solutions. Each of the four jobs in progress involves installations of optical equipment, and each requires a method of moving a roof structure to permit camera work in good "seeing" weather.

#### A. Optical Testing Laboratory, Lexington Field Station

The optical testing laboratory is designed to provide operational checkout facilities for the 48-inch spectrometric telescope adjacent to the Laboratory before it is installed at Arbuckle Neck for use in connection with reentry bodies launched from Wallops Island. The building is of masonry construction, 76 feet long by 30 feet wide. The long axis of the building runs true north and south to properly orient an interior line of sight with Polaris. The telescope section of the building is 30 feet square, two stories high, with a rolling roof. The basement houses a generator room, telescope support pedestal and access to the mount drive. The upper floor provides access to the optics and controls, and connects directly to the office and laboratory facilities. The roof over the telescope consists of corrugated aluminum siding on a structural steel frame, rolling on a track system to provide a clear opening. Figure 75-1 shows this assembly. The telescope section is unheated to properly maintain the optics at ambient conditions.



Fig. 75-1. Rolling roof system, optical testing laboratory.



Fig. 75-2. Laboratory space, optical testing laboratory.



Fig. 75-3. General view of camera house, Arbuckle Neck.

The remaining portion of the building includes offices, mechanical and electrical shop space, washrooms, a boiler room and an unheated optical tunnel for boresight calibration of the telescope. Figure 75-2 shows a portion of this space.

Power is supplied at 2400/4160 volts, transformed to 120/208 volts in a substation adjacent to the building. Transformer capacity is 75 kva.

The office section of the building was occupied in mid-March 1961. The remainder of the building is scheduled for completion early in April, and site work, including paving an access driveway, will be done as soon as ground conditions permit.

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#### B. Camera House, Arbuckle Neck Field Site

The camera house at Arbuckle Neck was built in two stages. The first was an equipment room to house two Super Schmidt meteor cameras and other instrumentation; this consists of a concrete slab on grade, camera support piers, and 5-foot-high concrete block walls. The second stage provided a darkroom, a photographic reduction room and a rolling roof over the camera equipment room. Recent revisions have included motorizing the roof drive and additional power capacity for another instrument. Figure 75-3 shows the completed installation.

J. B. Paddleford

#### C. Camera House, Eastville, Virginia

A similar camera house is presently under construction adjacent to a SAGE communications facility near Eastville, Virginia. This installation is also being built in two stages, with the first step concerned with having the camera support piers ready in time for an early reentry vehicle launching; a later order will be issued to provide for construction of the office and the rolling roof system. The roof for this house will consist of a multiplate corrugated steel arch assembly on a light steel frame; this structure gives promise of providing more enclosed volume at less cost and weight than the wooden frame structure at Arbuckle Neck. Completion of the camera house is expected within the second quarter.

J. B. Paddleford

#### D. Telescope House, Arbuckle Neck Field Site

Following operational checkout at the Lexington Field Station, the 48-inch spectrometric telescope will be installed in a new building at Arbuckle Neck. This facility is currently being designed and construction is planned to start during the second quarter of 1961. The building will be separated into two areas, for the telescope and for office and laboratory support. The telescope area will be two stories high, of reinforced concrete construction, with a sliding roof of plywood panels on steel framing. The building is designed for conversion to a rotating astronomical dome if this becomes desirable in the future. The laboratory wing will be two stories high, of concrete block construction. Over-all size of the facility will be 36 feet wide by approximately 74 feet long.

Other than the sliding roof system, the major structural problem with this installation is concerned with the foundations. Test borings have been taken and indicate an 8-foot thick sand lens approximately 20 feet below grade, underlain by a soft silt to approximately 100 feet below grade. Preliminary foundation design calculations indicate that piling driven into the upper sand

GROUP 75

bearing layer will be satisfactory to carry the vertical and torsional loads due to the telescope. Since stability for the telescope is of primary importance, however, several factors remain to be checked before final plans are prepared.

Power will be provided by a new 150-kva substation served by the NASA primary line. The laboratory space will be air conditioned to provide proper climate for electronic apparatus. Construction will start near the end of the second quarter.

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DEVELOPMENT ENGINEERING  
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# DEVELOPMENT ENGINEERING

## GROUP 76

### I. INTRODUCTION

Through the cooperative efforts of Groups 71, 75 and 76, the 150-foot-diameter metal space-frame (MSF) radome for Haystack Hill is approaching its installation stage. This radome, which is the largest in the world, is scheduled for erection within the forthcoming quarter.

Basic loading and deflection studies in proportionately sized thin paraboloidal shell antennas are progressing. This computer-oriented investigation is now considering shells with circular boundaries which will typify actual designs.

In the radome hardening program, data reduction of the shock tube results on both foam and MSF model radomes is in process. The objectives for this series of tests were to determine the threshold level and mode of failure, along with other effects on various design types.

The first phase of the TTR (Target Tracking Radar for the Nike-Zeus system) experimental feasibility study to provide preliminary data on optimum geometry has been completed. A choice of geometry has been made which is based on the results from antenna pattern tests and boresight shift measurements. Final test models are being constructed in which metal member cross section and dielectric-membrane thickness will be consistent with the 2-psi overpressure structural requirement.

A 55-foot-diameter MSF prototype radome is being procured and will be tested both structurally and electrically in order to correlate data with that from model test results. This structure should be erected by midsummer 1961.

In the materials and processing category, measurements of the density profiles are being continued for assistance in improving the uniformity of foam for use in radomes and interpreting foam model behavior from the shock tube tests.

### II. RADOME DEVELOPMENT

#### A. Status of the CW-412/FPS Radome

All phases of the CW-412/FPS 150-foot radome program are proceeding satisfactorily and on schedule. No problems are foreseen at this time which could delay the schedule date of 15 May 1961 for the start of the MSF radome erection on Haystack Hill.

All radome metal parts, excluding the radome extension, are completed and crated. The hubs, cap strips, base angles and hub caps of the radome extension are ready for shipment, with the remaining items to be completed by mid-April 1961. The reinforced plastic membrane fabrication is practically complete; painting, installation of seals and crating of panels will be completed by the latter half of April. The erection equipment has been test assembled and has passed contractor load tests on the West Coast.

Instrumentation of the 1/15-scale model at Stanford University is complete, and the results indicate that more uniform tightening of the bolts is desirable. Static testing is scheduled to begin during the next quarter. When the static testing is completed, the fiberglass skins will be installed, and it is expected that the model will be wind-tunnel tested in May 1961.

### B. 55-Foot-Diameter MSF Radome

Since the last report on this project,<sup>1</sup> a few minor changes were made in the design of this radome. The frame material for the base panels was changed from the 1/2 inch wide by 2-1/2 inches deep AISI C 1020 steel to the 7/16 inch wide by 1-3/16 inches deep low-carbon high-strength alloy steel which comprises the remainder of the radome frames. The membrane material is now specified as 0.010 inch thick polyester glass cloth laminate, made of two plies of No. 116 glass cloth reinforcement laminated with Hetron 32A resin. Finally, the adhesive for the bonding operation has been changed to Epibond 1210. The pretreatment operation specified previously has been eliminated, since the new adhesive requires only a solvent wipe of the metal parts before application.

During this quarter, it was decided to procure a prototype radome for full-scale structural and electrical testing. Since the radome procurement can be divided into the fabrication of metal parts and the bonding operation, bids were solicited on this basis from local firms that are qualified to handle each phase. All bids have been returned and evaluated, and purchase orders placed. The delivery date for the completed radome parts is scheduled for 30 July 1961.

This procurement will make available a prototype radome with large bandwidth capabilities. Electrical performance data obtained with a model of this radome indicated that transmission efficiencies of at least 85 per cent can be expected in the S- and C-band frequency regions.<sup>2</sup> Measurements made with a 50-foot-diameter model indicated that the transmission efficiency did not change appreciably at the X- and K<sub>a</sub>-band frequency regions<sup>3</sup> and that the one-plane radome boresight shift is of the order of 0.2 milliradian. All tests indicated that, on the average, there were no changes of antenna side-lobe levels at the 20-db level, 1-db increases at or about the 26-db level and 3-1/2-db increases at or about the 32-db level. (All side-lobe levels are relative to the peak intensity of the main lobe.)

### C. Radome Hardening Program

The radome hardening program includes a semiempirical study involving static and dynamic testing of radome models. The objective of this investigation is to establish structural design parameters for blast-resistant radomes. An important phase of this study includes tests on radome models made from polyurethane foams which include a range of densities and R/t values. In the last quarterly progress report, a static test of a 10-pcf polyurethane foam shell was described.

During the current reporting period, several foam models were tested under dynamic loading in the Armour Research Foundation (ARF) shock tube. Since the data have not been completely reduced, and the scatter in the test results has not been evaluated, only tentative remarks are in order. As expected, it appears that the resistance to overpressure damage increases substantially with increasing density and decreasing values of R/t. Two different commercial polyurethane products have been considered and both gave substantially the same performance.

## III. THIN SHELL ANALYTICAL STUDY

In the Division 7 Quarterly Progress Report [U] of 15 January 1961,\* it was pointed out that, for a paraboloidal shell of revolution under distributed surface loading, the membrane force

\* ASTIA 253840.

equations (for  $N_{xx}$ ,  $N_{yy}$ , and  $N_{xy}$ ) derived from the system of shell coordinates with regular Cartesian parameters  $x$  and  $y$  can be reduced to two partial differential equations of the Poisson type whose solutions are readily available. The use of shell coordinates with Cartesian parameters, however, is not suitable for the analysis of those shells that are of immediate interest; namely, shells with circular boundary (or boundaries). Attention is therefore turned to the membrane equations

$$\gamma \frac{\partial N_r}{\partial \gamma} + N_r - N_\theta + \sqrt{1 + \gamma^2} \frac{\partial N_{r\theta}}{\partial \theta} = -2f\gamma \sqrt{1 + \gamma^2} P_r$$

$$\gamma \frac{\partial N_{r\theta}}{\partial \gamma} + 2N_{r\theta} + \sqrt{1 + \gamma^2} \frac{\partial N_\theta}{\partial \theta} = -2f\gamma \sqrt{1 + \gamma^2} P_\theta$$

and

$$\frac{N_r}{1 + \gamma^2} + N_\theta = -\sqrt{1 + \gamma^2} P_n$$

derived from a system of shell coordinates with polar parameters  $\gamma$  and  $\theta$  (see Fig. 76-11 of the Division 7 Quarterly Progress Report for 15 January 1961).

It can be shown that the membrane stresses must take the following form:

$$N_r = a_0(\gamma) + a_1(\gamma) \sin \theta$$

$$N_\theta = b_0(\gamma) + b_1(\gamma) \sin \theta$$

and

$$N_{r\theta} = c_1(\gamma) \cos \theta$$

where  $a_0(\gamma)$ ,  $a_1(\gamma)$ ,  $b_0(\gamma)$ ,  $b_1(\gamma)$  and  $c_1(\gamma)$  are completely determined by the system of ordinary differential equations

$$\frac{a_0(\gamma)}{1 + \gamma^2} + b_0(\gamma) = 2f\rho h \cos \varphi$$

$$\gamma a_0'(\gamma) + a_0(\gamma) - b_0(\gamma) = 2f\rho h \cos \varphi \{\gamma^2\}$$

$$\frac{a_1(\gamma)}{1 + \gamma^2} + b_1(\gamma) = 2f\rho h \sin \varphi \{\gamma\}$$

$$\gamma a_1'(\gamma) + a_1(\gamma) - c_1(\gamma) \sqrt{1 + \gamma^2} - b_1(\gamma) = -2f\rho h \sin \varphi \{\gamma\}$$

and

$$\gamma c_1'(\gamma) + 2c_1(\gamma) + b_1(\gamma) \sqrt{1 + \gamma^2} = -2f\rho h \sin \varphi \left\{ \gamma \sqrt{1 + \gamma^2} \right\}$$

where

$$(\ )' = \frac{d(\ )}{d\gamma}$$

and by the relevant edge constraints. The terms on the right-hand side of the above equations constitute the surface loading intensities of the shell, although no attempt will be made here to give a complete account of these terms. The first two equations of the above system yield

$$a_0(\gamma) = \frac{2f\rho h \cos \varphi}{3} \frac{\sqrt{1+\gamma^2}}{\gamma^2} \left\{ (1+\gamma^2)^{3/2} + B_1 \right\}$$

and

$$b_0(\gamma) = 2f\rho h \cos \varphi \left\{ 1 - \frac{1}{3\gamma^2 \sqrt{1+\gamma^2}} \left[ (1+\gamma^2)^{3/2} + B_1 \right] \right\}$$

where  $B_1$  is a constant of integration to be determined by the prescribed edge condition. The remaining three equations can be reduced to

$$b_1(\gamma) = \frac{-a_1(\gamma)}{1+\gamma^2} + 2f\rho h \sin \varphi \{ \gamma \}$$

$$c_1(\gamma) = \frac{1}{\sqrt{1+\gamma^2}} \left\{ \gamma a_1'(\gamma) + \left[ 2 - \frac{\gamma^2}{1+\gamma^2} \right] a_1(\gamma) \right\}$$

and

$$a_1''(\gamma) + \left\{ \frac{5}{\gamma} - \frac{2\gamma}{1+\gamma^2} \right\} a_1'(\gamma) + \left\{ \frac{3}{\gamma^2} - 6 + \frac{9\gamma^2}{1+\gamma^2} - \frac{3\gamma^4}{(1+\gamma^2)^2} \right\} a_1(\gamma) = -4f\rho h \sin \varphi \left\{ \frac{1}{\gamma} + \gamma \right\}$$

Thus, we need solve only the third equation to complete the analysis for the membrane stresses. Although a series solution can be obtained for  $a_1(\gamma)$  after first expanding the coefficients of the equations into power series [note that the power series for these coefficients as well as the series solution converge for all positive (real)  $\gamma$ ], such an approach to the solution is undesirable. A more practical method must be sought. As long as the smallness of the error can be guaranteed, exactness of the solution in the present study is not of paramount importance, since the membrane analogy itself is only an approximation to the true behavior of the shell.

Different approximations of the differential equation for  $a_1(\gamma)$  were made, the corresponding analytic (approximate) solutions obtained, and a study of the error accrued to these approximate solutions completed. These approximate solutions of the membrane stresses were then used to compute the displacements on the middle surface of the shell via the stress-strain and strain-displacement relations.<sup>4</sup> Approximate (analytic) solutions of these middle surface displacements have also been obtained. Data are presently being generated from these analytical expressions and will be published in a future report.

#### IV. TTR RADOME

##### A. Experimental Study

The evaluation of four radome models to provide preliminary performance data and to establish the type of geometry to be used for final test models for the TTR radome feasibility study has been completed. The results of the antenna pattern model testing, which were reported previously,<sup>5</sup> indicated that the random icosahedron geometry model would be more desirable

than the regular snub dodecahedron geometry since its effects on the side lobes of the test antenna were less pronounced. The subsequent testing of the random and regular geometry boresight models indicated that the peak-to-peak values of boresight shift in the azimuth and elevation planes were the same for both geometries. Therefore, the antenna pattern (7.42-foot diameter) and boresight (11-foot diameter) models for final testing will use the random icosahedron geometry. These final models are currently being fabricated so that metal member cross section and dielectric membrane thickness will be consistent with the 2-psi overpressure requirement for structural stability.

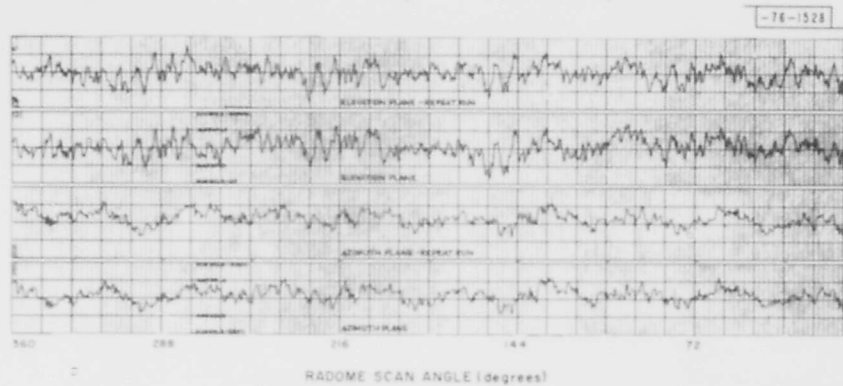


Fig. 76-1. Preliminary azimuth and elevation plane boresight shift data for the 11-foot-diameter regular snub dodecahedron radome model.

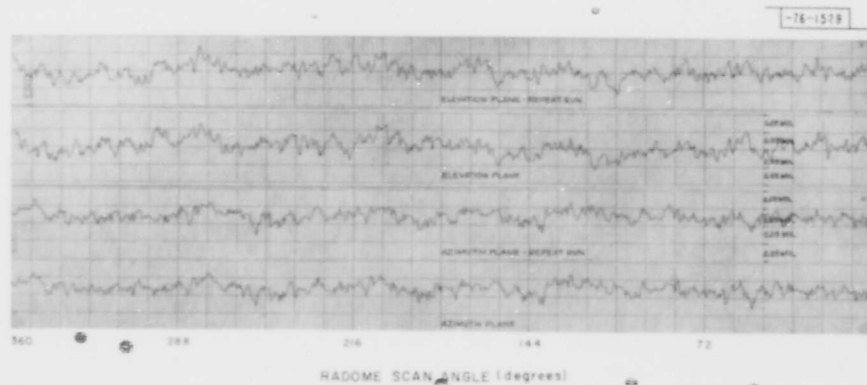


Fig. 76-2. Preliminary azimuth and elevation plane boresight shift data for the 11-foot-diameter random icosahedron radome model.

Typical two-plane boresight data obtained with the preliminary random and regular models at a frequency of 23.5 kMcps are shown in Figs. 76-1 and 76-2. These radomes were tested at elevation increments between  $10^\circ$  above the equator and  $10^\circ$  below the zenith by means of the measurement techniques reported previously. Maximum peak-to-peak values of 0.10 milliradian in the azimuth plane and 0.15 milliradian in the elevation plane were measured.

One of the problems encountered in the evaluation of these low boresight shift radomes has been to maintain the stability of the measurement system to within 0.01 of a milliradian. To

date, this has been possible only during periods when the environment has been humid and foggy accompanied by very low winds, and it was during these periods that the data reported above were obtained. System tests conducted during periods of relative instability recorded short time variations (of the order of seconds) corresponding to 0.03 milliradian.

The test antenna and mount are located in a 20-foot cubicle, enclosed on five sides. The sixth side, which faces the transmitter source, has a metal roll-up door which is opened when boresight measurements are being made. Tests indicated that a cyclical rotation of the test antenna mount occurred when the metal roll-up door was opened. These tests further indicated that there were no short-term mechanical vibrations present. The cyclical mount rotations, which was apparently caused by temperature differences between the ambient of the test cubicle and the outside environment, was corrected with the installation of a low-loss dielectric foam door on the side of the test cubicle that faces the transmitter source. This foam door effectively enclosed the test area in a more uniform environment. The door was fabricated in three sections; each foam section was made from low density (4 to 4.7 pcf) polystyrene slats which were thermally fused to form a section 20 feet high, 6-2/3 feet long, and 2 inches thick. Three of these sections were bonded together with an epoxy resin to form a 20' x 20' x 2" thick slab which was inserted in an aluminum framework support and attached to the open side of the test cubicle, just inside the metal roll-up door. The dielectric values of the door media involved are listed in Table 76-I.

	K'	Tan $\delta$
• No joint	1.077	0.0006
• Fused joint	1.205	0.0004
• Epoxy glued joint	1.232	0.0052
Frequency: 24 kMcps		

Measurements made before and after the installation of the foam door indicated that it had no effect on the two-plane boresight shift data. The installation of the foam door, although correcting the cyclical mount rotation, did not effectively eliminate the short-term amplitude variations of the test system.

#### B. Structural Status

Dynamic test schedules were altered by the plans of the U.S. Air Force to move the 6-foot-diameter shock tube to Albuquerque, New Mexico. However, by combining the planned second and third periods into a final test phase, the shock tube tests at the U.S. Air Force Shock Tube Laboratory were completed. The test setup and procedure were identical to those previously reported. All radome models were tested to destruction in the 0° orientation. They were subjected to a number of shots, starting with an overpressure substantially below threshold and increasing incrementally through threshold damage overpressures. Table 76-II lists the highest

uncorrected free-stream overpressures causing no visible model damage and the lowest uncorrected free-stream overpressures resulting in visible damage. Also listed are the total number of shots to which each model was subjected. The test results previously obtained (Phase 1) on the random geometry spherical space frames are also shown in Table 76-II. From this table it is seen that the threshold free-stream overpressures are well determined. Neglecting model D-8, the mean overpressure preceding damage is 2.25 psi with a probable error of the mean of about 1 per cent.

The uncorrected test results for the 20-inch-diameter aluminum shells are shown in Table 76-III. These shells were designed and fabricated by the same techniques used on the

	Model	No. of Shots	Overpressure Preceding Damage (psi)	Overpressure Causing Damage (psi)
First Test Phase	D-1	23	2.33	2.5
	D-2	5	2.39	2.43
	D-3	11	-	1.95
	D-4	8	2.2	2.7
	D-5	10	2.5	2.55
Second Test Phase	D-7	6	2.12	2.3
	D-8	42	1.40	1.41
	D-9	5	1.98	2.40

	Model	No. of Shots	R/t	Overpressure Preceding Damage (psi)	Overpressure Causing Damage (psi)
First Test Phase	J-9	9	284	11.69	12.60
	J-10	12	313	11.48	12.41
Second Test Phase	J-4	32	333	10.25	9.10
	J-5	17	294	14.88	15.06
	J-6	66	294	16.9	17.2
	K-2	1	1110	-	1.5
	K-4	33	877	2.02	2.28
	K-7	10	870	1.71	1.63
	K-8	4	885	1.48	1.81

4-inch-diameter shells previously tested in the M.I.T. Aeroelastic and Structures Research Laboratory shock tube. Preliminary comparison of these test results indicates no discernible effects due to model size at a nominal 10-psi free-stream overpressure. This reinforces our anticipation of no outstanding effects due to model size at 2-psi overpressure for the TTR radome.

Joint efforts between Bell Telephone Laboratories and Lincoln Laboratory personnel have resulted in a field blast model design which is currently being procured by the Bell Telephone Laboratories. In order to expedite the design, maximum use was made of the gross results of shock tube tests and a small amount of carefully selected and manually reduced data. This resulted in a revision in the schedules for the more detailed, digitized data reduction which is in process.

## V. MATERIALS AND PROCESSING

### A. Physical and Dielectric Testing

An investigation of porous materials has been extended to provide necessary background and design information for foam hardened structures. This program was initiated to provide specific static and high-speed dynamic data on foam materials. These data will serve as guides in adapting polymer materials to withstand shock loadings. The mechanical behavior of the more promising foams will be investigated with respect to time, temperature and stress. The rheological data will supplement the static and high-speed data in the tailoring of high-energy impact-absorbing foam formulations.

Static, slow-load-rate tests and high-speed tests are being conducted on formulations used in recent shock tube model tests and will be reported later. Correlating experimental tests to measure the dielectric constant and loss tangent of the various components that could make up a rigid structural foam are also in process. By selecting those ingredients with the lowest dielectric values and studying the extent of their influence in the chemical reaction, a better understanding of foam dielectric properties will be obtained.

### B. Foam Density Studies

The need for a uniform density foam radome product which will satisfy both electrical and physical property requirements has been documented in preceding quarterly progress reports of Group 76. Consequently, a considerable amount of profile data has been accumulated for both tested shock tube foam models and controlled experiments with various parameters. Interpretation of these data has produced the following facts which are briefly stated with their experimental evidence:

- (1) For solvent blown systems, the molar quantity of gas for cell generation in a closed 10-pcf foam product should be approximately 2-1/4 moles per ft.<sup>3</sup> When an appropriate charge of 10-pcf formulated foam, i.e., one with the prescribed amount of blowing ability, is introduced into a mold, the resulting product will have a density variation up to 10 per cent. This is exclusive of the 30-mil skin zone depth. A 10-pcf formulation utilized as a 13- or 16-pcf product will have density variations of 17 to 25 per cent. Less than the above quantity will blow a product insufficient to fill the mold cavity and an excess will generate a distorted overpressured product in which the density variation is difficult to estimate. It should be

noted that the above conclusions relate to high surface area to thickness ratio products. Very thin sections requiring extensive foam rise will not necessarily be governed by the above. Very thick pours also may deviate from these conclusions because of the entrapped exotherms involved.

- (2) The preceding experiment was performed as a prelude to replacing the standard polar halogenated aliphatic blowing agent with low-boiling non-polar halogenated aliphatics. Pentane, hexane, heptane and, for contrasting interest, polar 2-methylbutane have been introduced as blowing agents and they all foam competitively well on a screening run. Currently, controlled density molded products are being prepared for dielectric measurement and tests to determine the change in fire retardancy caused by the low flash point of these blowing agents.

Preliminary information indicates that the standard chloromonofluoromethane has a dielectric constant as a liquid of 2.28 vs heptane's 1.97. The loss tangent of the latter compound at 3000 Mcps is less than  $2.5 \times 10^{-4}$ .

- (3) Stress cracks occurred in early production radome foam panels<sup>7</sup> which had skin zone densities five times greater than the core density. Present molding procedures and controls have reduced this density variation to an order of one and one-half to two times and confined these mostly to the first 1/32-inch depth.
- (4) A laboratory foam-metering and dispensing machine was reactivated this past quarter. Several pump parts were replaced and modifications made for evaluating a CO<sub>2</sub>-blown polyether polyurethane. This foam system was chosen for two reasons: first, its components had viscosities which required no thermostatic temperature regulation, and second, for evaluating polyethers vs polyester-based urethane foams.

The dispensed meter-machined product is significantly more uniform than the air-bubble-filled batch-mixed product. Preliminary physical tests have indicated an improved tensile strength. After modifications of the tensile specimen mold, sufficient specimens will be prepared to document this prediction. Dielectric tests and infrared analysis of batch-mixed vs meter-mixed are being prepared to determine the completeness of the cross linking in the chemical reaction, since residual unreacted hydroxyl and isocyanate groups are detrimental physically as well as dielectrically.

- (5) A nylon cloth temporary overlay on the top surface of a molded panel eliminates the typical defects of air entrapments on this surface. This removable cloth acts as an air bleeder and produces a matching surface to the usually-superior bottom surface finish.

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1. Division 7 Quarterly Progress Report [U], Lincoln Laboratory, M.I.T. (15 July 1960), ASTIA 221707.
2. Ibid.
3. Op. cit., 15 October 1959 (Classified).
4. Op. cit., 15 October 1960 [U], ASTIA 249920.
5. Op. cit., 15 January 1961 [U], ASTIA 253840.
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7. Op. cit., 15 July 1960.

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