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FABRICATION TECHNIQUES AND PRINCIPLES FOR FLAT PLATE ANTENNAS

SEPTEMBER 1973
FINAL REPORT

Prepared for
DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
OFFICE OF VEHICLE STRUCTURES RESEARCH
Washington DC 20591

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16. Abstract

This final report documents the work performed by Rantec under Department of Transportation Contract No. DOT-TSC-390. Defined herein are the fabrication techniques and principles Rantec has selected to produce one million and ten million flat plate antennas per year.

An engineering analysis of the reliability, electrical intergrity, and repeatability is made, and a cost analysis summary is included for a production run of both one and ten million units per year, and a technical discussion of the maximum RF frequency to which these fabrication techniques can be extended without performance degradation and/or major cost increase is included.

The fabrication techniques selected by Rantec to produce 1 and 10 million flat plate antennas per year include die casting, pierce and blanking, injection molding, and cold heading. The flat plate antenna would be fabricated in six elements using these techniques. An automatic assembly center would be used to achieve the high volume production runs. One such unit operating at maximum efficiency will produce 1 million units per year at a cost of \$0.41 per unit. Two additional stations will achieve production runs in excess of 10 million per year at a cost of \$0.30 per unit, not including overhead.

The flat plate antennas can be scaled to a frequency of 17.5 GHz with no cost impact or significant effect on performance. Scaling to a frequency of 21 GHz is possible but at a higher cost per unit.

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PREFACE

The work described in this report was performed in the context of an overall program at the Transportation Systems Center to evaluate anticipatory crash sensor concepts as applied to activation of automobile passive restraint systems. This report specifically examines the fabrication techniques and mass-production costs for antennas associated with a radar crash sensor. The program is sponsored by the National Highway Traffic Safety Administration, Office of Vehicle Structures Research, Department of Transportation. This program supports Government activities designed to promote greater safety on the nations highways and reduce injury and fatalities in traffic accidents.

We are grateful for the assistance provided by the Rantec Division of Emerson Electric Co., Calabasas, California, who conducted these studies.

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INTRODUCTION

This final report documents the work performed by Rantec under Department of Transportation Contract No. DOT-TSC-390. Defined herein are the fabrication techniques and principles Rantec has selected to produce one and ten million flat plate antennas per year.

An engineering analysis of the reliability, electrical integrity, and repeatability is made, and a cost analysis summary is included for a production run of both one and ten million units per year. Finally, a technical discussion of the maximum RF frequency to which these fabrication techniques can be extended without performance degradation and/ or major cost increase is included.

SECTION II

FABRICATION PRINCIPLES AND TECHNIQUES (1 MILLION UNITS/YEAR)

2.1 HIGH VOLUME TECHNIQUES

The fabrication techniques defined below have been selected for producing the flat plate antennas because they represent tried and proven high volume production methods:

- Die casting technique - Permits economical production of close tolerance, irregularly shaped parts in high volume. This technique has world-wide acceptance.
- Pierce and blanking fabrication technique - Present design practices and available die steels, combined with speed short stroke presses and automatic feeding devices, has made this technique most economical.
- Injection molding technique - Similar to casting of metal. The material is heated to a temperature that causes a near molten state. This molten material is injected in cavities to produce parts.
- Cold heading technique - Clearly the most economical method of producing simple parts in large quantities.

2.2 DETAIL IDENTIFICATION

The antenna will be fabricated in six details and then assembled. (See Figure 2-1.) These details are:

- Cavity
- Radiating Face
- Feed Guide/Connector Shell
- Center Conductor
- Teflon Support
- Radome

These details will be produced using one of the high volume techniques listed in para 2.1.

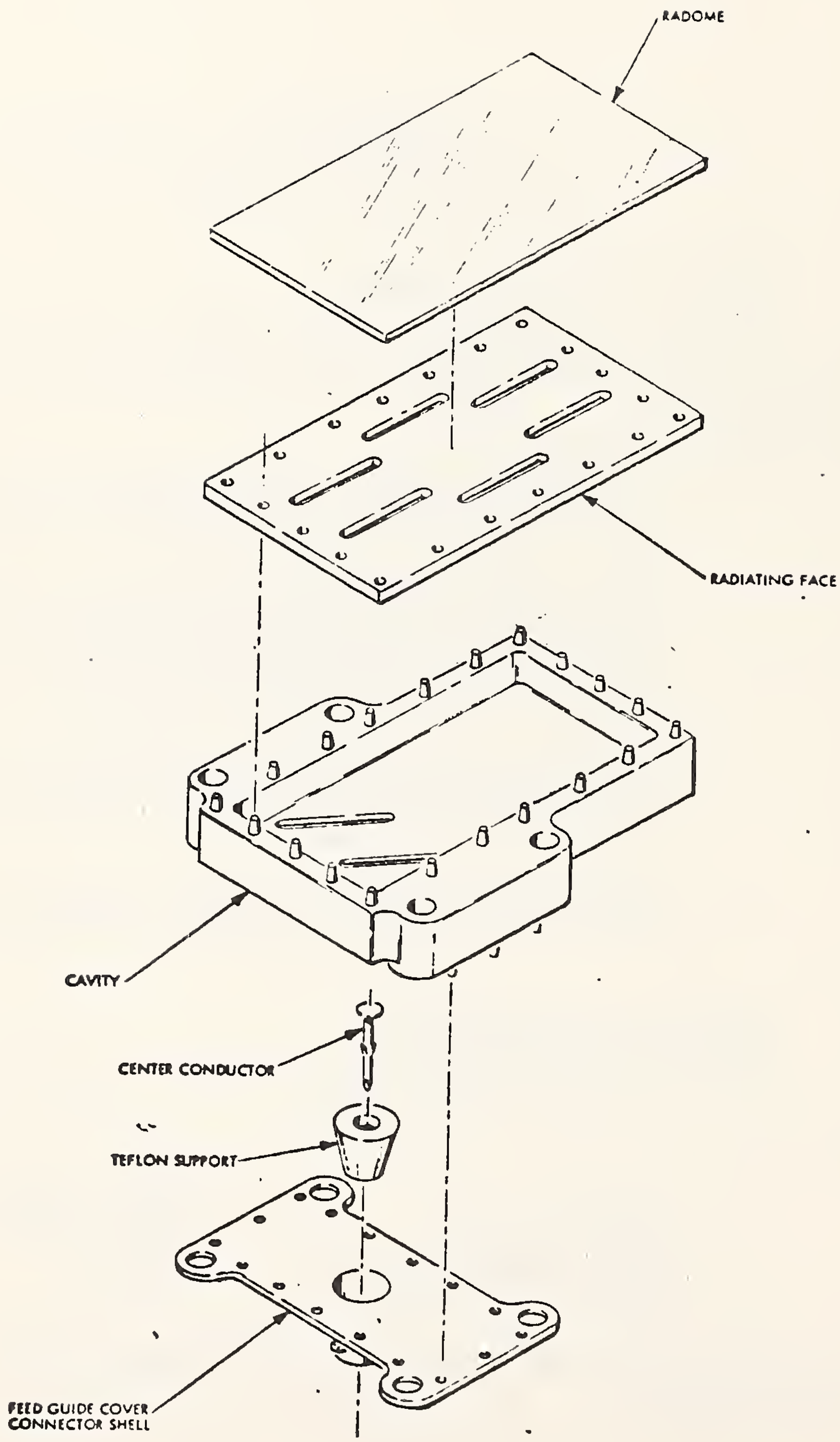

Figure 2-1. Flat Plate Antenna Details

2.2.1 Cavity

The manufacturing technique selected for this detail is die casting because of its dimensional repeatability and economical nature. The use of aluminum alloy 380 and multiple cavity tooling will ensure a minimum of 500,000 to one million parts without serious tool breakdown. The most critical cavity dimensions can be maintained throughout the life of the tool by quick replacement punches and locaters.

Multiple tooling for this part has been quoted at $18,500 with a cost of $76 per thousand. Production of 500 to 1000 parts per hour can be maintained. The die casting technique with the capability of holding tolerances of ±0.004 inch per linear inch* (see Figure 2-2) eliminates the need for machining. The natural finish of die parts permits the use of a wide range of mechanical, chemical and organic finishes with minimum surface preparation.

The die casting technique is far from unique. Intricately shaped die cast parts are produced daily. The die casting machines available today can rapidly fill the die cavities while maintaining low die temperature, which results in long die life and dimensional consistency of the part. The molten metal, under pressure in excess of 1000 tons, can be pushed into any shape. Parts meeting close tolerances can be produced using current state-of-the-art techniques.

The tooling does have a high initial cost but, with the die steels available, obsolescence of the parts usually occurs before die replacement. Die castings are used extensively in the manufacture of products such as cash registers, small housings, washing machine parts, and many automotive parts (see Figure 2-3).

2.2.2 Radiating Face

The manufacturing technique selected for this detail is pierce and blanking because of its dimensional repeatability and economical

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*American Society for Metals; Aluminum, Fabrication and Finishing; Vol III

Type A Dimension: Between two points in same part of die, not affected by parting plane or moving parts

Specified dimension, in.	Tolerance, ±, in. Critical	Noncritical
Up through 1	0.004	0.010
Over 1 to 12	0.004 + 0.0015 in./in. over 1 in.	0.010 + 0.002 in./in. over 1 in.
Over 12	0.0205 + 0.001 in./in. over 12 in.	0.032 + 0.001 in./in. over 12 in.

Type B Dimension: Across parting plane. A-type dimension plus following:

Projected area of casting, $A_1 \times A_3$, sq in.	Additional tolerance for parting plane, in.
Up through 50	0.005
Over 50 to 100	0.008
Over 100 to 200	0.012
Over 200 to 300	0.015

D Dimension: Draft

Depth of draw, in.	Draft, deg Critical	Noncritical
Up through 0.1	6	18
Over 0.1 to 0.5	3	6
Over 0.5 to 1.0	2	3
Over 1.0 to 3.0	1	1½
Over 3.0 to 9.0	¾	1

Type C Dimension: Affected by moving parts. A-type dimension plus following:

Projected area of casting affected by moving part, $A_3 \times G$, sq in.	Additional tolerance for moving part, in.
Up through 10	0.005
Over 10 to 20	0.008
Over 20 to 50	0.012
Over 50 to 100	0.015

E Dimension: Minimum wall thickness, 0.090 in.

F Dimension: Allowance for finish

Maximum dimension, in.	Nominal allowance, in.
Up through 5	0.020
Over 5 to 12	0.030
Over 12 to 18	0.040

Minimum diameter of cored holes, 0.140 in.

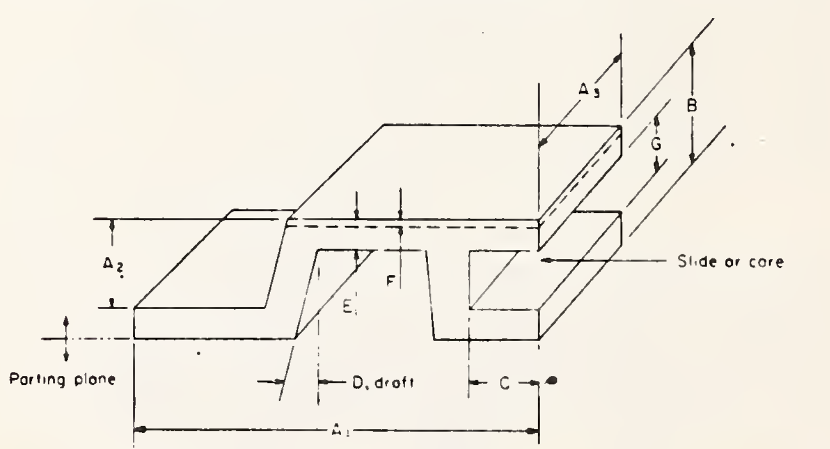

Figure 2-2. Suggested Dimensional Tolerances for Die Castings

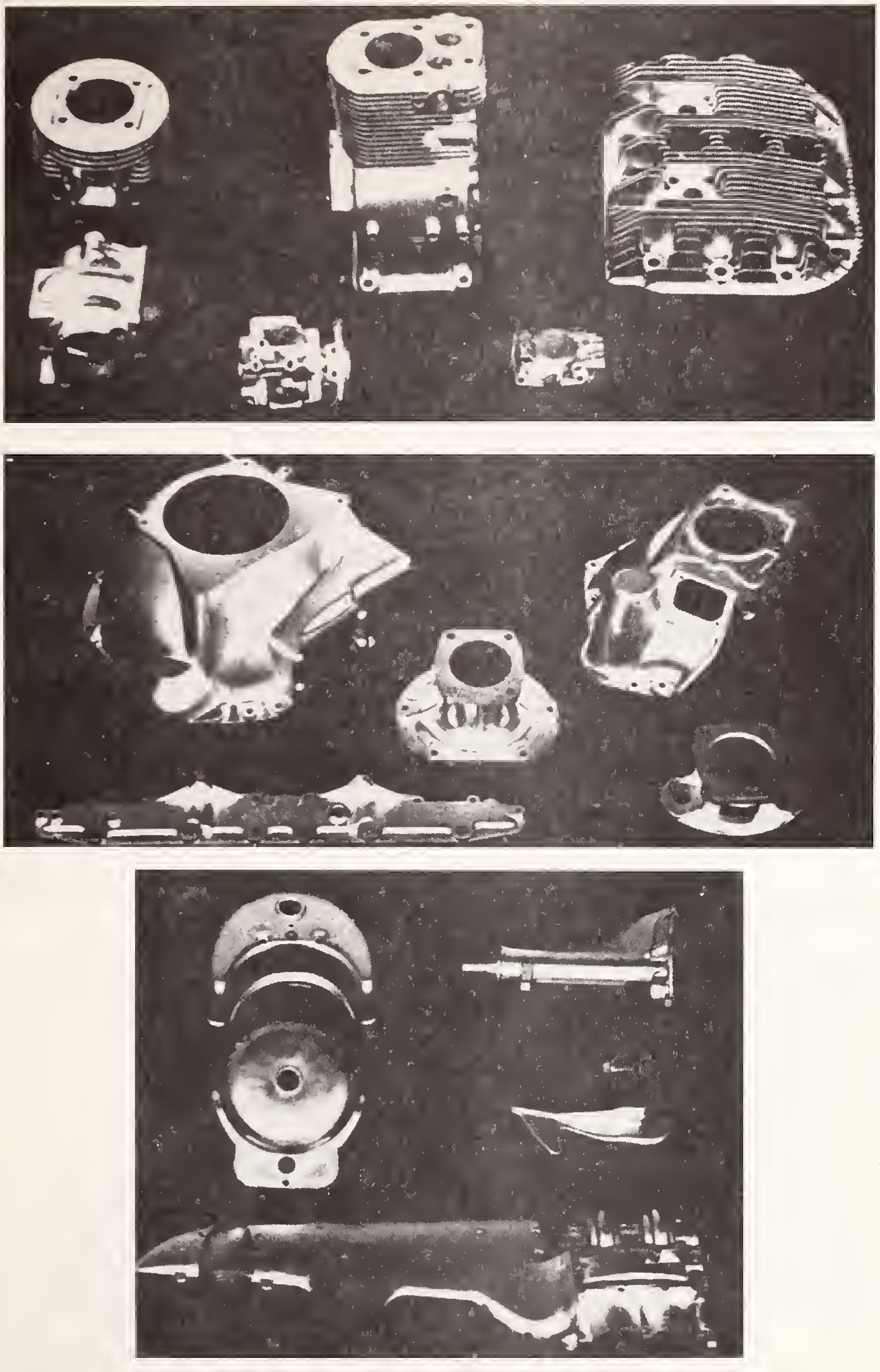

Figure 2-3. Typical Aluminum Die Castings

nature. The use of a high-speed, short stroke press with automatic feed and carbide steel tooling will ensure production rates in excess of 5000 per hour. The breakout (material torn away on punch exit side) will be minimized by selecting annealed stock and controlling the clearance between punch and die. Critical dimensions (such as location, length and width of slots) can be held to ±0.001 inch.

Allowing a double strip to be used, carbide tooling has been quoted at $7500 with a cost of $30 per thousand. Carbide tooling is universally used for long, high speed runs. For example, laminations used in transformer and electrical motors are blanked on carbide dies. Use of carbide steels minimizes down time.

Blanking of the radiating face would be an automatic operation. Coils of the material to be pierced and blanked are set in position and automatically fed through the press. The short press stroke, usually a maximum of 1 inch, eliminates idle time. The press runs until a sensor indicates the end of the coiled material; then another coil is positioned in place and the operation continued.

2.2.3 Feed Guide Cover/Connector Shell

The manufacturing technique selected for this detail is die casting because of the part's irregular shape. The casting technique will produce a part complete with either threads or bayonet lock pins.

Tooling has been quoted at $23,000 with a cost of $60 per thousand. Critical tolerance (hole size and depth) can be held to ±0.002 inch in production without constant monitoring. Production of 500 to 1000 parts per hour can be maintained.

The feed guide cover/connector shell is similar to the antenna cavity and thus lends itself to die casting. Since the material content of this part is less than that of the cavity, the tooling may be designed with additional cavities resulting in more parts per hour.

The tooling will be designed to permit opening of each cavity to clear the thread or bayonet lock pin area. By designing the tooling for quick replacement of inserts, downtime can be minimized.

2.2.4 Center Conductor

The manufacturing technique selected for this detail is cold heading because of its simplicity. Annealed copper wire will be fed into the cold header, where the end is formed to a specified diameter. The closing of the holding collet will automatically barb the shank, and the automatic cutoff feature will produce the required length and tapered end on the center conductor. Subsequent heat treatment and plating operation will be done in bulk to minimize part cost.

Cost of this part has been estimated at less than $10 per thousand. Tooling cost is minimal. This approach is unquestionably the most economical.

2.2.5 Teflon Support

The manufacturing technique selected for this detail is injection molding because of the part simplicity. Multiple cavity tooling will hold the tolerances of the complete part to ±0.002 inch. The cost of this part is primarily the material cost. Tooling for the teflon support has been estimated at $3500 with a cost of $0.03 each. A production rate of 1200 per hour can be readily maintained.

2.2.6 Radome

The radome will be purchased in roll form. It will be pre-stamped and positioned on a silicone faced paper carrier. The side of the radome contacting the antenna will be coated with a pressure-sensitive adhesive. The position of the radome on the carrier strip will be keyed to index holes on each edge of the paper carrier. These index holes will be used to advance the paper carrier through the assembly operation.

2.3 FINAL ASSEMBLY

Figure 2-4 depicts the total assembly operation. The assembly consists of six details as discussed in para 2.2. The assembly sequence will begin at Station 1 by the feed guide cover/connector shell being positioned manually (see Figure 2-5). At Station 2, the teflon support will be driven into position (see Figure 2-6). The interference fit between the feed guide cover/connector shell and the teflon will lock them together. The partial assembly will be advanced to the third station where the center conductor is driven into the teflon (Figure 2-7). The barb on the center conductor will permanently secure it to the teflon. At Station 4, the cavity will be dropped onto the subassembly (Figure 2-8) by a large capacity magazine. These magazines will have quick-disconnect/connect features to facilitate replacement when empty.

At Station 5, the radiating face will be automatically dropped in position by using magazine feeds (see Figure 2-9) similar to those used in Station 4. These feeds will have a total capacity of 2000 parts and will be manually loaded as required. At this point, all parts are positioned for swaging operations.

Station 6 (Figure 2-10) will clamp the cavity, radiating face, and feed guide cover/connector shell. In the clamped position, swaging punches will compress the die cast protrusions ensuring metal-to-metal contact between the feed guide cover/connector shell casting, the radiating face, and the cavity casting. The critical dimension between the cavity and the center conductor end will be obtained within ±0.003 inch.

The radome, which is positioned on the silicone faced paper carrier, will be assembled to the antenna assembly. The assembly will be

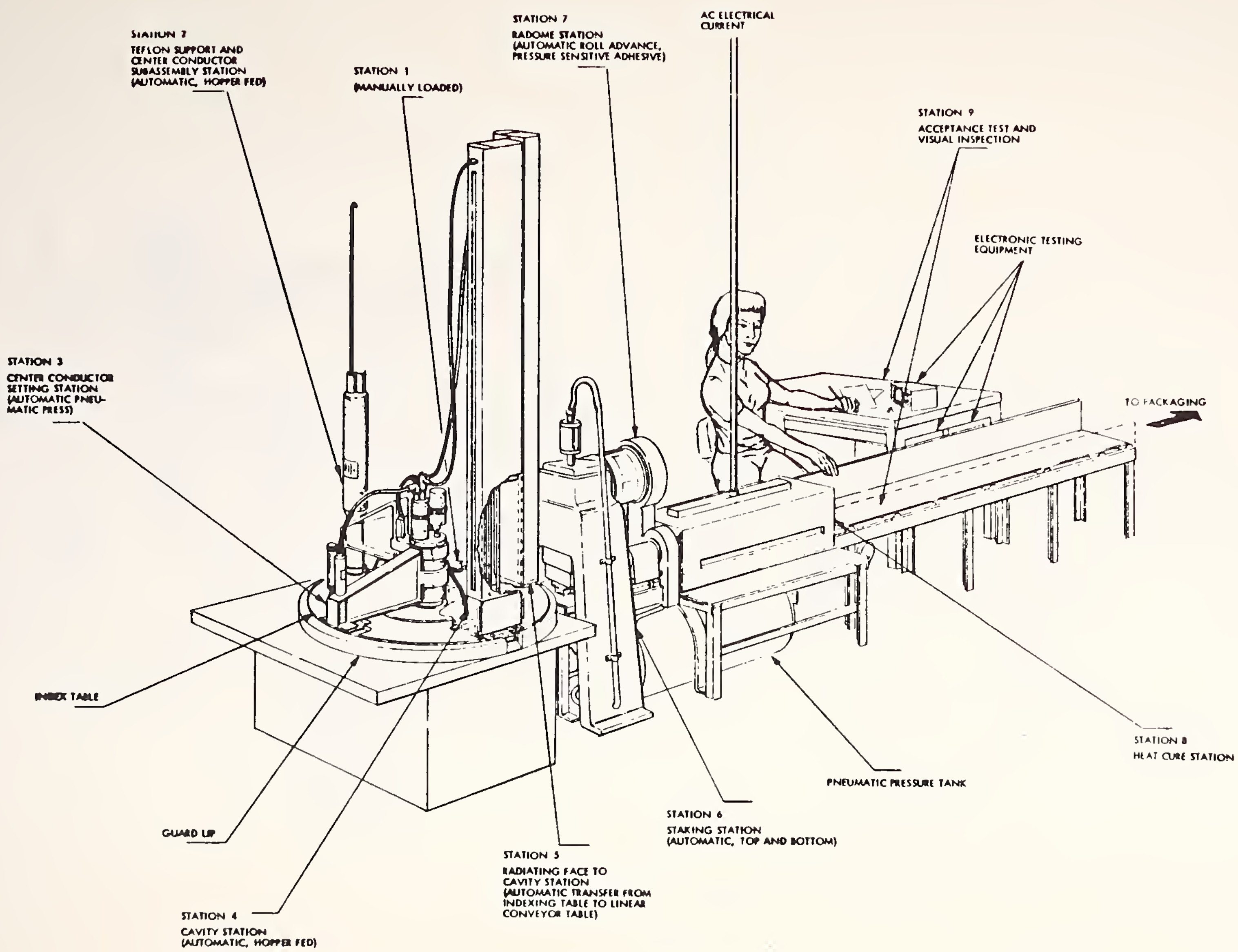

Figure 2-4. Flat Plate Antenna Assembly Center

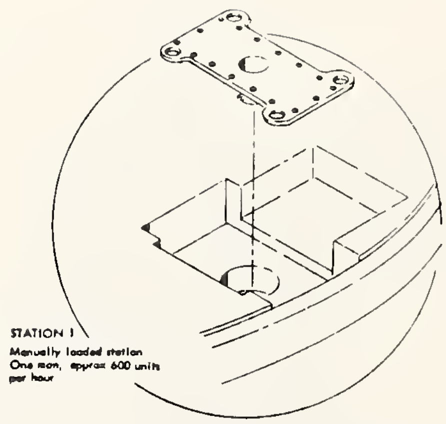

Figure 2-5. Station 1

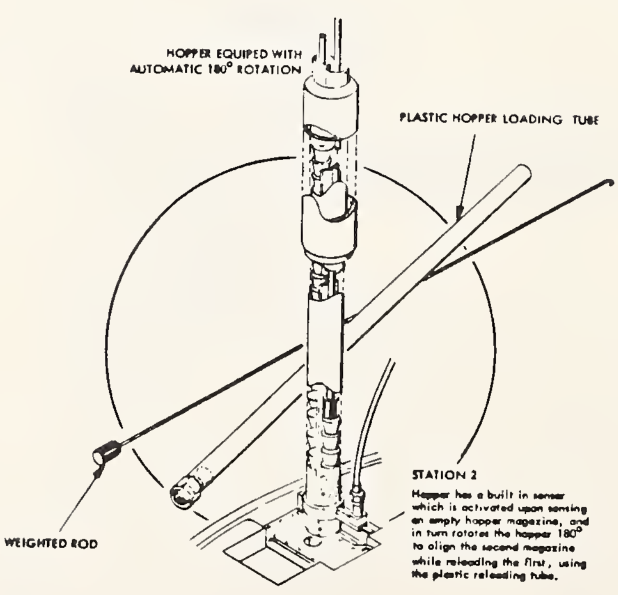

Figure 2-6. Station 2

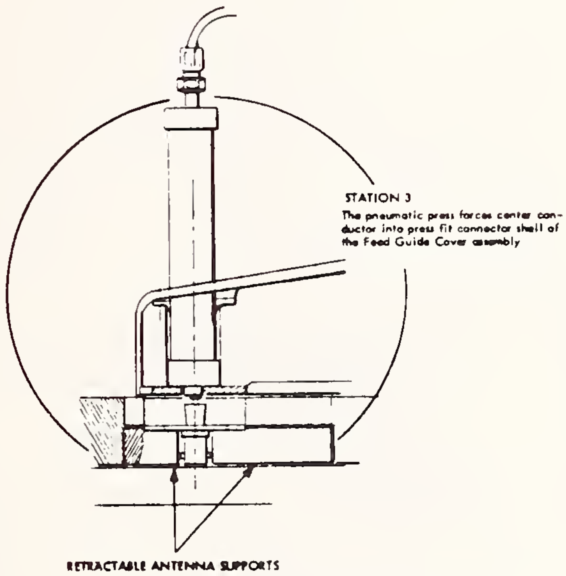

Figure 2-7. Station 3

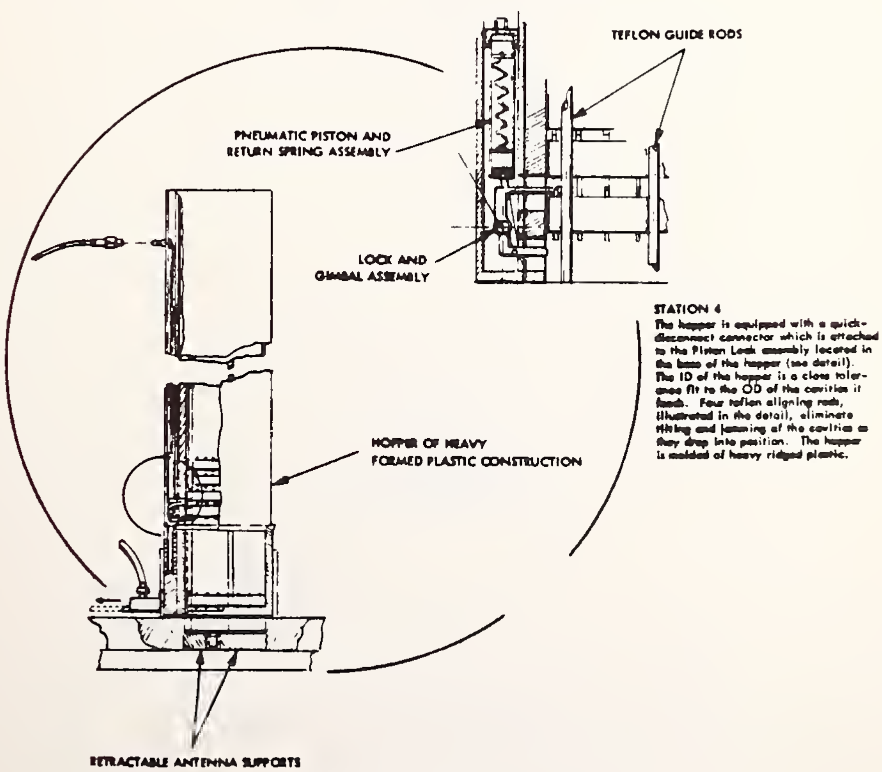

Figure 2-8. Station 4

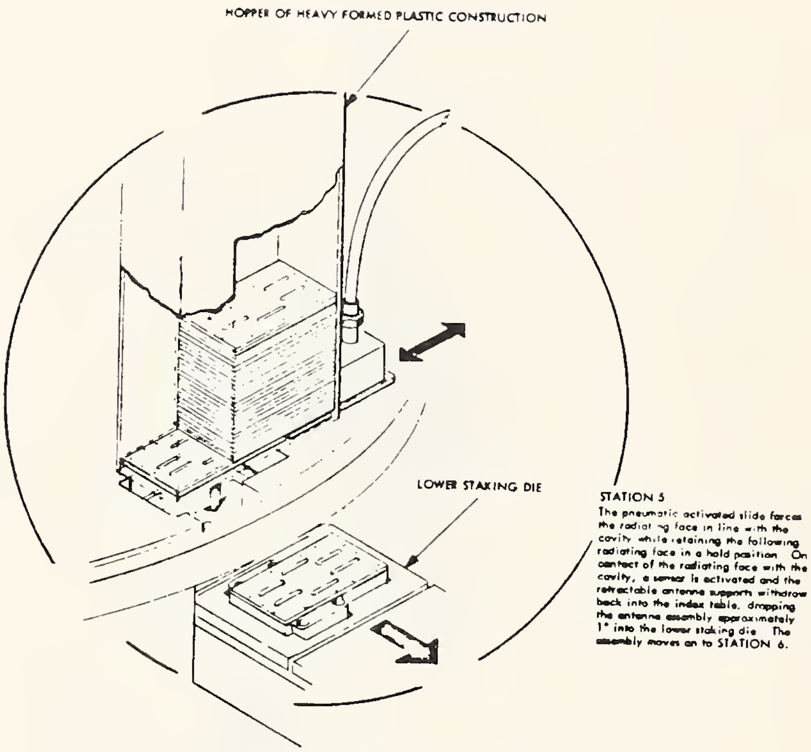

Figure 2-9. Station 5

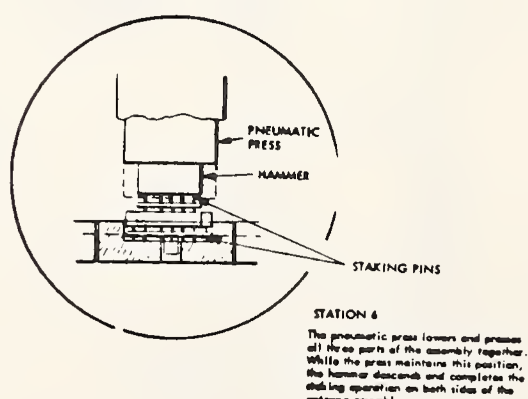

Figure 2-10. Station 6

raised by a cam mechanism until it contacts the radome. A spring load will prevent damage to either the radome or the antenna assembly. A teflon faced clamp will be positioned by a cam against the radome and heat applied to accelerate the cure cycle. The finished assembly will be automatically dropped from the indexing table into a packing box which is then sealed.

The cost of the assembly center has been estimated at $90,000 with an assembly of 600 antennas per hour.

SECTION III

FABRICATION PRINCIPLES AND TECHNIQUES (10 MILLION UNITS/YEAR)

Another consideration given in the selections of fabrication technique previously described for the production of 1 million units per year was the ease of transition from 1 million to 10 million units per year. These techniques, with some tooling additions, will produce quantities in excess of 10 million per year. These additions are as follows:

- Cavity and Feed Guide Cover/Connector Shell (die casting - The addition of two sets of tooling for each detail would permit the transition from 1 to 10 million units per year production.

  Assuming an average production rate of 750 parts per hour and imposing two 10-hour shifts, the yield will be in excess of 10 million per year.

- Radiating Face - Pierce and blank tooling defined with an average production of 3000 parts per hour can produce 10 million parts per year with one additional die.

- Teflon Support (injection molding) - The addition of two sets of injection mold tooling and imposing two 10-hour shifts will yield in excess of 10 million parts per year.

- Center Conductor (cold heading) - Minimum tool requirement will satisfy both 1 and 10 million parts per year.

The assembly technique defined in Section II (1 million parts per year) is at maximum efficiency. The addition of two assembly stations and imposing two 10-hour shifts will produce units in excess of the required 10 million.

The major portion of assembly center cost is related to tool proofing; therefore, it would be advantageous cost-wise to fabricate similar assembly centers. This would reduce tool proofing cost in the second and third units. Use of similar centers would also facilitate corrective actions, and new improvements can be incorporated easily.

SECTION IV
COST SUMMARY

Cost summaries for production runs of 1 and 10 million parts per year are contained in Tables I and II, respectively. The cost figures contained in these tables exclude overhead.

TABLE I

COST SUMMARY (1 MILLION PARTS/YEAR)

Detail	NRE	Tooling	Amortized Cost of Tooling and NRE	Piece Price
		PURCHASED PARTS		
Cavity	$ 4,600	$13,900	$0.0185	$0.076
Radiating Face	1,900	5,600	0.0075	0.030
Feed Guide Cover	5,700	17,300	0.0230	0.060
Center Conductor	100	400	0.0005	0.010
Teflon Support	900	2,600	0.0035	0.030
Radome	--	--	--	0.020
Tool Maintenance	--	5,000	0.0050	--
Total	13,200	44,800	0.0580	$0.226
		IN-HOUSE COST		
Final Assembly and Test	22,200	67,800	0.0900	
Tool Maintenance	--	7,000	0.0070	
Labor (4 Men)	--	--	0.0300	
Total	$22,200	$74,800	$0.1270	

TOTAL COST	
Amortized Cost of Tooling and NRE (Purchased)	$0.0580
Cost per Part (Purchased)	0.226
Amortized NRE for Tooling (In-house)	0.0222*
Amortized Tooling (In-house)	0.0678
Amortized Tool Maintenance	0.0070*
Labor per Part	0.0300*
TOTAL	$0.4110

*Excluding overhead

TABLE II

COST SUMMARY (10 MILLION PARTS/YEAR)

Detail	NRE	Tooling	Amortized Cost of Tooling and NRE	Piece Price
		PURCHASED PARTS		
Cavity	$ 4,600	$ 41,700	$0.00463	$0.0760
Radiating Face	1,900	11,200	0.00131	0.030
Feed Guide Cover	5,700	51,900	0.00576	0.060
Center Conductor	100	400	0.00005	0.010
Teflon Support	900	7,800	0.00087	0.030
Radome	--	--	--	0.020
Tool Maintenance		15,000	0.00150	
Total	$13,200	$128,000	$0.01412	$0.226
		IN-HOUSE COST		
Final Assembly and Test	22,200	203,400	0.02256	
Tool Maintenance	--	21,000	0.00210	
Labor (10 Men)	--	--	0.03000	
Total	$22,200	$224,400	$0.05466	

TOTAL COST

Amortized Cost of Tooling and NRE. (Purchased)	$0.01412
Cost per Part (Purchased)	0.2260
Amortized NRE for Tooling (In-house)	0.00222*
Amortized Tooling (In-house)	0.02240
Amortized Tool Maintenance	0.00210*
Labor per Part	0.03000*
TOTAL	$0.29684

*Excluding overhead

SECTION V
ENGINEERING EVALUATION OF FABRICATION TECHNIQUES

Engineering responsibility lies in two general areas. The first is to maintain an antenna that will meet all the electrical specifications. To prepare this antenna assembly for large volume fabrication, several changes must be made to the connector and center conductor assembly. Since the impedance match of the antenna is directly related to the connector and center conductor, a minor redesign in this area is required. Because of the simplicity of the antenna and the relatively small bandwidth, there will be no substantial problems in rematching this new antenna assembly.

The second area engineering will be exploring is the integrity and repeatability of the high volume antenna assembly. During the initial stages of production, several antenna assemblies will undergo a complete acceptance test. This will ensure that the design is still meeting all specifications. The tight tolerances maintained during the fabrication process eliminate the need to continually check all electrical specifications (specifically, radiation patterns and antenna gain). However, provisions will be made to check VSWR of the antenna assemblies on a random basis. As the finished antennas come off the assembly line, they will be visually inspected and a VSWR test will be performed at a sampling rate of 30 to 40 assemblies per hour. If two or more failures occur during an hour, the assembly will be stopped and appropriate action taken. A complete acceptance test will be performed on a weekly basis on 10 to 20 antennas randomly removed from the assembly line during that week.

Using these inspection techniques to monitor the integrity and repeatability of these antenna assemblies will result in an antenna that will consistently meet all specifications.

During the final assembly operations, the radiating face and feed guide cover/connector assembly are swaged onto the cavity. This process attaches the parts together by expanding the ends of small pins that protrude from one part through the other part. The pins will be located close together in terms of wavelengths (approximately 1/4 to 3/8 inch) to prevent the possibility of RF leakage between these parts. This will produce a good short circuit between the parts, and the swaging action will provide a good metal-to-metal contact. It is anticipated that no leakage problems will occur. However, during the initial production stage, tests will be made to substantiate that there is no leakage.

SECTION VI
MAXIMUM FREQUENCY ANALYSIS

6.1 INTRODUCTION

As requested by the Department of Transportation in their specification, a discussion of the maximum operating frequency using the present design and production techniques follows.

6.2 ANALYSIS

It is a relatively simple task to change the operating frequency of a slot array while retaining the same design. The proven technique of scaling allows:

- The slot length and width to be changed by the ratio of the old to the new frequency
- The waveguide size to be changed by the ratio of the new $(\lambda g/\lambda) \cdot (B/A)$ to the old $(\lambda g/\lambda) \cdot (B/A)$.
- The radiating slots offset to be changed by the ratio of the new A dimension and the old A dimension.

If these calculations are made correctly, the new scaled slot array will exhibit the same characteristics as the old array. There are, however, three factors that limit the maximum operating frequency that this slot array can be scaled. They are:

- Maximum tolerances manufacturing can work with
- Minimum protection required from the lexan radome
- Maximum insertion loss allowed

The same techniques used to scale the slots, waveguide and connector dimensions must be used in scaling their tolerances. For example, if the operating frequency were doubled, the length of the radiating slot and the tolerances on that length would be halved. For this particular antenna, the critical design areas are as listed on the following page.

- Slot length, width, and position
- Waveguide dimensions
- Distance from cavity wall to center conductor end

The dimensions of the radiating slots are now held to a tolerance of ±0.003 inch. Using the pierce and blanking technique described previously, these dimensions will be held to a tolerance of ±0.001 inch. The coupling slots are held to ±0.005 inch. The casting operation will be able to hold a tolerance of ±0.002 inch. The waveguide dimensions are now held to ±0.005 inch. Because of the longer length involved, the casting operation will hold the waveguide to ±0.003 inch. The distance from the cavity wall to the tip of the center conductor is held to a tolerance of ±0.005 inch. The assembly technique described will hold this dimension to ±0.003 inch. Therefore, the critical areas are the waveguide dimensions and the distance from the cavity wall to the center conductor. Both of these dimensions will be reduced from a tolerance of ±0.005 inch to ±0.003 inch. This results in a maximum frequency of 0.005/0.003" x 10.5 GHz, or 17.5 GHz.

The lexan radome presently used is 0.007 inch thick. Any thicker piece degrades the antenna electrical performance without substantially improving the protection. Scaling the antenna frequency to 17.5 GHz requires that the lexan radome thickness be reduced to approximately 0.004 inch. The primary purpose of the lexan radome is to prevent dust and water from collecting in the antenna. It also provides a certain amount of protection from low velocity obstacles. Reducing the lexan thickness will not degrade its primary function; however, there will be some reduction in the amount of protection from obstacles. At this point in the program, and with no other definition available, no problems are anticipated in reducing the lexan material from 0.007 inch to 0.004 inch.

At 10.5 GHz, calculations* show that there will be approximately 0.02 db waveguide loss in the antenna. At 17.5 GHz, waveguide loss will increase to 0.03 db. This loss is insignificant and therefore will cause no problem.

6.3 CONCLUSIONS

Using the previously described high volume production techniques, the highest frequency this antenna can be scaled while retaining the same electrical performance is approximately 17.5 GHz. The reason is that the large dimension of the radiating waveguide and the distance between the tip of the center conductor and the cavity wall can be held to a tolerance of ±0.003 inch in quantities of 1 and 10 million.

Higher frequencies are obtainable, but with an added unit cost. The tolerances on the cavity casting can be reduced. However, the casting vendor will have to inspect each part and reject those parts that do not meet the tighter tolerance. Thus, an added unit cost results. A tolerance of 0.003 inch on the distance between the tip of the center conductor and the cavity wall is sufficient for scaling to a higher frequency. However, since the distance is crucial to the antenna VSWR, a much tighter testing procedure must be adopted. This again will add to the unit cost. It is estimated that scaling this antenna to 21 GHz is possible without a substantial increase on unit costs.

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*Cox, Richard, "Fight Waveguide Losses Five Ways," Microwaves, August 1966.

SECTION VII
SUMMARY

The fabrication techniques selected by Rantec to produce 1 and 10 million flat plate antennas per year are as follows:

- o Die casting
- o Pierce and blanking
- o Injection molding
- o Cold heading

The flat plate antenna will be fabricated in six details using the high volume techniques listed above.

An automatic assembly center will be used to achieve the high volume production runs as shown in Figure 7-1. One such unit operating at maximum efficiency will produce 1 million units per year at a cost of $0.41 per unit. Two additional stations will achieve production runs in excess of 10 million per year at a cost of $0.30 per unit.

The flat plate antenna can be scaled to a frequency of 17.5 GHz with no cost impact or significant effect on performance. Scaling to a frequency of 21 GHz is possible but at a higher cost per unit.

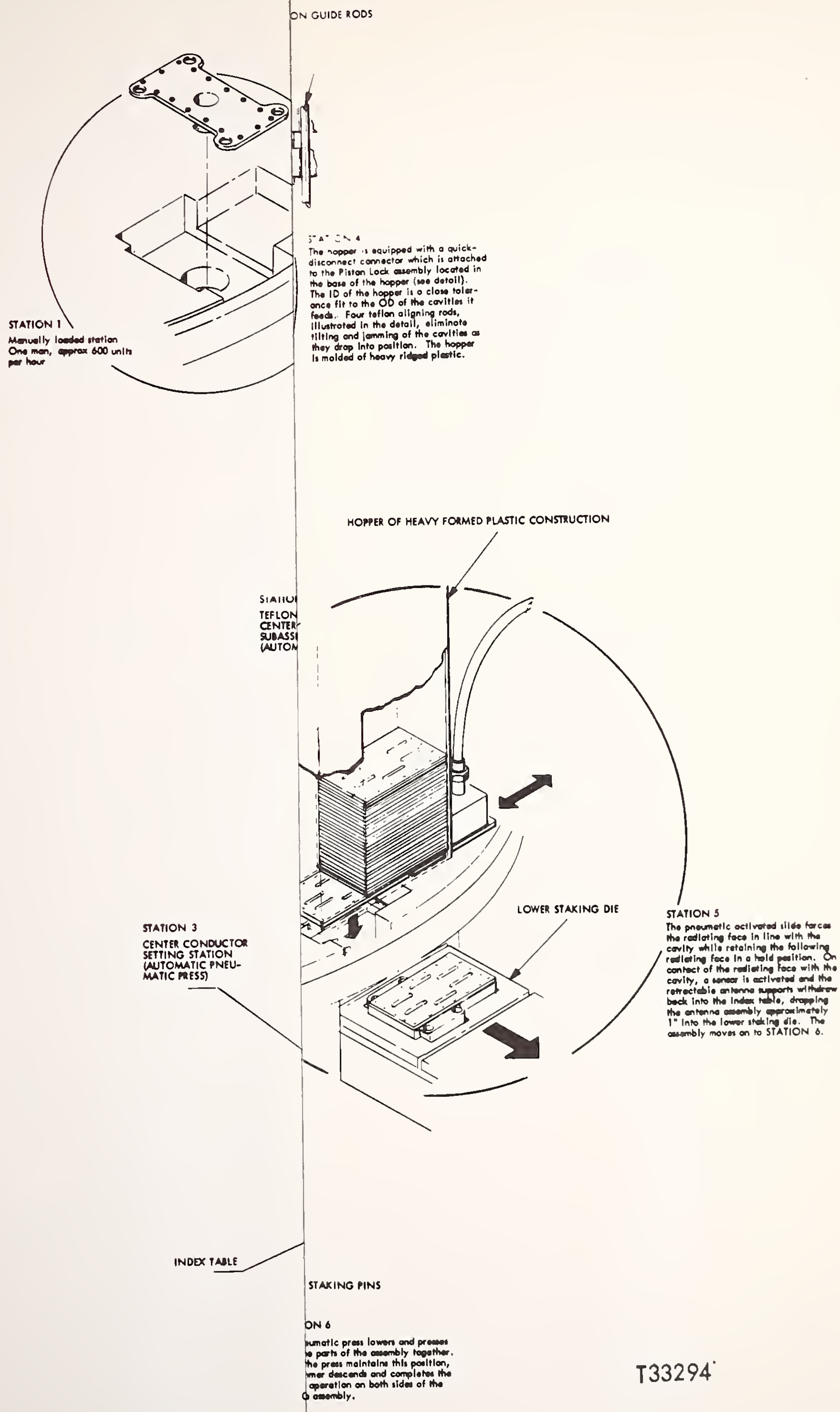

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Figure 7-1. Flat Plate Antenna Assembly Center and Station Details

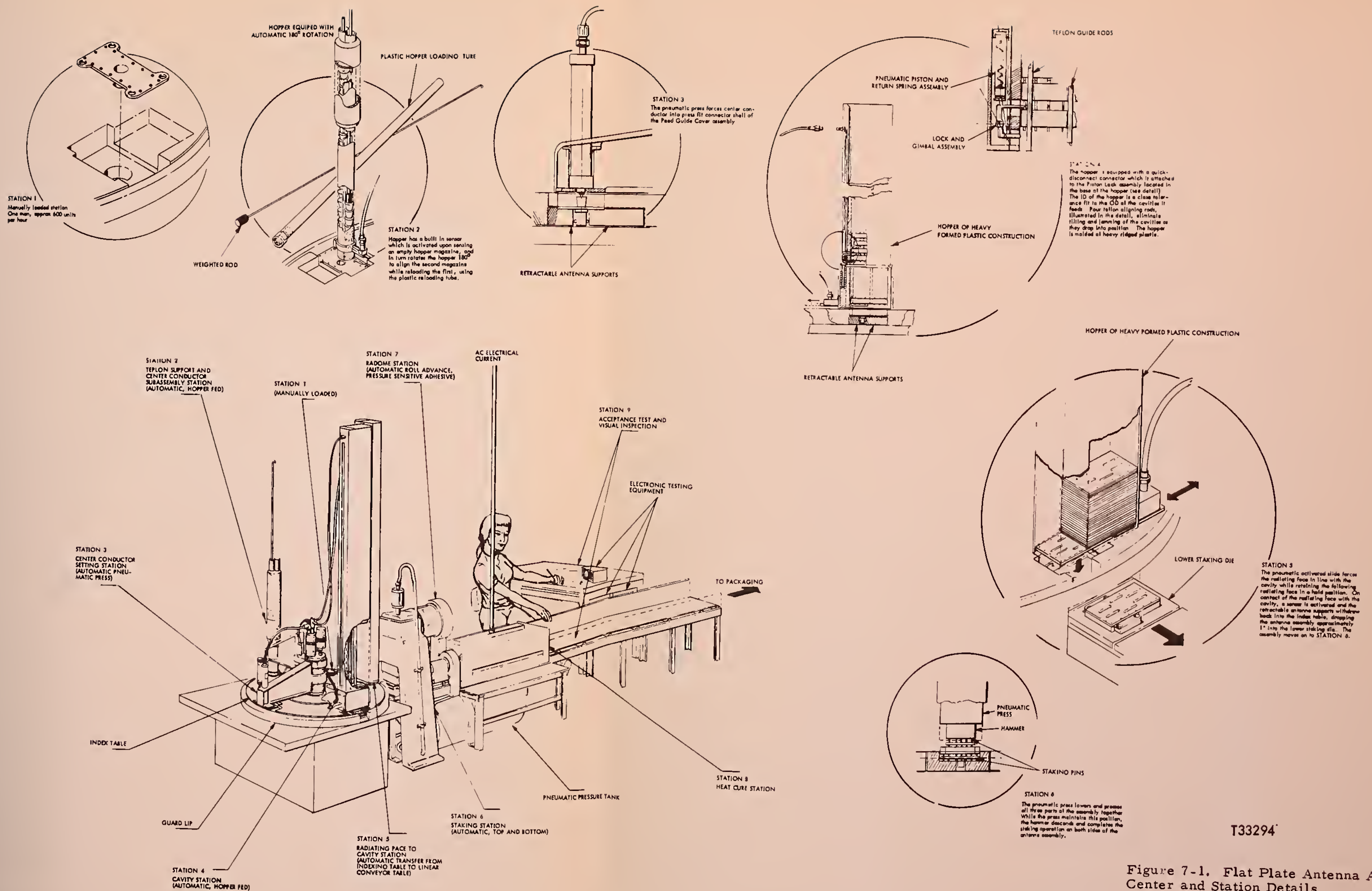

Figure 7-1. Flat Plate Antenna Assembly Center and Station Details