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LF336A LIFT FAN FINAL REPORT

L. J. Volk

April 1, 1969

Prepared under Contract No. NAS2-4130 by

GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

Two 36" diameter, 1.3 pressure ratio lift fans were built under contract NAS2-4130 for use in wind tunnel tests of large-scale aircraft models. This report briefly describes the fan design & summarizes the static test program. Additional information is contained in the following reports:

1. LF336A Design Report (R67FPD376)
2. LF336A Performance Report (R69AEG181)
3. LF336A Installation, Operation & Maintenance Manual

The LF336A fan is a single stage, turbotip, rotor-stator design. The primary power source is a non-afterburning J85-5 turbojet engine. The fan, however, is also capable of operation with the J97 engine. Fan pressure ratio is 1.3 and the fan diameter is 36 inches. Scroll nozzle area is adjustable to accomodate engine variations and installations with other than design duct pressure losses. Major scroll area adjustments can be made to accomodate the J97 engine. The fan is primarily designed to be wing mounted, however provisions are made for lift pod mounting. Static parts are of non-flight-weight, low-stress design, to lower the design and manufacturing cost and to provide configuration flexibility. The fan and turbine stators can be removed in sectors of 24 degrees, and the front frame can be modified to support inlet guide vanes. Overall installation is shown in Figure 1. The system performance summary is given in Table I.

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FAN DESIGN

System Design

The objective of this program is to design and manufacture two high pressure ratio lift fans to be used as research vehicles for obtaining cross flow performance of fan-aircraft systems. Ideally this calls for a complete flight-weight fan design powered by a J97 type engine. However, because of cost, engine availability, timing and test configuration flexibility, the following compromises were made:

1. Non-flight-weight static fan components.
2. The primary power source is one J85-5 with limited operation possible with a J97.

Non-flight-weight static parts design affects the system performance only to the extent of increasing fan weight. The overall dimensions, aerodynamic parameters and fan performance are not significantly affected by the type of construction. The installed performance is therefore representative of advanced design, high pressure ratio fans and high energy engines.

The measurement of vibratory response of the heavily loaded rotor in the flow field existing in the shallow fan-in-wing configuration is of major importance. The flight-weight rotor design assures that the mechanical performance in cross flow obtained with this rotor is representative of other high pressure ratio lift fan designs.

The choice of J85-5 as a power source is logical from the cost and availability standpoint, however it appreciably affects the system performance. Lift fan studies conducted under several other programs show that optimum fan pressure ratio from system standpoint increases as the engine specific horsepower increases. The optimum for J85-5 powered powerplant is approximately 1.15, for J97 approximately 1.25 and for more advanced gas generators 1.30 plus. There are four basic reasons why low specific horsepower engines powering high pressure ratio fans are not optimum:

Thermodynamic - the low specific horsepower engine driving a high pressure ratio fan results in a low bypass, relatively high specific fuel consumption system.

Aerodynamic - the high pressure ratio fan has to operate at relatively high tip speed for optimum efficiency and minimum size. The low specific horsepower turbine must operate at relatively low tip speeds for optimum efficiency.

Mechanical - high pressure ratio fans imply high power loading (horsepower/fan area). To obtain this power with a low energy gas generator requires a large turbine area and consequently, high tip loads and large rotor weight penalties.

Installation - the large turbine buckets, scroll and other ducting, result in a thicker fan installation than could be obtained with a higher specific energy engine.

The major objective was to design the fan similar to one powered by a J97 engine. The design objective was a 1.3 pressure ratio, 36-inch diameter fan.

From the installation standpoint, all efforts were made to reduce the scroll gooseneck height and the scroll bubble diameter. Also, in the area where the bubble diameter exceeded the basic fan thickness, the bubble was underslung so that the inlet depth could be maintained at a minimum defined by the gooseneck (See Figure 1).

Several departures from previous scroll designs were made to reduce its depth. Turbine bucket length was reduced by increasing the turbine rotor axial Mach number. This change by itself resulted in insufficient turbine energy to drive the fan. To increase the turbine energy output, the exhaust flow was diffused in the turbine stators. This design has two other major advantages: 1) smaller turbine size and weight, and 2) lower pressure differential across the front turbine-to-fan seal and consequently, lower tip leakage.

The scroll struts which are required for structural reasons were made to turn the gas flow more toward a radial direction, resulting in a lower gooseneck profile.

The above changes resulted in inlet depth reduction of 1 inch and a reduction in maximum bubble diameter of 1.2 inches when compared with the previously-used design techniques. These changes have reduced the turbine efficiency and increased the scroll pressure losses somewhat. However, they allow an inlet depth reduction more in line with what can be accomplished with a high energy engine. The overall installation depth is still defined by the scroll and is considerably more than the minimum possible with a J97 engine. This additional scroll thickness is placed below the fan proper where the effect on fan and wing performance will be minimized.

In summary, the fan aerodynamic design is essentially the same as if it were designed specifically to be powered by a J97 engine. The rotor weight and stresses are relatively high because of the large turbine mass.

The inlet depth is slightly more than minimum possible with a J97 engine. The overall maximum installation thickness is considerably more because of the large scroll bubble diameter. To handle the same total gas horsepower at the same pressure loss the J85-5 scroll is over 40 percent larger in diameter than the J97 scroll.

The turbine power is 1.5 percent higher than required to drive the fan at its design speed and pressure ratio. This is done intentionally to allow for additional inter-turbine pressure losses which are likely to be encountered in a wind tunnel installation. Toward the same end, the scroll area can be increased 4 percent to accommodate the additional pressure losses and/or a poorer-than-average engine.

Fan Aerodynamic Design

Fan aerodynamic design is based on two branches of technology:

1. The conventional axial compressor technology accumulated over the years of turbojet engine design and more recently augmented by the high pressure ratio, single stage fan designs like the CJ805-23, TF39 front fan, 80-Inch Cruise Fan, and the GE1 family front fans.

2. The 10 years experience accumulated with fan-in-wing fan designs like the X353-5 and X376 fans used in the XV-5A aircraft, with their unique design problems associated with installation and mode of operation.

The basic single-stage fan design methods were modified as necessary to insure compatibility with the fan-in-wing installation environment. Specifically, the inlet design, rotor incidence angle selection, fan flow path, and radial energy input distribution are greatly influenced by the fan-in-wing experience.

The most significant fan aerodynamic design parameters are given in Table II. Figure 2 shows the predicted fan map of fan total pressure ratio versus flow. Figure 3 shows the predicted fan map of fan efficiency versus flow.

Turbine Aerodynamic Design

The LF336 tip turbine is an axial flow, impulse turbine fed by a 360-degree double inlet scroll and exhausting into a short, vaned diffuser. The turbine design point was set at a nominal admission arc of 346 degrees but this can be increased to 360 degrees for gas generator matching. Table III lists the significant aerodynamic design parameters.

The tip turbine drive gas conditions correspond to the sea level standard day exhaust gas conditions of a J85-GE-5 (Model Specification E-1024C, dated 29 June 1962) General Electric turbojet engine at military power setting, except for 8 percent assumed duct and scroll total pressure loss (inter-turbine loss).

The tip turbine design speed and power output are matched to the fan at its sea level standard day design point. To make the turbine flow path geometry compatible with the fan tip flow path and scroll geometries, there is an inward slope of about 15 degrees in the turbine flow path. Because of the difficulty of providing a good air seal over the bucket tip shroud, it was very desirable to design the turbine for zero static pressure drop across the bucket tip. This is achieved by designing a curvature into the flow path in the region between nozzles and buckets which cancels the radial static pressure gradient which would otherwise exist due to the nozzle exit swirl velocity.

Static Parts Mechanical Design

All of the static parts are of non-flight-weight, minimum cost, maximum test flexibility design. Material selection and manufacturing methods are not typical of any previous lift fan designs. The design criteria are based on on the type of operation and environment likely to be encountered in the 40-x-80-foot NASA-Ames wind tunnel and/or a typical outdoor static test stand. No attempt has been made to design to flight environment and maneuver loads. The design criteria common to all static components are given in Table IV.

Front Frame. - The front frame (Figure 4) is the major structural component of the fan. It transmits the rotor lift and moment directly through the rotor shaft and through the major and minor struts to the airframe or facility mounts. Some of the scroll loads, and indirectly, the rear frame loads, pass through the front frame struts to the airframe model mounts. The front frame establishes the fan inlet flow path, positions the forward honeycomb air seal between the fan and turbine flow paths, and supports the scroll seal which prevents leakage of hot gas into the airframe model. The major front frame components are cast from 17-4 PH steel, a readily available material with the desirable material properties of tensile strength, ductility corrosion resistance, and low thermal growth coefficient.

The major strut is cast integrally with the hub at the center and a short section of the bellmouth on the outside. The strut forms an inverted "T" section beyond the bellmouth to retain section properties while providing clearance over the scroll. Radially outboard of the scroll, the strut drops down below the wing surface for attachment to the airframe. Two 3/4-inch diameter holes are provided at the center for a lifting fixture. A channel is provided the length of the strut for instrumentation routing. The major strut transmits rotor lift, one component of rotor gyroscopic moment, part of the bellmouth lift, part of the scroll and rear frame lift, and the scroll piston force to the fore and aft airframe mounts.

Rear Frame. - The rear frame shown in Figure 5 houses the fan and turbine stators and defines the fan and turbine exit flow paths. This frame structure carries only loads generated by the stators. The rear frame can be completely removed, without affecting the structural strength of the fan, to provide the desired testing flexibility. The fan and turbine stators are cast in sectors of three vanes each, for a total of 15 sectors. In addition to removal of the entire rear frame, it is also possible to remove up to 4 sectors of fan and/or turbine stators.

Scroll. - The scroll directs the gas from engine discharge to the tip turbine. The major scroll components are the inlets, scroll shell, torque tube, struts and nozzle partitions. Top and bottom views of the scroll are shown in Figures 6 and 7.

The scroll is a full admission design with provisions for reducing the nozzle discharge area as necessary to match various engine exhaust conditions. The entire structure is designed to operate at or near the gas temperature to reduce thermal gradients and stresses. To accomplish this all stiffeners, baffles and the torque tube are vented to the gas stream and the entire scroll is insulated.

The scroll has two design points; one with a full admission J85-5 engine and one with partial admission advanced engine.

Mounting. - The fan mounting must be compatible with fan-in-wing and fan-in-pod installation. This requirement, and the full admission scroll design, result in a mounting arrangement quite different from previous lift fan designs. Some front frame loads are transmitted to the facility (airframe) through the scroll at 3 and 9 o'clock. The front frame-to-scroll mount is bolted to the bellmouth at the end of the minor strut. This mount extends into the unibal in the scroll. The scroll transmits rear frame loads and gyroscopic and cross flow moments from the front frame, through a tube to another unibal which is in turn connected to the facility mount. The scroll transmits loads to the front frame at 6 and 12 o'clock through a rubbing block and pad into the major strut. Only upward (lift) loads from the scroll can be transmitted in this manner. Rubbing pads are lubricated to prevent binding. Piston loads from the scroll inlets are carried through links into clevises mounted at the sides of major strut ends. Major strut loads are in turn transmitted to the facility through the unibal at the ends of the struts.

The rear frame is mounted to the scroll by fifteen links. These links carry stator lift and torque loads from the rear frame assembly to the scroll brackets which are attached to the torque tube on the scroll.

The fan has the unique requirement that it also must be capable of being mounted in a pod position. To achieve this, the scroll can be rotated 90 degrees relative to the front frame. A pair of minor strut extensions, two additional auxiliary scroll-to-front frame mounts, and two additional major strut-to-airframe mounts are required. (Not supplied with fan).

Rotating Parts Mechanical Design

It was the intention at the beginning of the program to use existing state-of-the-art (LF2 and X376 technology) in the LF336A rotor design to insure low-cost trouble-free components. The rotor geometric appearance is similar to the X376 (XV-5B pitch fan) with the rotating outer bearing race. However, there are significant differences which necessitated advancements in the existing lift fan rotor technology.

The hub and tip are sloped 15 degrees, requiring a new approach to disc and carrier design, as well as requiring changes in blade dovetail and tang transitions. The design rotor tip speed is 15 percent higher than demonstrated on any previous tip turbine rotor, and the resulting "g" field in which the carrier operates is two times that of the geometrically-similar X376 rotor. The bucket length is 1.5 times that of the X376, resulting in a three-fold increase in blade tip load.

As a result of these difficult requirements, improvements in materials and design technology had to be made.

The rotor is shown in Figure 8. The rotor components weight is as shown below:

Turbine Carrier System	
Blades (including tangs and dovetails)	
Disc	
Sump and Miscellaneous Hardware	
TOTAL	131.16 pounds

The rotor design reflects some conservatism which is necessary to provide the desired reliability and adaptability for conducting development testing of various configurations under extreme operating conditions.

Blades. - The fan blade shown in Figure 9 is similar in construction to the other General Electric Company tip turbine lift and lift/cruise fan blades. The fan rotor consists of 42 blades made of 6AL-6VA-2SN titanium alloy. Each blade is held in place by an integral, single hook dovetail mounted on the slotted rim of the rotor disc.

The blade circular arc airfoil is attached to the dovetail through a section of platform and a shank of rectangular cross-section. The blade tip airfoil transitions into a tang of rectangular cross-section through a fillet. The faces of the tang are normal and parallel to the rotor axis of rotation. The function of the tip tang is to hold the turbine sectors (one sector for every two blades) by means of a bolt through the tang hole.

Turbine Carrier Assembly. - The turbine consists of a single bucket row located at the fan blade tip. This annular turbine is divided into 21 individual sectors, or carriers, each of which is attached by bolts to two fan blades. There are 189 buckets in the design, 9 buckets in each of the 21 bucket carrier brazed assemblies. See Figure 10.

Disc. - The disc is shown in Figure 11. The disc contains integral flow path platforms, integral blade retainers, axial dovetail slots in the rim, and flanges at the hub for bearing housing attachment. The disc is of solid titanium construction. Disc weight could be reduced by half through the use of a hollow titanium structure at increased cost. Rotor polar moment of inertia is 3.58 pound-feet per second squared with the disc and sump contributing only 0.38 pound-foot per second squared.

Sump. - The LF336/A has a ball bearing sump and a roller bearing sump. Both sumps have multi-purpose bearing retainers which retain the bearing to the disc and bearing housing, and which form a grease cup and a sealing surface for the piston ring seals. Grease cavities are adjacent to the bearing, formed by the bearing retainer and an internal deep cup seal. Piston ring seals prevent loss of grease from the grease cavities. Bearing housings mate to the disc and hold the bearing outer ring and seal runners. The ball bearing is located to facilitate fan disassembly. By removing the two ball bearing retainers and the outside inner ring, the entire rotor can be removed from the front frame.

FAN STATIC TESTING

The static tests were conducted at the General Electric Flight Test Center at Edwards Air Force Base, California. Contract provisions specified that one fan be tested a minimum of ten hours to define mechanical and performance levels, then be disassembled, inspected, repaired as necessary and reassembled. The second fan was to be tested a minimum of two hours to determine performance levels and to assure mechanical integrity.

Test Configuration

Figure 12 shows the front view of the LF336A in the test stand. A rear view is shown in Figure 13. The fans were tested with the rotational axis horizontal and about 10' above the ground to eliminate ground effects. The J85 engine was mounted with its rotational axis perpendicular to the fan axis. The J85 exhaust was ducted to the fan scroll by the "pants legs" duct assembly shown in Figure 14.

Test Run Summary

Fan 001 was tested a total of 5 hours and 56 minutes. Table V is a run summary for fan 001. Fan 002 was tested for 13 hours and 7 minutes, then the required disassembly and inspection was performed. Following reassembly, fan 002 was run for an additional 3 hours and 57 minutes. The total time on fan 002 is 17 hours and 4 minutes. Table VI is a run summary for fan 002.

Problems During Testing

Turbine FOD. - During the tests of fan 001, FOD was experienced in the scroll nozzles and turbine buckets. This FOD was caused by small particles of weld spatter, braze spatter, cutting chips, burrs and the like, left in the scroll during manufacture and assembly. Scroll turbine nozzle damage was slight and was corrected by simple bench operations. Turbine bucket damage was more serious - almost all carrier assemblies of fan 001 showed some evidence of FOD. Most of the damage consisted only of slight scratches or buck shot size dimples and dents which do not affect mechanical integrity or performance. Other damage consisted of dents, dings and tears which required repair. Figure 15 illustrates the kind of damage incurred.

Following run 5A of fan 001 (see Table V), the fan was disassembled and the damaged carriers were sent to the General Electric Company Lynn facility (the carrier manufacturer) for repair.

A study was underway at this time, under contract NAS2-4340, to identify a technique for repair of similar damage on XV-5B turbine bucket carriers. This study had identified a brazed patch technique and a braze process, which were applied to the LF336A carriers. Figures 16 and 17 illustrate typical patch repairs for a turbine bucket and a turbine shroud.

In an attempt to prevent the same problem from occurring on fan 002, the scroll of fan 002 was mounted in the test stand (Figure 18) and blown out by the J85 engine. The scroll for fan 001 was mounted in the assembly dolly and manually rotated while stethescope sensings were taken. No loose particles were heard. But after return to test, a small amount of turbine FOD was again experienced on fan 001 in run 8, a high speed run. The stethescope sensings failed to detect these fine particles still in the scroll. Except for a few scattered hits during the high speed runs following run 8, no other FOD was experienced on fan 001. During the testing with the damaged buckets, no crack propagation was observed on any of the buckets.

The repeat of FOD in fan 001 indicated that running with the engine was not necessarily sufficient to clean out the scroll. Therefore, before the start of testing fan 002, the scroll for fan 002 underwent extensive shop work. Access ports were cut at several locations for visual internal inspection. All burrs and weld flash were carefully removed. Shop air lines were used at several torque tube vents to clean out the scroll cavities and these holes were then baffled. Finally, the scroll was once more blown out at the test stand by the engine.

These scroll cleaning runs consisted of about one hour of running at max engine speed, plus a series of engine throttle bursts and chops. Following run 14, similar shopwork and scroll blow out were performed on fan 001. FOD due to scroll residue, therefore, is not expected to be a concern in the wind tunnel.

The carrier brazed patch repair process has worked very well, high speed fan operation with the repaired carriers has adequately demonstrated the integrity of the repair method.

Bucket Stresses. - Unusually high turbine bucket stress caused concern in runs 6-8 on fan 001. For run 9, the two scroll blocker plates (used to trim gas generator discharge area) were removed. The bucket stresses were cut in half. The two plates were not adjacent, but were separated by one open scroll nozzle partition. This spacing apparently induced bucket excitation. Turbine stresses were well within limits for all subsequent runs.

Roller Bearing Wear. - Unusual wear patterns were observed on the roller bearing on fan 001. The bearing assembly was sent to Evendale for examination. The pattern was caused by skidding. The bearing housing on both fans has been machined to better seat the bearing and improve the bearing contact. There was no damage to the roller bearings. Similar wear patterns were observed on fan 002, indicating that the bearing housing adjustment did not eliminate the problem. The wear is caused by skidding of the rollers when under light load. A replacement set of bearings with tighter radial clearances has been ordered from the vendor for each fan. These will be shipped as fan spare parts and can be installed in the fans during the next scheduled fan disassembly at the wind tunnel. The bearings now in the fans are quite adequate for present use and impose no restrictions on fan operation.

Blade Tang Temperature. - Fan 001 went to test with two blade tangs instrumented with thermocouples to monitor blade tang temperature. Excessive tang temperatures were experienced during the initial checkout runs. The fan blades and tangs are made of 6-6-2 titanium. For the stress levels experienced by the blade tangs, the maximum allowable temperature is 600°F. Operation at temperatures above 600°F will decrease blade life.

The air deflector (Figure 19) is a metal strip which covers the honeycomb forward air seal around the fan inlet. The function of the air deflector is to prevent turbine leakage from penetrating the fan inlet flow stream by deflecting any such leakage against the fan tip wall. Runs were made with this deflector both on and off. No apparent effect on fan performance or on tang temperature was observed.

There is a small clearance or gap between adjacent carriers. Suspecting hot gas leakage through these gaps, a metal tab (nicknamed the bowtie) was made and was installed beneath the torque links to cover these gaps, as shown in Figure 20. Tests were run, and the results showed these bowties to have no apparent effect on tang temperature.

In run 5, shop cooling air was piped into the turbine carrier region. No effect on tang temperature was noted.

Runs 5 and 5A were made with two end plates inserted in the gaps between carriers, one plate on each side of the tang which recorded high temperatures. A drop of about 40°F in tang temperature was observed, indicating that hot gas leakage to the tang through the open ends of the carrier assembly was a likely cause of tang overtemperature. Fan 001 was removed from the stand and disassembled following run 5A. End plates (Figure 21) were welded on all carriers. The fan returned to test with these end plates and with improved clearance on the forward air seal. Tang temperature was reduced, but not enough. Additional testing was done in a systematic effort to solve the problem.

A ceramic insulation was applied to the tang bolt and carrier walls of one instrumented tang to reduce heat transfer from the turbine to the tang. But this had no observable effect on tang temperature.

The carrier tang slot was enlarged as shown in Figure 22. (Compare the slot shape in Figures 10 and 22). Tang temperature was lowered significantly.

Ramps and dams (Figure 23) were tested. A ramp is a tab attached to the carrier at the discharge side of the tang slot to create a low pressure and thus draw cooling air through the slot. A dam is a similar tab attached to the carrier at the inlet side of the tang slot to direct more cooling air into the slot. The tests showed that dams were more effective than ramps. Honeycomb dams (Figure 22) were brazed to all carriers.

The tang faces which contact the carrier were coated with a copper-nickle-indium coating to inhibit fretting. This full-face coating was removed and replaced with two thin strips of similar coating, one strip on each side of the tang hole. (This will not affect the ability of the coating to inhibit fretting). There was no apparent effect on the tang temperature.

During initial testing of fan 002, tang temperatures were less than before, but still too high for the high ambient temperature environment expected during wind tunnel use. During the scheduled teardown inspection of fan 002, the forward air seal axial overlap was increased and radial clearance decreased. For run 19A on fan 002, higher dams were added to the fan. These changes significantly decreased the tang temperature. The two fans were shipped with these new dams and with the adjusted forward air seal clearances. Figure 24 is a curve of tang temperature as a function of ambient temperature and engine EGT. This curve is based on the total results of the tang temperature investigations, and represents the fans as shipped to the wind tunnel. The data indicates that wind tunnel ambients as high as 120°F can be experienced in the wind tunnel without exceeding the 600°F tang temperature limit based on static tests. Effect of crossflow on tang temperature is unknown and should be monitored during initial wind tunnel operation.

Fan 002 Inspection Results

The contract specified a minimum of ten hours of fan operation prior to the inspection. The total running time on the fan at start of teardown was 13 hours and 7 minutes. The fan was completely disassembled and inspected. All parts were inspected using zyglo penetrant or a 10X glass. In addition, five repaired bucket carriers were returned to Evendale and X-rayed.

The following three deficiencies were found during the inspection:

- One tang nut was cracked, probably due to being over-torqued during assembly. Corrective action taken: Torque to be applied during rotor assembly has been reduced.
- Several minor scroll braze cracks were found at the nozzle and strut braze joints. These cracks are the self-relieving type and do not leak. They are similar to those previously found after fan 001 operation and were expected after initial thermal cycling of the scroll. Corrective action taken: Cracks were brazed with gold-nickle alloy.
- A small local misalignment was noted between the scroll nozzles and turbine buckets due to scroll eccentricity. Corrective action taken: The scroll nozzle passages were benched to remove this eccentricity.

No other discrepancies were found. The inspection results have adequately demonstrated the mechanical integrity of the fans.

Fan Map Characteristics

The fan map characteristics were measured using fan 002. An instrumented measuring section was used. This measuring section was mounted to the fan discharge as shown in Figures 25 and 26. The fan discharge area was varied by a nozzle which was bolted to the end of the measuring section outer casing, and by an inner cone which was bolted to the end of the measuring section centerbody. Five nozzles were used for the tests. The fan discharge area variation available was from 61.7% to 108.5% of the fan discharge design area.

Figure 27 shows the measured fan map characteristics. During these tests, the fan performance, particularly at high speeds, was deficient due to gas leakage from the forward air seal. Following the scheduled teardown and inspection, the fan was run with the forward air seal adjusted to give greater axial overlap and decreased radial clearance between the rotor running lip and the stationary honeycomb ring. The fan performance was much improved. Figure 28 shows the estimated fan map characteristics, obtained by extrapolating the test results of Figure 27 to the new measured performance levels. Figure 28 represents the fan performance for the fans as delivered to the wind tunnel.

Figure 29 compares the estimated fan map characteristics for the fans as shipped (Figure 28) to the initial predicted fan map (Figure 2). The same trend is evident for the LF336A fans as has been noted for other lift fan designs, namely, the lift fan measured map characteristics show the lines of constant speed to be flatter than predicted. Fan pressure ratio at constant speed does not drop off with increasing airflow as fast as the analytical design methods would predict.

Figures 30 and 31 show thrust versus speed and speed versus delivered horsepower, for the fan 002 final configuration. These data represent the performance of the fan as delivered.

Fan Performance with Exit Louvers

By amendment to contract NAS2-4970, noise measurements were taken on one fan (fan 002 was used) as follows:

1) in the design configuration, without exit louvers

2) in the design configuration, with exit louvers

3) with rotor-stator spacing increased to two chords, without exit louvers. (This two-chord spacing configuration is denoted as the LF336B). There was no apparent change in fan performance between the LF336A and the LF336B configurations.

These noise measurements data are now being evaluated and will be reported under contract NAS2-4970.

Figure 32 shows fan 002 with the exit louvers (NASA-supplied) installed. The louver cascade consisted of 10 variable-camber airfoils having 6.1 inch chords with 4.35 inch spacing. For these tests, the louvers were held rigid so that the camber of the louver airfoil did not vary from that at the zero-degrees vector angle. The cascade was installed with the louver leading edges located 5.75 inches axially down stream of the fan stator trailing edge. Figures 33, 34 and 35 show the lift, thrust, and total thrust of the fan as functions of louver angle and fan speed.

Measured Thrust Performance Summary

The contract target thrust of the fans was 5210 pounds at rated horsepower. The measured fan thrust levels are:

	Fan 001	Fan 002
Thrust at 100% speed	5567	5709
Thrust at rated horsepower	5418	5445
Speed at rated horsepower	98.66	96.65

Both fans exceeded the contract target thrust level. The fan 002 performance represents the fan as delivered. The fan 001 forward air seal clearance was adjusted after the fan 001 tests, therefore, the fan 001 thrust at 100% speed and speed at rated horsepower for the fan as shipped are closer to the fan 002 performance than listed above.

TABLE I

SYSTEM DESIGN PERFORMANCE SUMMARY - SLS DAY

Fan Flow, lb/sec	218
Fan Pressure Ratio	1.3
Bypass Ratio	5.0
RPM	6047
Fan Tip Speed, ft/sec	950
Turbine Flow Function	$W\sqrt{T_T/P_T} = 57.3$
Turbine Inlet Flow, lb/sec	44.12
Turbine Inlet Temperature, deg	1251°F (1711°R)
Turbine Inlet Pressure, psia	31.84
Inter Turbine Pressure Loss, pct	8
Fan Thrust, lb	4426
Turbine Thrust, lb	1120
Total Thrust, lb	5546

TABLE II

FAN AERODYNAMIC DESIGN PARAMETERS

Fan Pressure Ratio	1.3
Fan Flow, lb/sec	218
Fan Diameter, in.	36
Fan Tip Speed, ft/sec	950
Rotational Speed, RPM	6047
Radius Ratio	0.475
Flow Per Annulus Area, lb/sec-ft^2	40
Fan Thrust, lb	4426

TABLE III

TURBINE AERODYNAMIC DESIGN PARAMETERS

Inlet Total Temperature, ^{o}R	1711
Inlet Total Pressure, psia	31.84
Inlet Gas Flow, lb/sec	44.12
Total to Static Pressure Ratio	2.34
Total to Total Pressure Ratio	1.92
Turbine Exit Static Pressure, psia	13.62
Turbine Exit Total Pressure, psia	17.38
Speed, RPM	6047
Design Energy, Btu/lb	58.4
Turbine Tip Diameter, in.	42.93
Turbine Hub Diameter, in.	38.63

TABLE IV

STATIC PARTS DESIGN CRITERIA

Life - 300 Hours With J85-5 Engine
Life - 10 Hours With J97 Engine

No Weight Restrictions

Corrosion Resistant Material

Gyroscopic Load - 0.1 rad/sec Precession

Maneuver Load - ± 4 g's Vertically

All Airfoils Aero-Elastically Stable (Inverse Strouhal Number Less Than 2.0)

Maximum Ambient Temperature - 120°F

Maximum Cross Flow Velocity - 150 Knots

Scroll Admission Arc - 346° to 360° With J85-5 Engine
Scroll Admission Arc - 160° to 180° With Advanced Engine

Fan Capable of Operation Without Rear Frame Stators

Front Frame Capable of Accepting Inlet Guide Vane Loads

Primary Mounting Objective: Fan-In-Wing

Secondary Mounting Objective: Fan-In-Pod

TABLE V

FAN 001 TEST RUN SUMMARY

RUN	DATE	FAN MAX RPM	CUMULATIVE TEST TIME HR.	MIN.	COMMENTS
1	9/16/68	1975	0	6	First run of fan. Low speed checkout.
1A	9/16/68	2100	0	15	Repeat of run 1 at increased rpm.
2	9/18/68	2700	0	25	Low speed checkout. Air deflector added.
2A	9/18/68	3700	0	34	Repeat of run 2 at increased rpm.
3	9/19/68	4700	0	42	Repeat of run 2 at increased rpm.
4	9/20/68	3750	0	46	To evaluate effects of bow ties on tang temperature.
4A	9/20/68	3750	0	49	Repeat of run 4.
4B	9/20/68	5450	0	52	Repeat of run 4 at increased rpm.
5	9/24/68	3600	1	0	To evaluate effect of cooling air and temporary carrier end caps on tang temperature.
5A	9/24/68	3600	1	6	To evaluate effect of cooling air on tang temperature. After run 5A, fan was removed from the stand & disassembled. The forward air seal clearance was decreased & permanent carrier end plates were installed.
6	10/19/68	2810	1	19	First run after new buildup. Objective was to demonstrate mechanical integrity and to evaluate effect on tang temperatures for reworked forward air seal and for carrier end plates.
6A	10/19/68	3593	1	38	Repeat of run 6 at increased rpm.
6B	10/19/68	4800	1	53	Repeat of run 6 at increased rpm.
7	10/21/68	2850	2	5	To evaluate effect on tang temperature, for addition of insulation to tang bolt and carrier wall.
8	10/23/68	5615	2	25	High speed run. To evaluate air deflector effectiveness.

TABLE V (CONT'D)

RUN	DATE	FAN MAX RPM	CUMULATIVE TEST TIME HR.	MIN.	COMMENTS
9	10/24/68	4800	2	45	To evaluate effect of scroll blocker plates on bucket stress. To evaluate effect of bow ties and tang slot closing on tang temperature.
9A	10/24/68	2933	2	55	To evaluate effect of air deflector on performance and on tang temperature.
10	10/25/68	3616	3	15	To evaluate effect of ramps and dams on tang temperature.
10A	10/25/68	4940	3	37	To evaluate effect of ramps and dams and bow ties on tang temperature.
10B	10/25/68	3640	3	56	To evaluate effect of dams on tang temperature.
11	10/28/68	3632	4	16	To evaluate effect of carrier cooling slots on tang temperature.
12	10/29/68	3612	4	35	To evaluate effect of dams plus carrier cooling slots on tang temperature.
12A	10/29/68	3624	4	35	To evaluate effect of dams, carrier cooling slots and bow ties on tang temperature.
12B	10/29/68	3592	5	10	To evaluate effect of dam geometry on tang temperature.
13	11/4/68	4915	5	29	Instrumentation Checkout.
14	11/5/68	5945	5	56	Thrust Incentive Run.

TABLE VI

FAN 002 TEST RUN SUMMARY

		FAN	CUMULATIVE TEST	TIME	
RUN	DATE	MAX RPM	HR.	MIN.	COMMENTS
1-4		--	-	-	Scroll functional checkout, no rotor installed.
5	12/17/68	3640	0	16	Initial fan system checkout with measuring section installed. Nozzle No. 7, cone off, area 100%.
5A	12/17/68	4840	0	36	Repeat of run 5 at increased rpm.
6	12/20/68	5970	0	59	Performance data & Instrumentation checkout. Nozzle No. 7, cone off, area 100%.
7	12/31/68	5863	1	21	Fan map definition using measuring section. Nozzle No. 9, cone off, area 90.8%.
7A	12/31/68	5937	1	45	Fan map definition using measuring section. Nozzle No. 13, cone off, 82.9%.
7B	12/31/68	5950	2	07	Fan map definition using measuring section. Nozzle No. 7, cone off, area 100%. Repeat of run 6.
7C	12/31/68	5975	2	26	Fan map definition using measuring section Nozzle No. 7, cone on, area 78.8%.
8	1/2/69	3450	2	32	Fan map definition using measuring section. Nozzle No. 9, cone on, area 69.5%. Stall observed at about 2400 rpm.
8A	1/2/69	5950	2	54	Fan map definition using measuring section. Nozzle No. 11, cone off, area 108.5%.
9	1/3/69	5946	3	22	Repeat of run 8A with air deflector removed.
9A	1/3/69	5978	3	47	Measuring section removed. Air deflector installed.
10	1/7/69	4897	4	07	Checkout run to 80% rpm to evaluate effects of modified dams, modified air deflector, & RTV-filled forward air seal on tang temperature.

TABLE VI CONT'D

		FAN	CUMULATIVE TEST TIME		
RUN	DATE	MAX RPM	HR.	MIN.	COMMENTS
10A	1/7/69	4220	4	22	Run aborted-lost blade stress gages.
10B	1/7/69	5800	4	45	Repeat of run 10, at increased rpm.
11	1/8/69	5876	5	6	Same as 10, 10A & 10B, with RTV removed from seal. To evaluate effect of clean seal on performance & tang temperature.
12	1/10/69	5976	5	37	Checkout run at max speed.
13	1/14/69	4853	5	55	To evaluate effect of reduced clearance of forward air seal on performance & tang temperature
13A	1/14/69	5490	6	7	Repeat of run 13, at increased rpm.
13B	1/14/69	5880	6	19	Repeat of run 13, at increased rpm.
14	1/16/69	5938	9	42	LF336A noise measurements. Run time 3 hours & 23 min. No exit louvers.
15	1/17/69	5907	11	33	Noise measurements, exit louver angle 0 degrees.
15A	1/17/69	5998	11	46	Noise measurements, exit louver angle 40°.
15B	1/17/69	5920	12	35	Noise measurements, exit louver angle 30°.
15C	1/17/69	5928	12	49	Noise measurements, exit louver angle 20°.
15D	1/17/69	5995	13	7	Noise measurements, exit louver angle at maximum.
16	2/17/69	3000	13	12	Checkout run following teardown, inspection & rebuild. LF336B configuration (2 chords spacing). Seal overlap increased & seal clearance decreased.
16A	2/17/69	4225	13	27	Noise Measurements
16B	2/17/69	5350	13	43	Noise Measurements

TABLE VI CONT'D

RUN	DATE	FAN MAX RPM	CUMULATIVE TEST TIME HR.	 MIN.	COMMENTS
16C	2/17/69	5980	13	59	Noise Measurements
17	2/20/69	5930	15	48	Noise Measurements
18	2/26/69	5880	16	19	Fan returned to LF336A configuration. Checkout run.
19	2/27/69	5920	16	42	Thrust incentive run
19A	2/27/69	5940	17	4	Repeat of run 19.

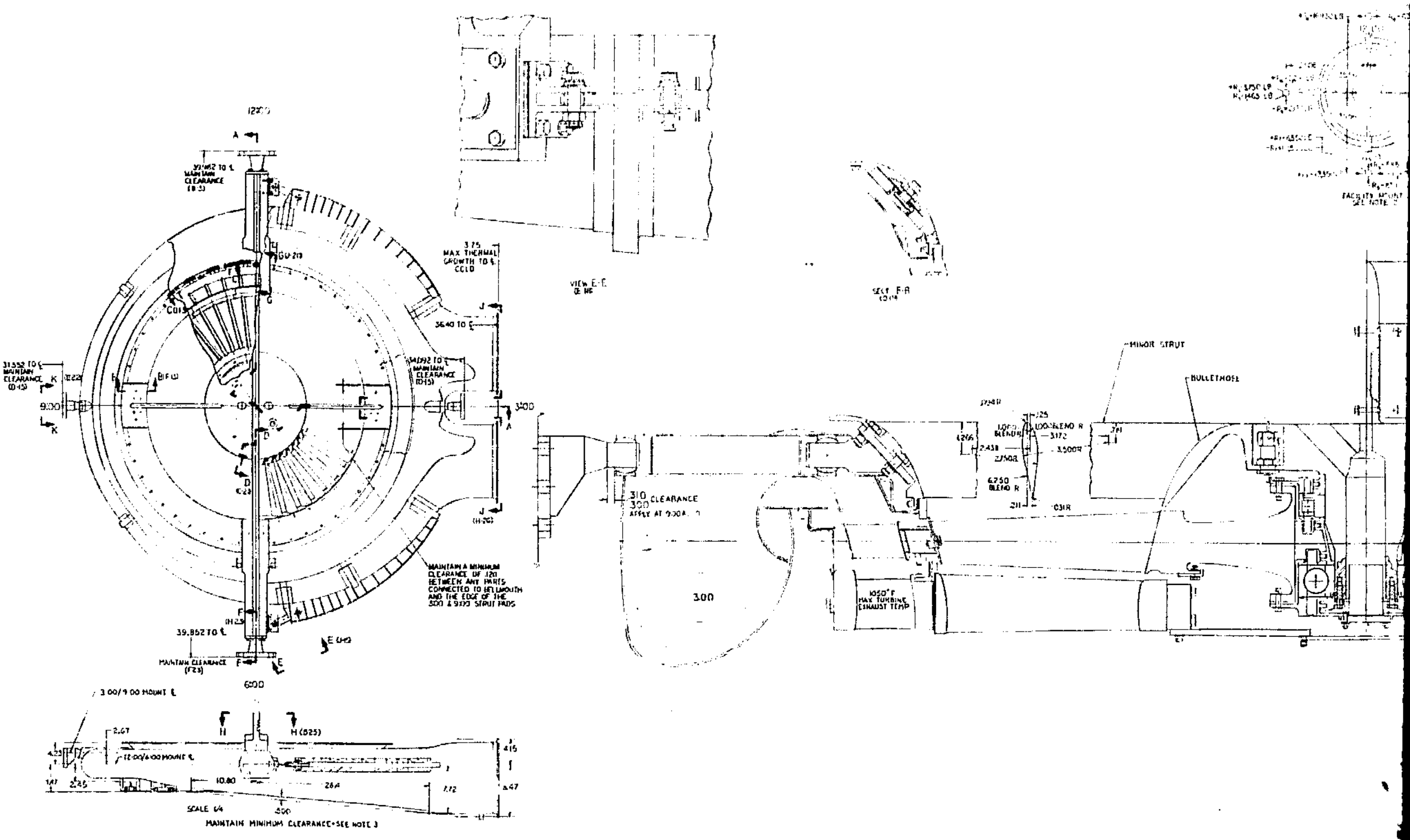
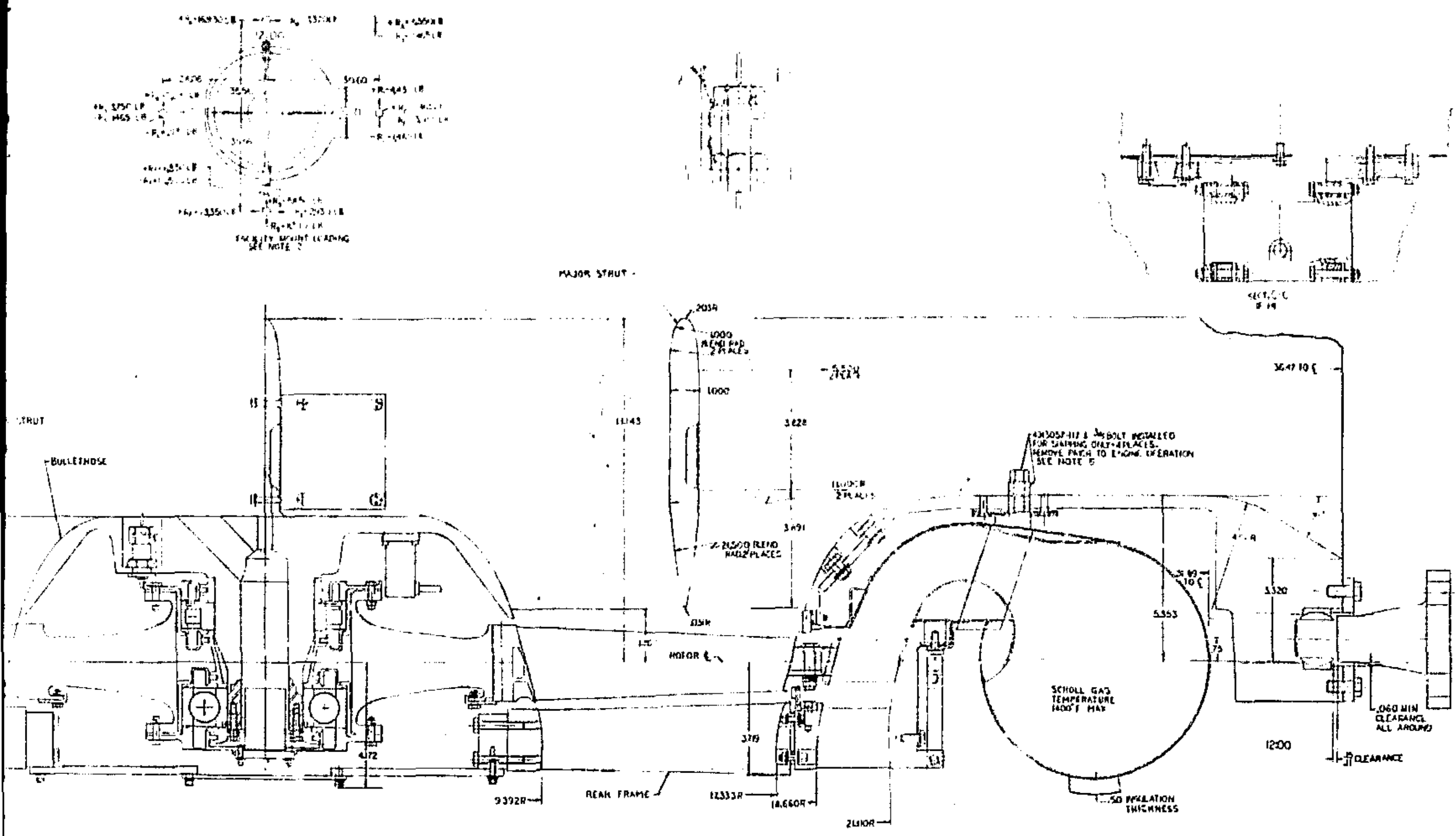


Figure 1 Fan Installation

FOLDOUT FRAME



6 BEFORE CONNECTING DUCTING TO THE FAN, REMOVE ALL DEBRIS IN THE SCROLL AND DUCT TO PREVENT DAMAGE TO THE ROTOR.

5 PRIOR TO SHIPPING INSTALL RETAINERS AS SHOWN (E4) SUPPORT THE ROTOR BY INSTALLING STRIPS OF FOAM RUBBER BETWEEN THE ROTOR AND REAR FRAME

4 ANY CONNECTION TO THE BELLMOUTH MUST BE FLEXIBLE. IT MUST NOT TRANSMIT LOAD FROM THE BELLMOUTH TO THE AIRFRAME.

3 THE GENERAL ELECTRIC CO. IS TO BE CONSULTED BEFORE LOCATING AIRFRAME PARTS OTHER THAN FAN CONNECTIONS WITHIN .500 OF THE FAN

2 THE ONLY FAN MOUNTING SYSTEM PERMITTED BY THE GENERAL ELECTRIC CO. IS SHOWN IN ZONE U-10. ANY OTHER SYSTEM REQUIRES CONSULTATION BY THE GENERAL ELECTRIC CO. THE LOADS SHOWN ARE THOSE EXERTED ON THE MOUNTS BY THE FAN AND INCLUDES 3.4G VIBRATORY LOADING IN ALL DIRECTIONS AND A 1.5 SAFTY FACTOR.

1 UNTOLERANCED DIMENSIONS ARE FOR REFERENCE ONLY. ANY MODIFICATIONS MUST BE MATED TO THE ACTUAL FAN ASSEMBLY.

Fan Installation Drawing

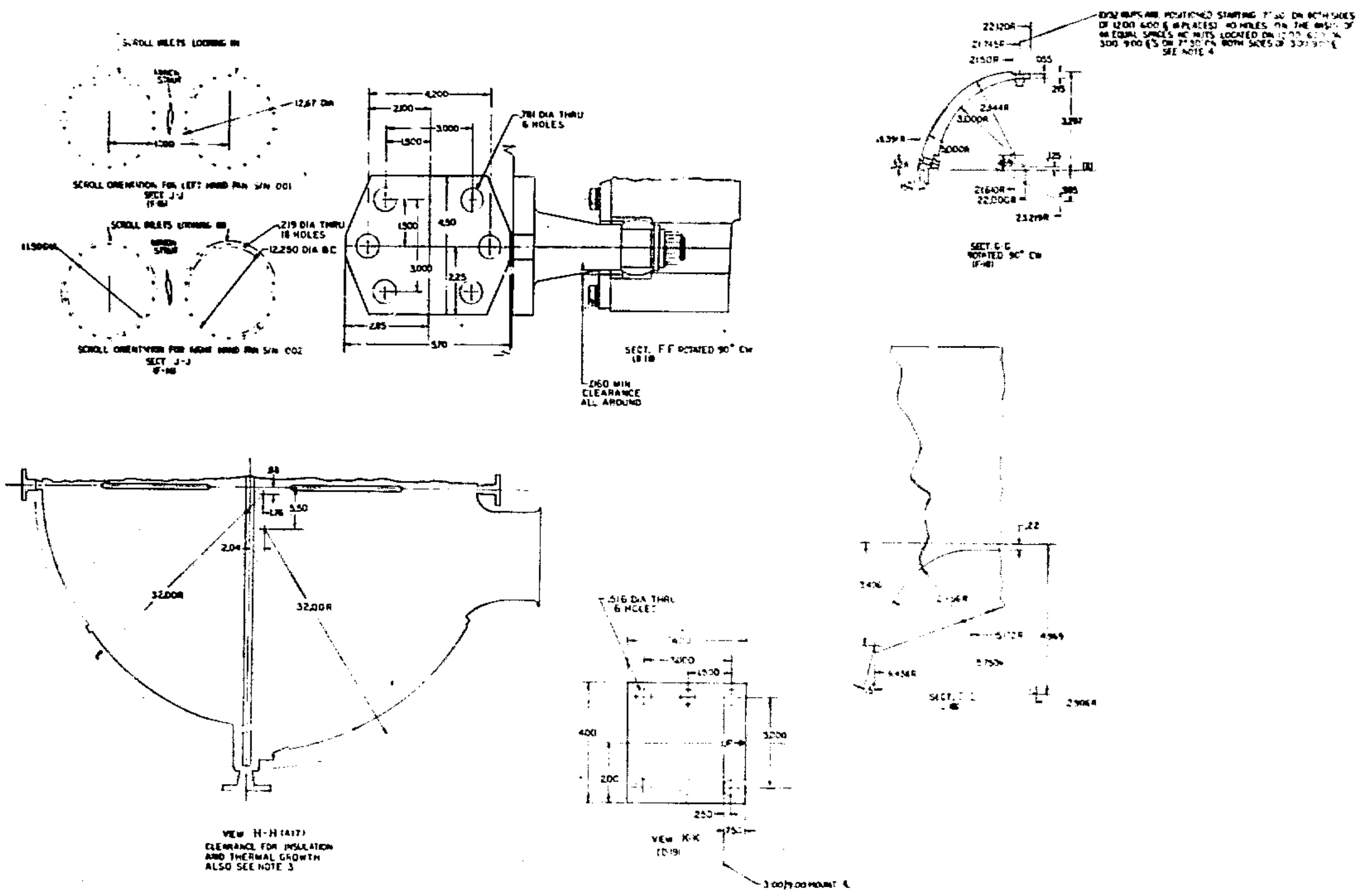


Figure 1. (Concluded)

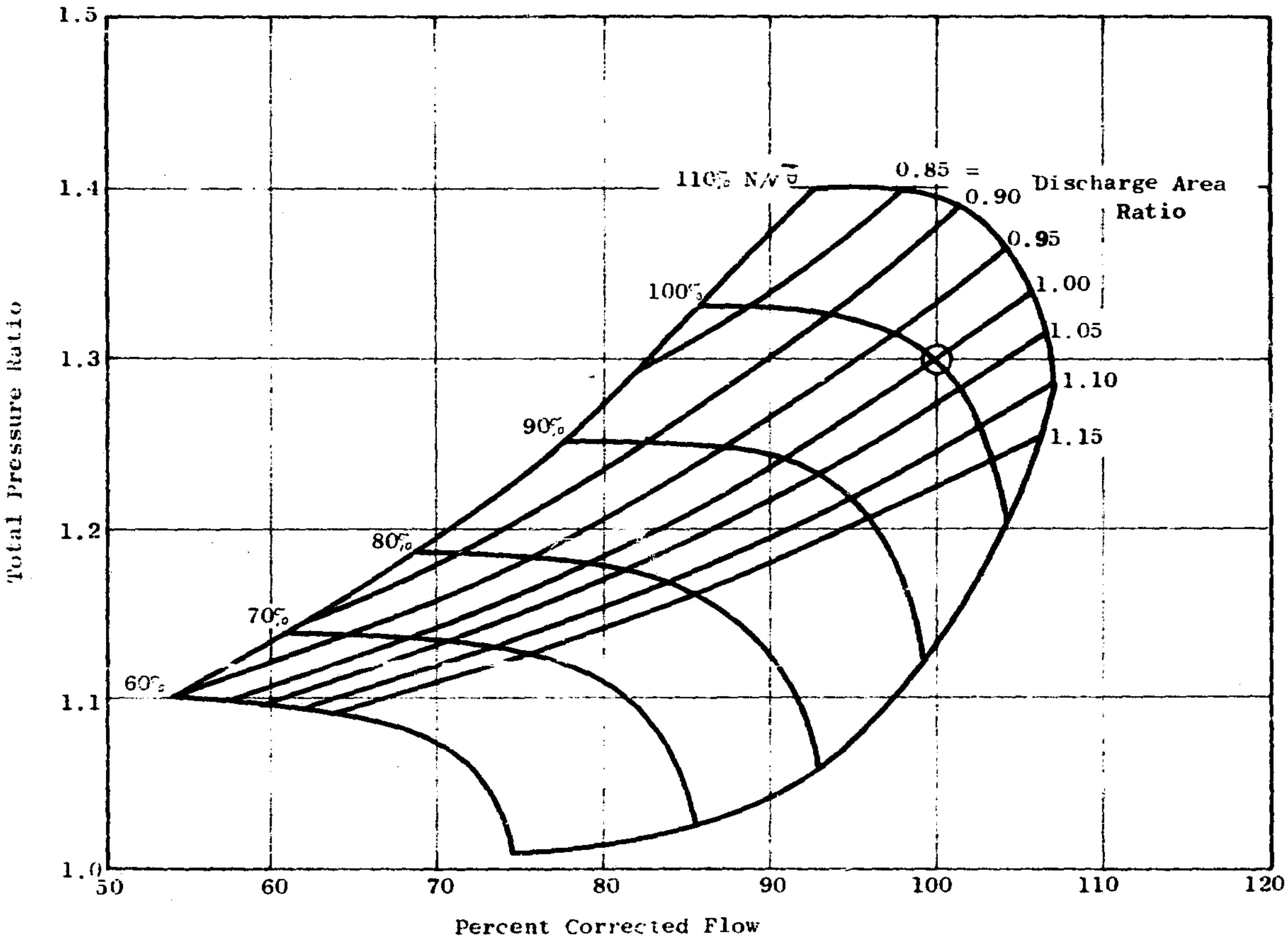


Figure 2. Fan Map - Total Pressure Ratio Versus Flow

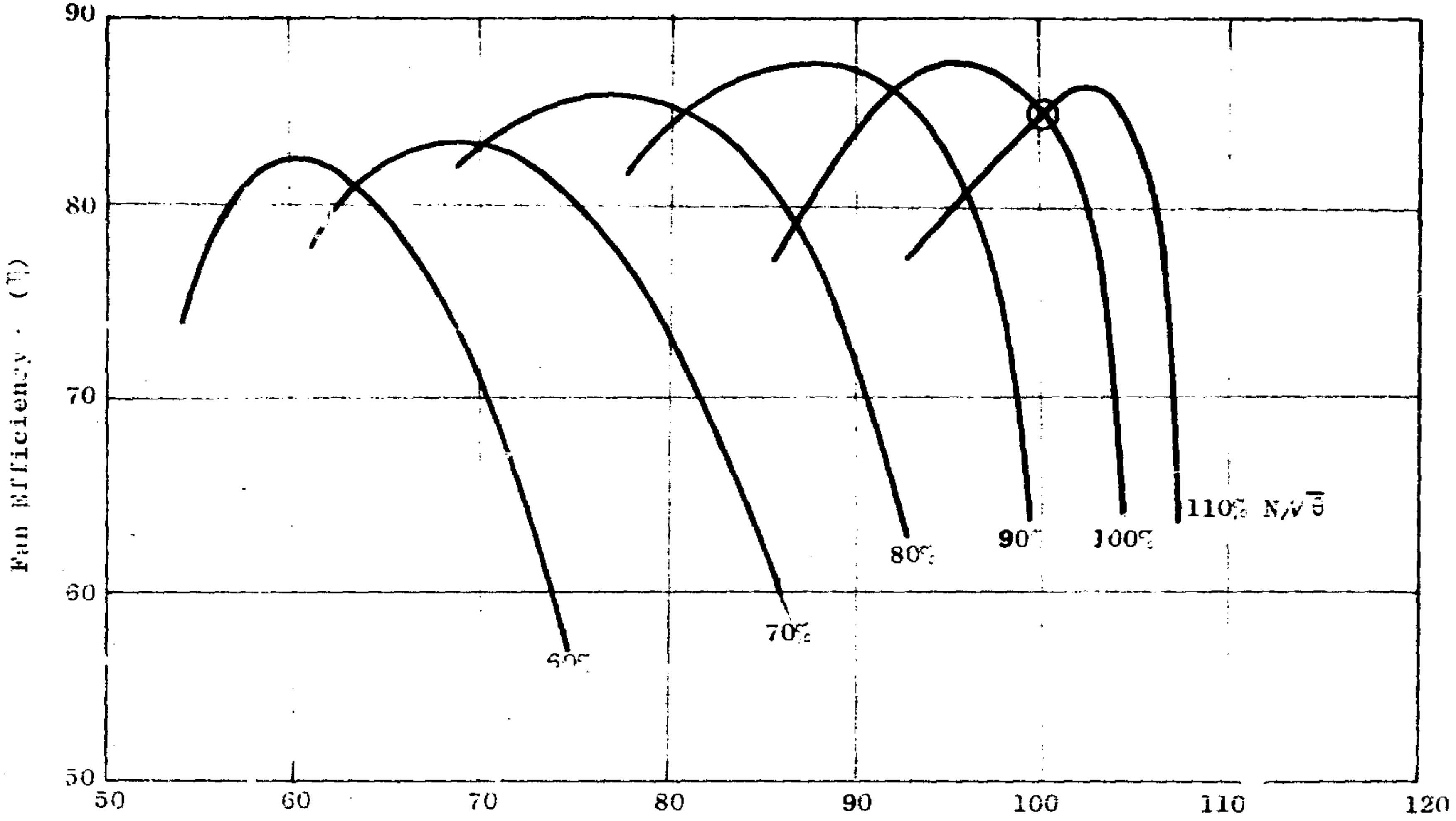


Figure 3. Fan Map - Efficiency Versus Flow

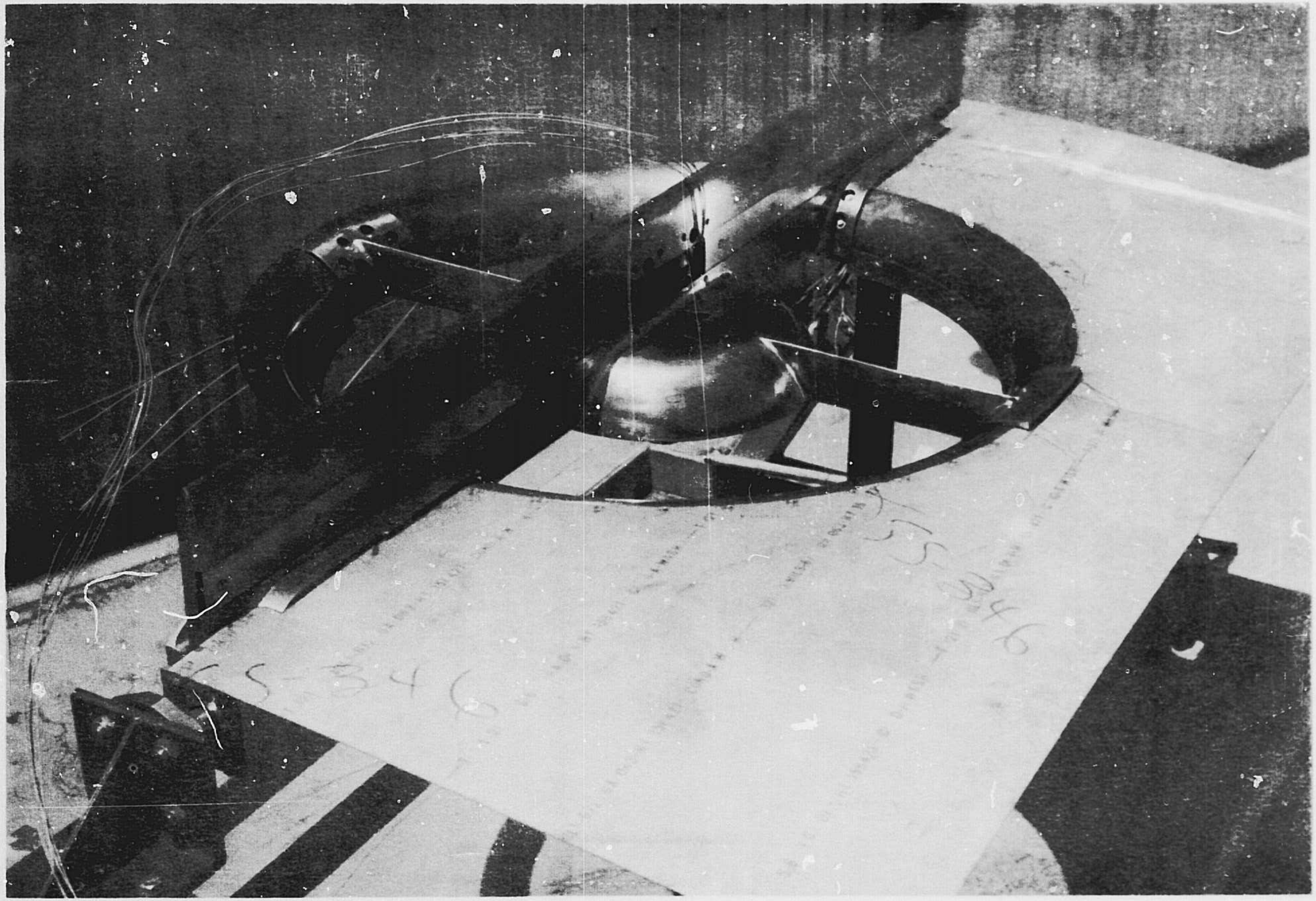


Figure 4. **Frame**

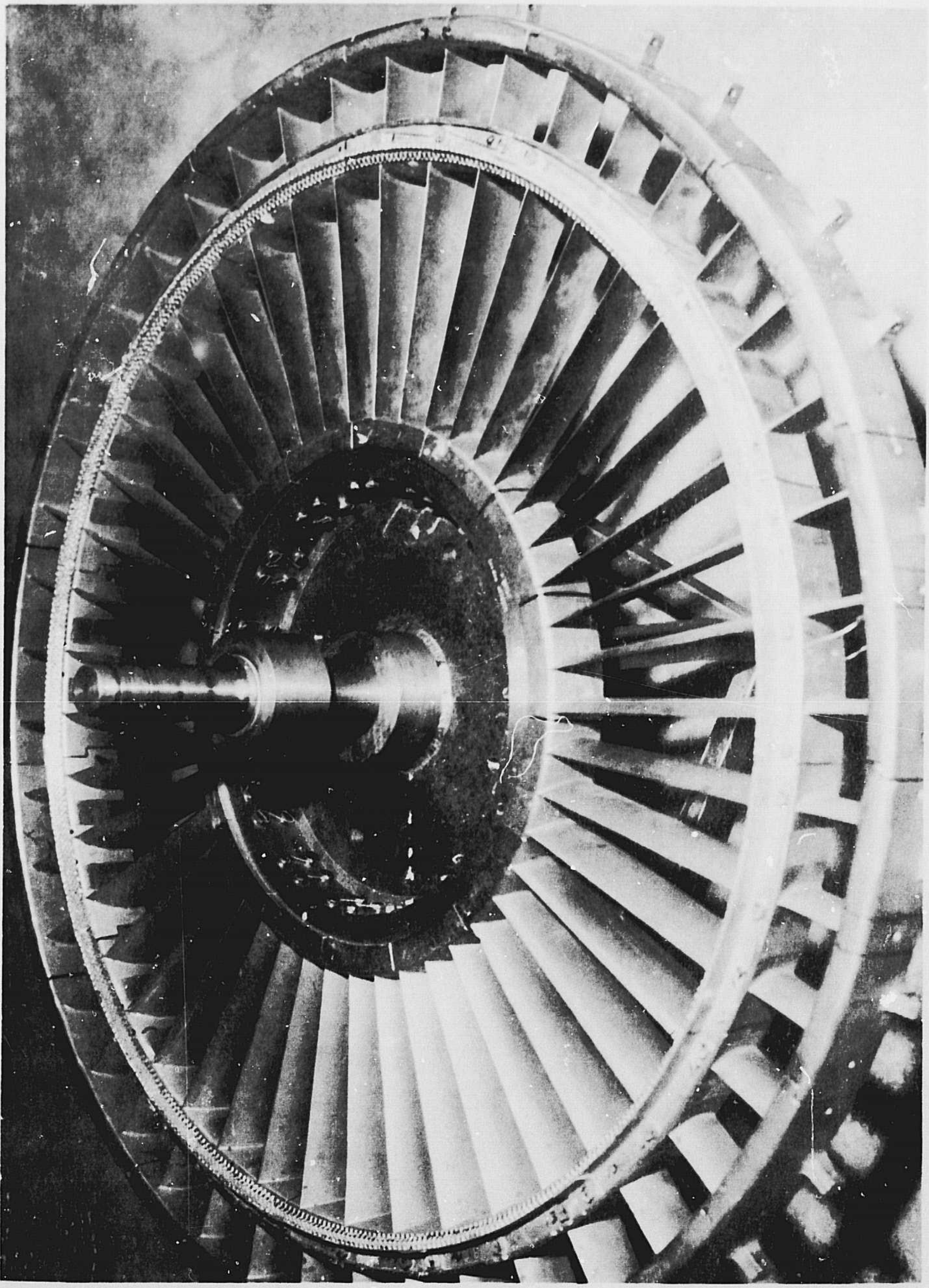


Figure 5. ar Frame Assembly

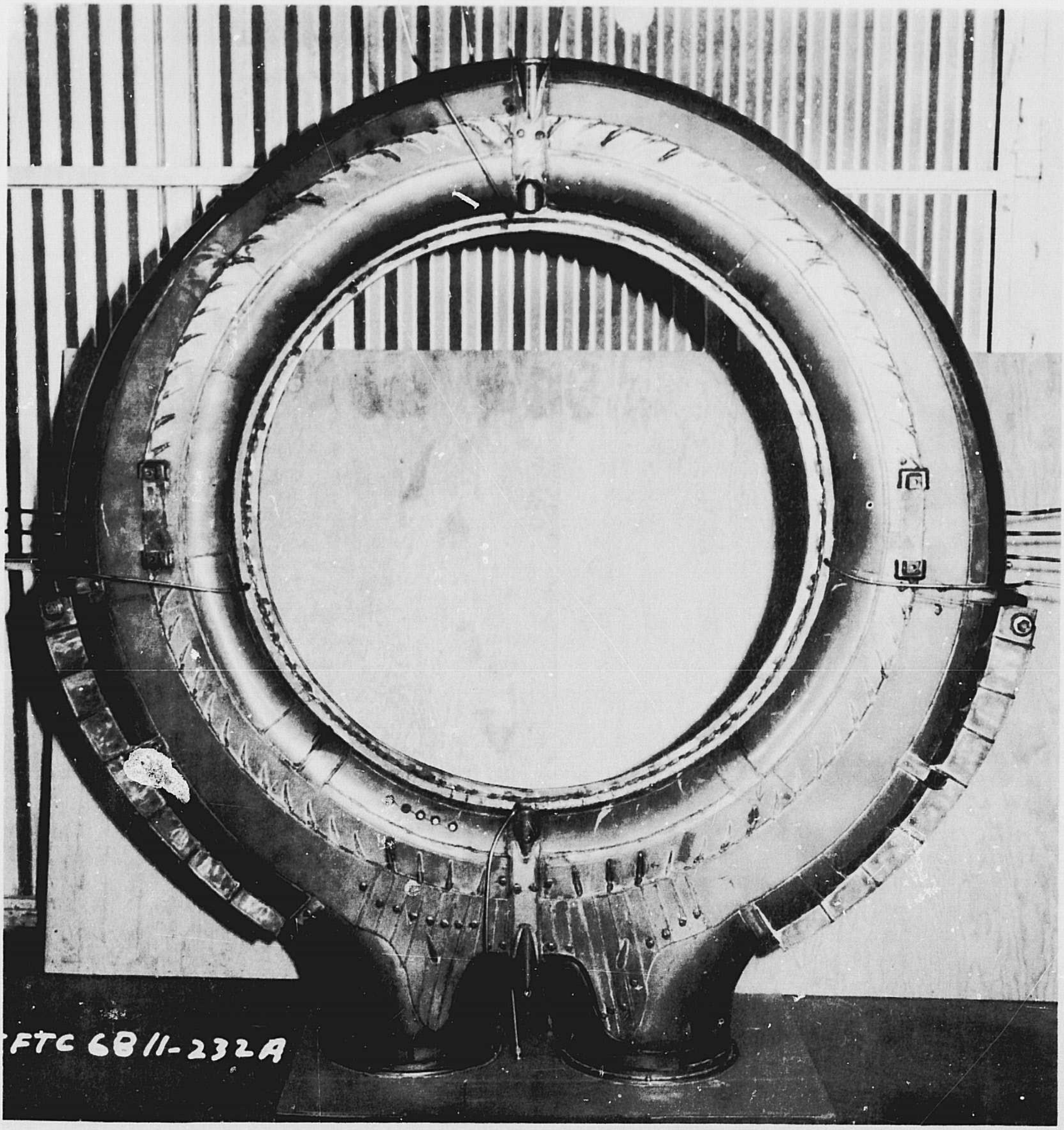


Figure 6. Scroll, Top View

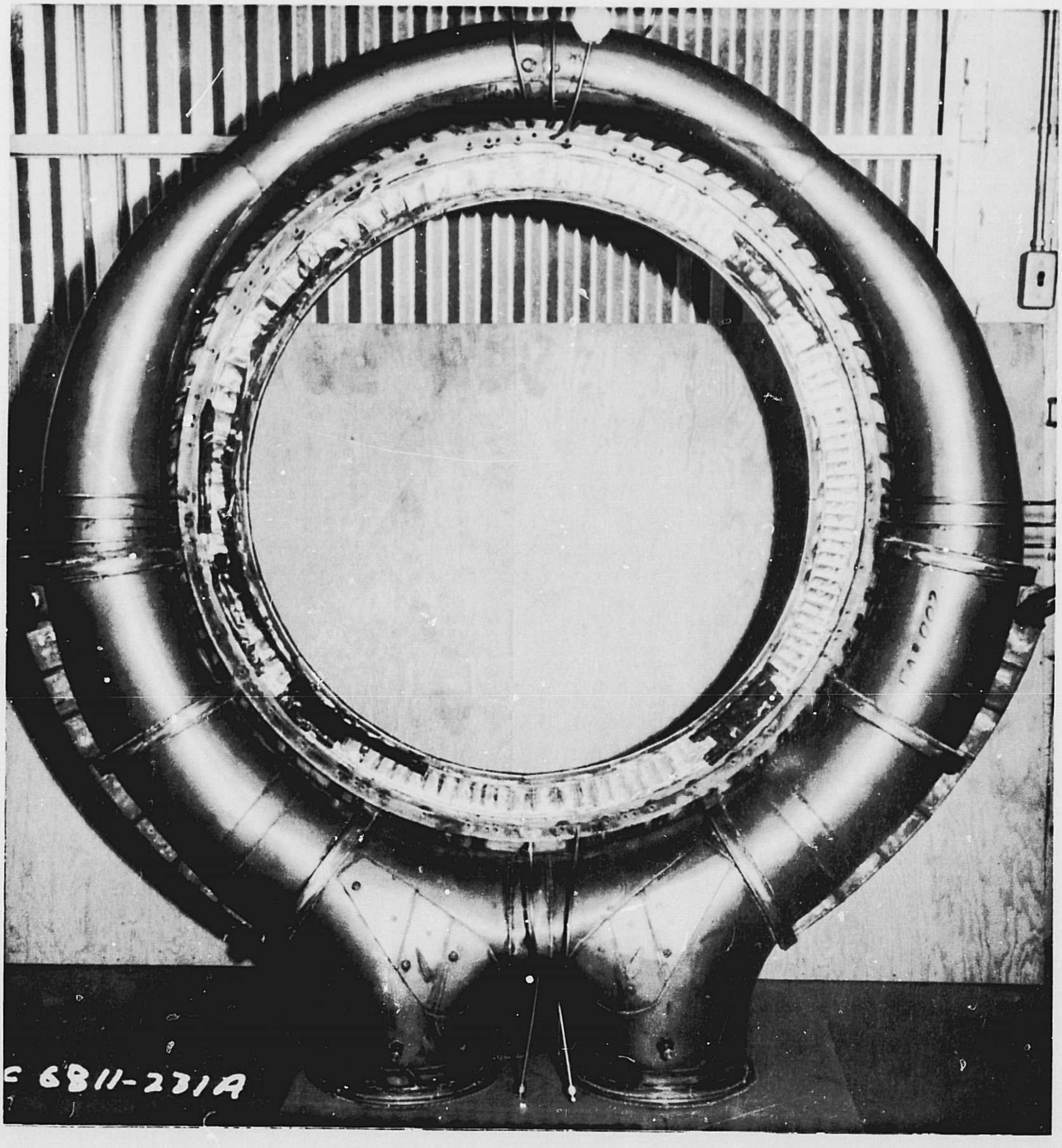


Figure 7. Scroll, Bottom View

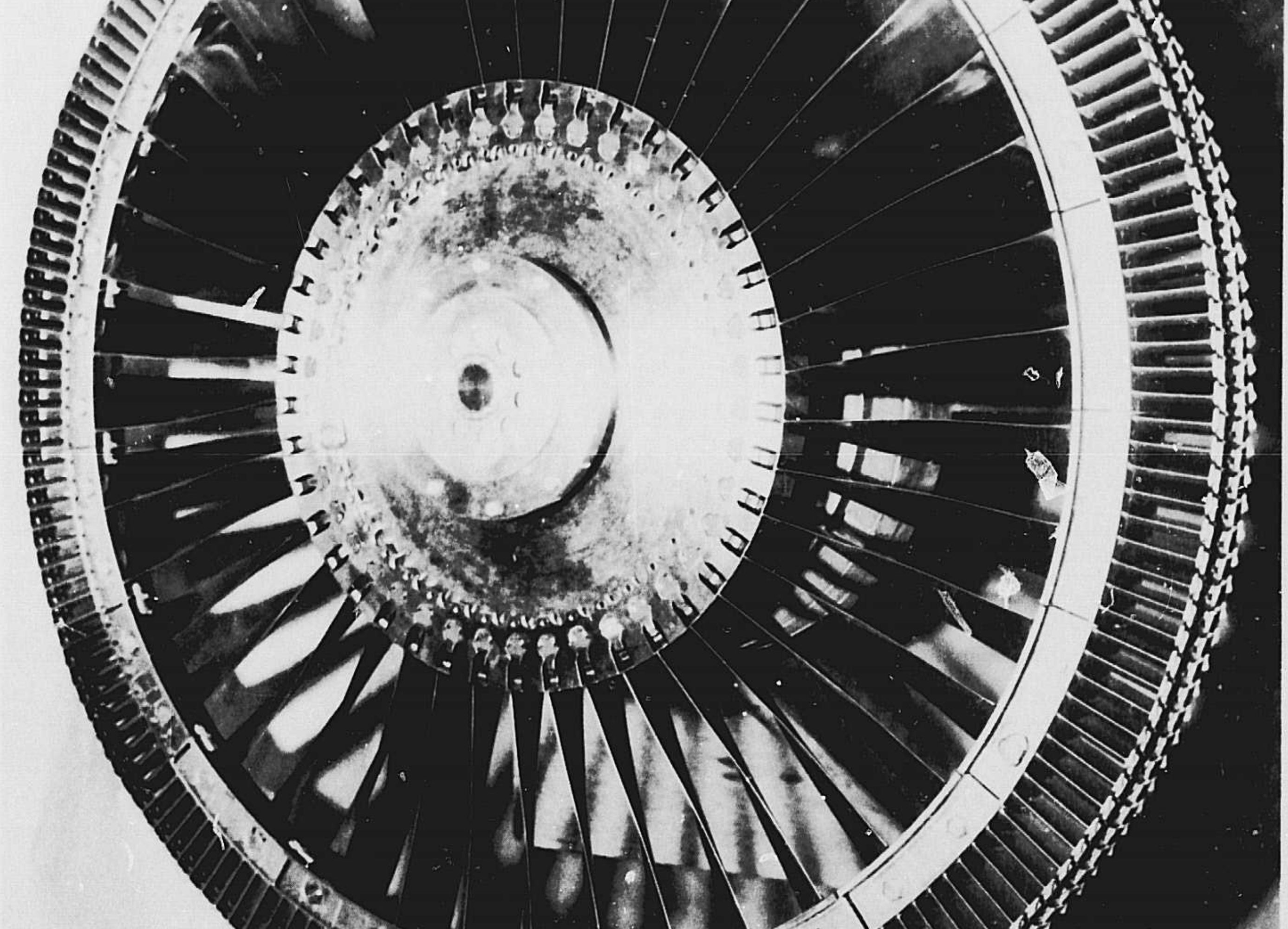


Figure 8. Rotor Assembly

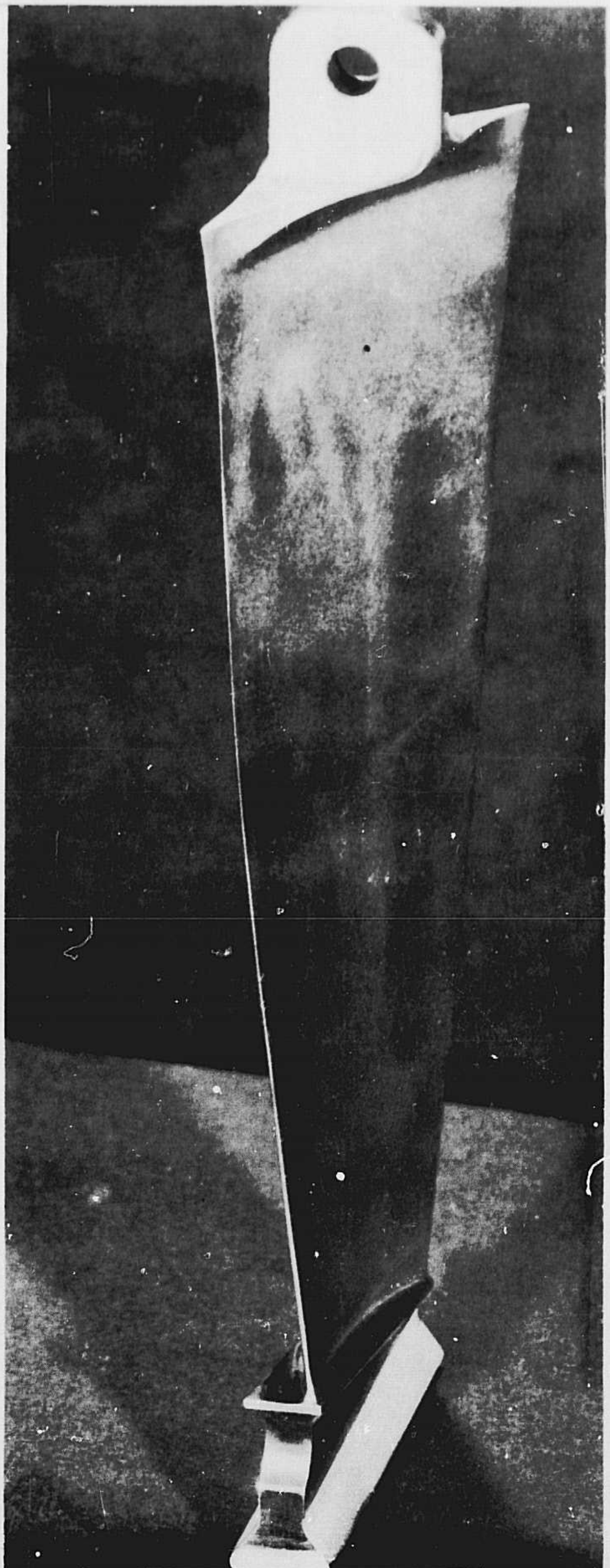


Figure 9. Blade

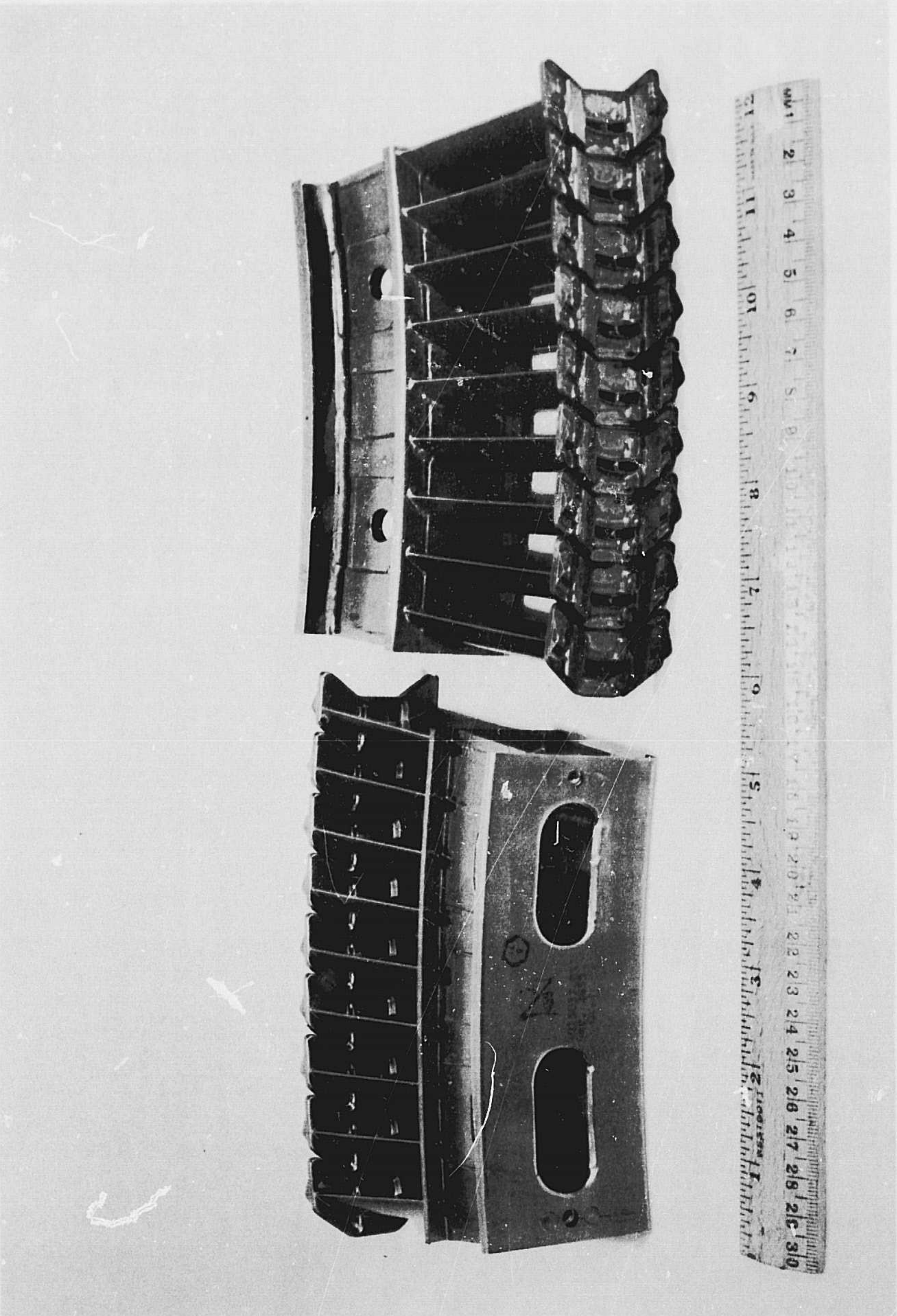


Figure 10. Turbine Bucket Carrier

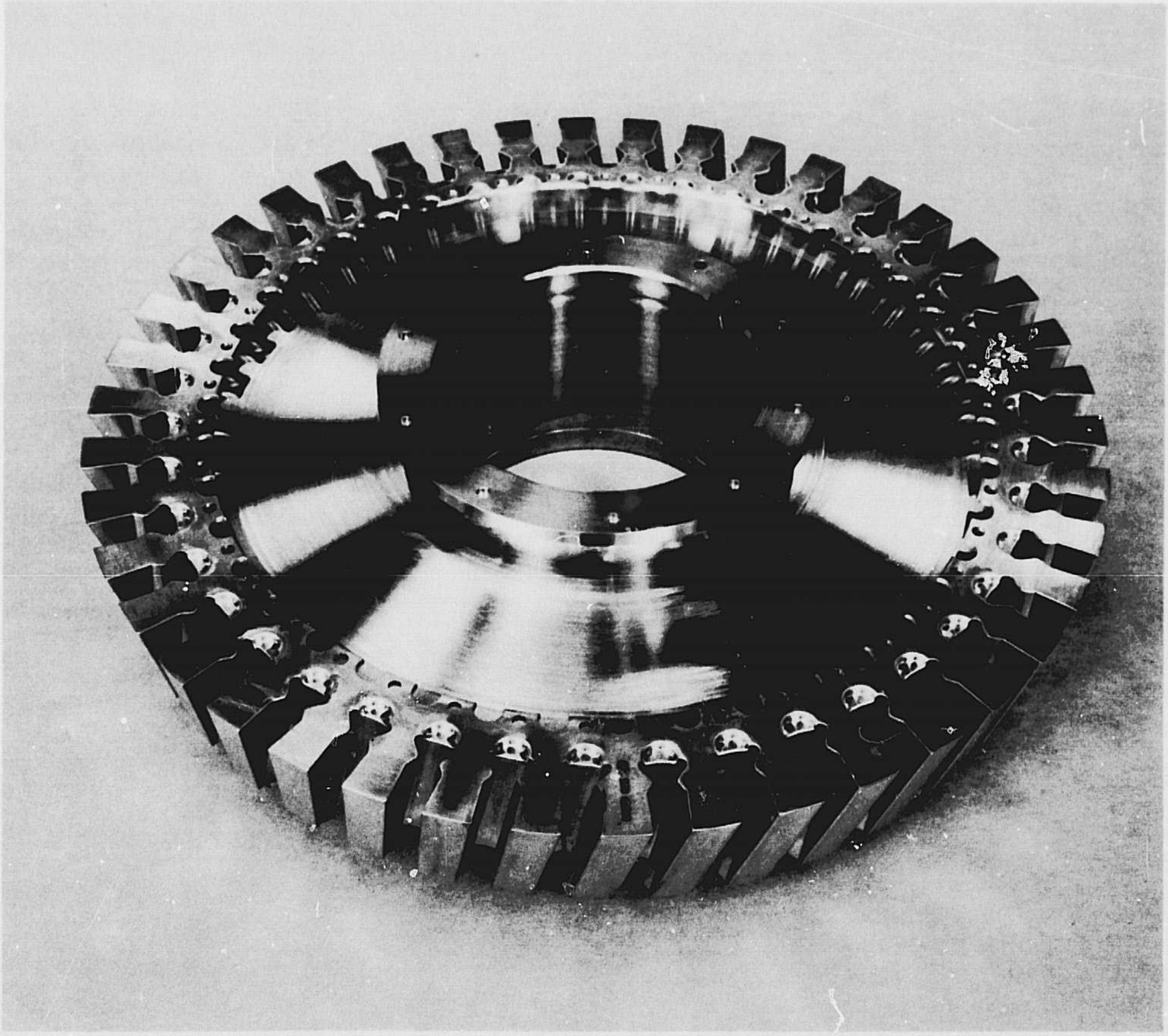


Figure 11. Disc

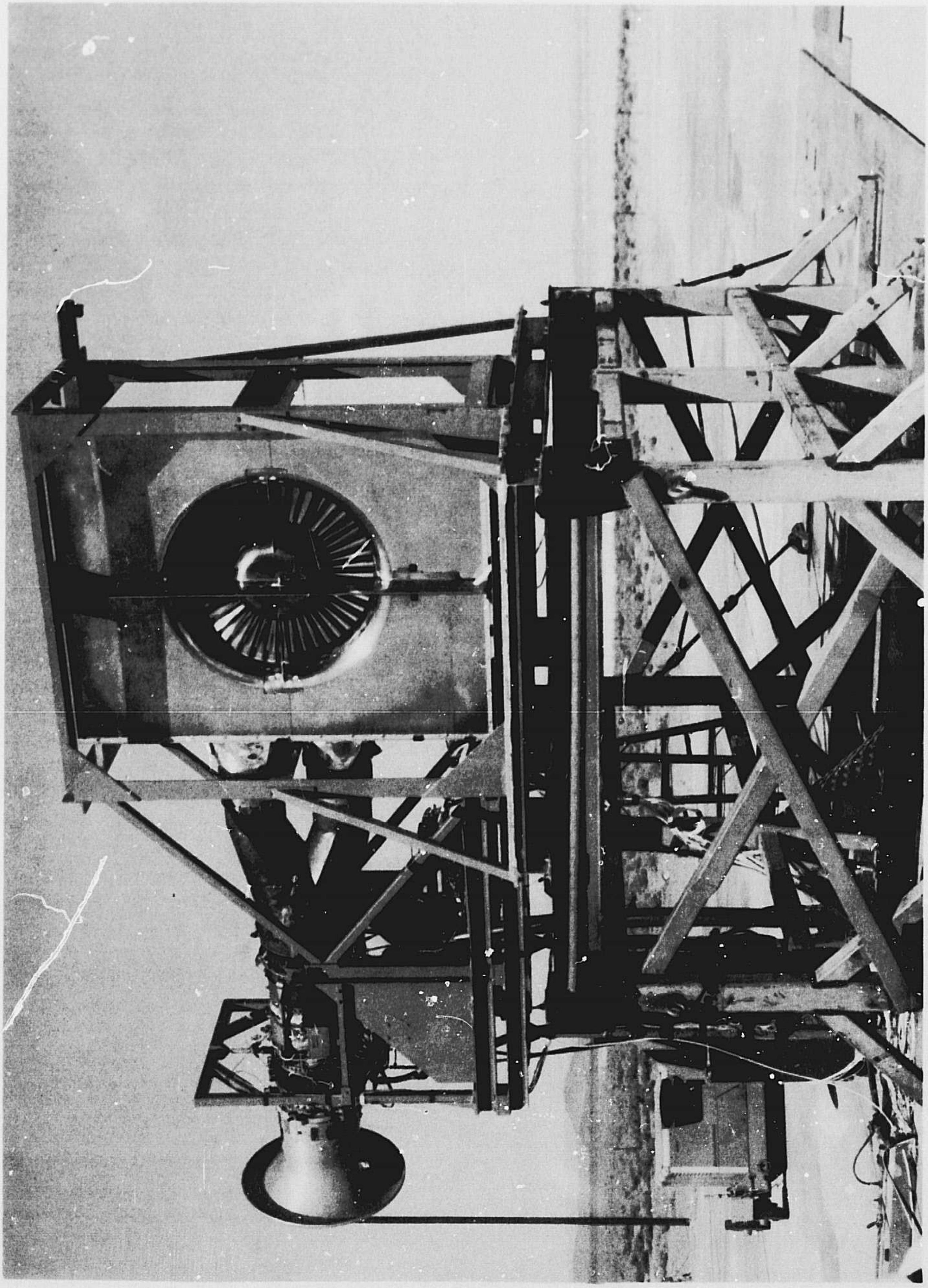


Figure 12. LF336A in Test Stand, Front View

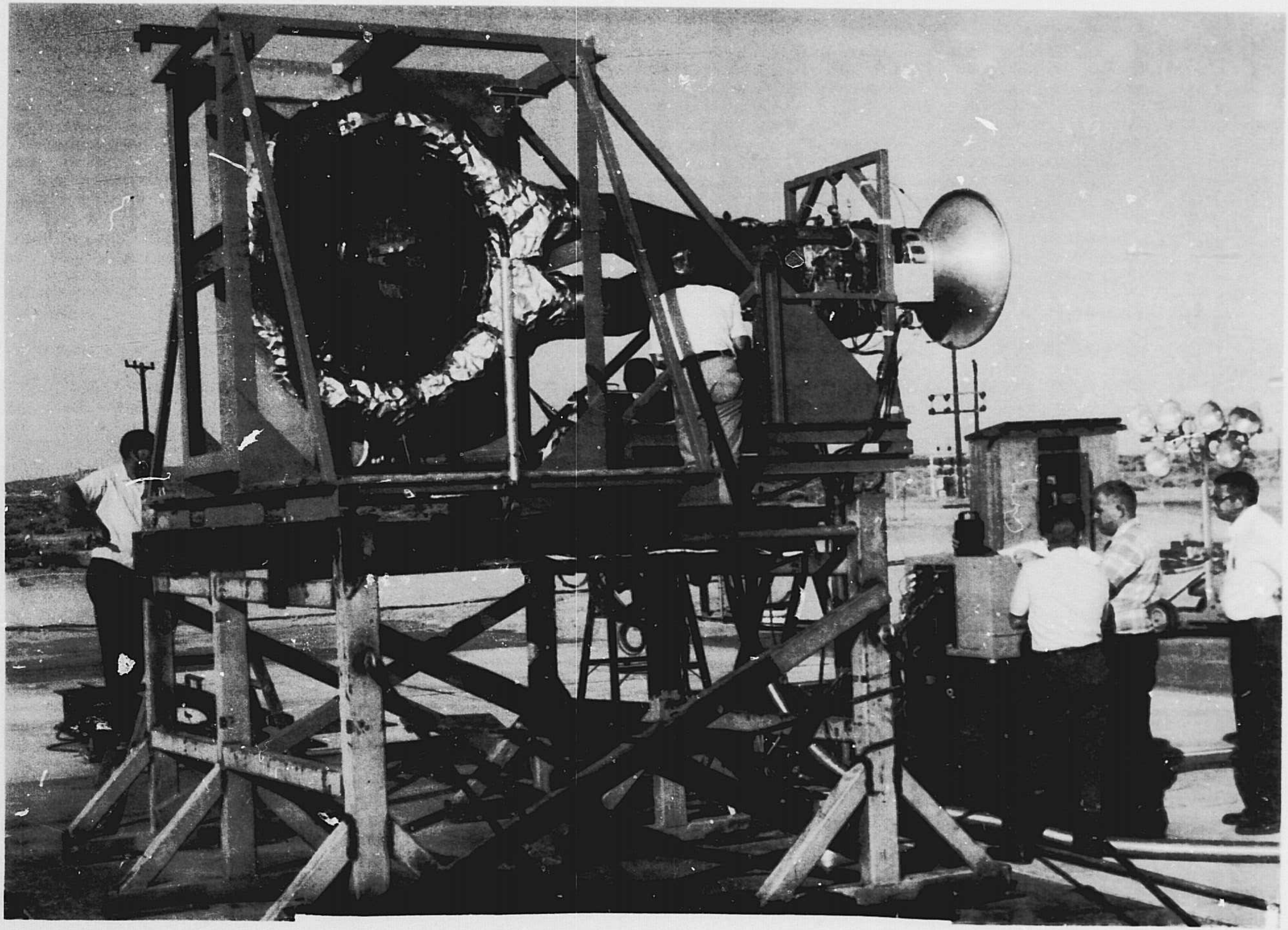


Figure 13. LF336A in Test Stand, Rear View

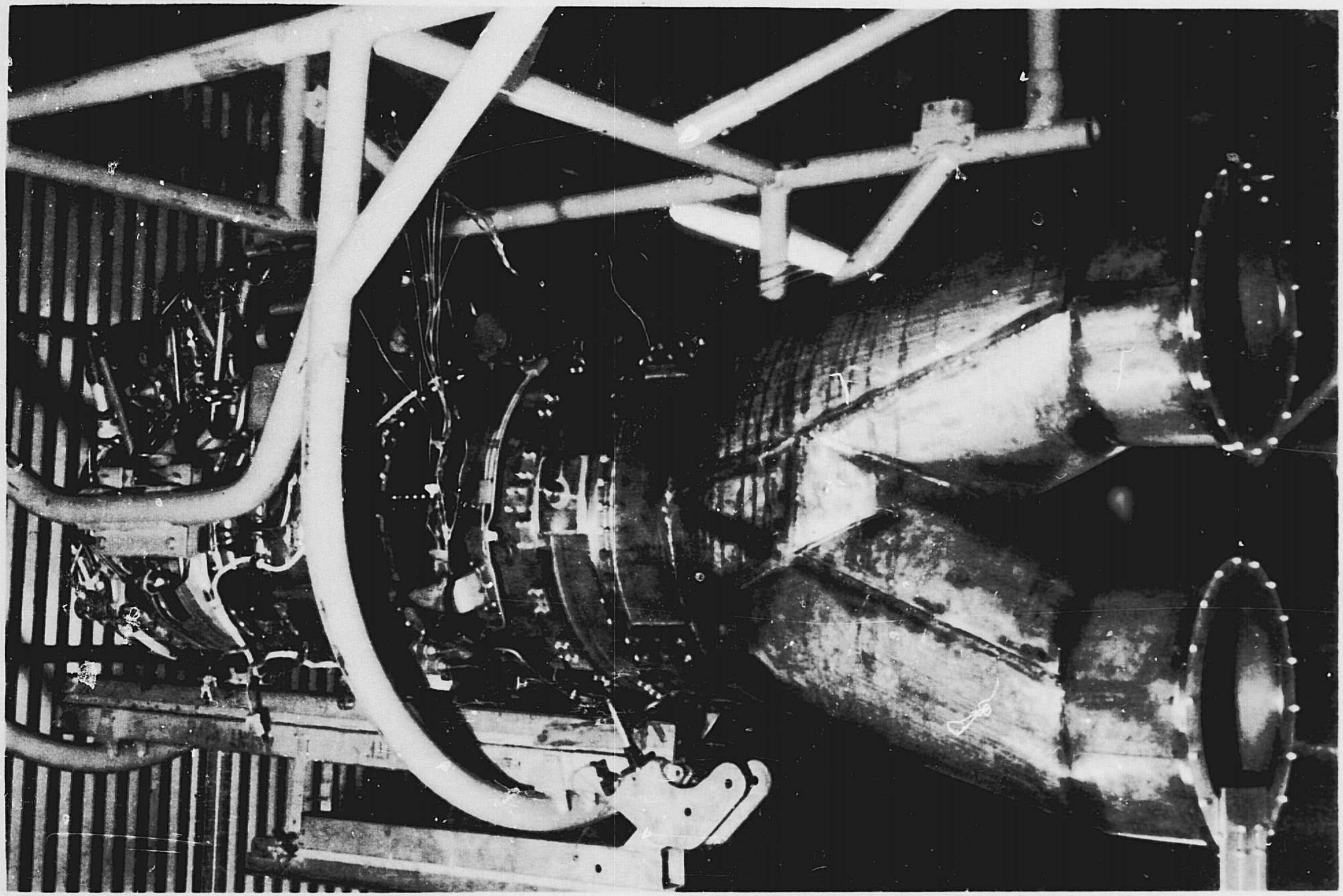


Figure 14. J85 "Pants Legs"

Figure 15. **Typical Turbine FOD**

Figure 16. Wrap-around Bucket Brazed Patch

Figure 17. Tip Shroud Brazed Patch

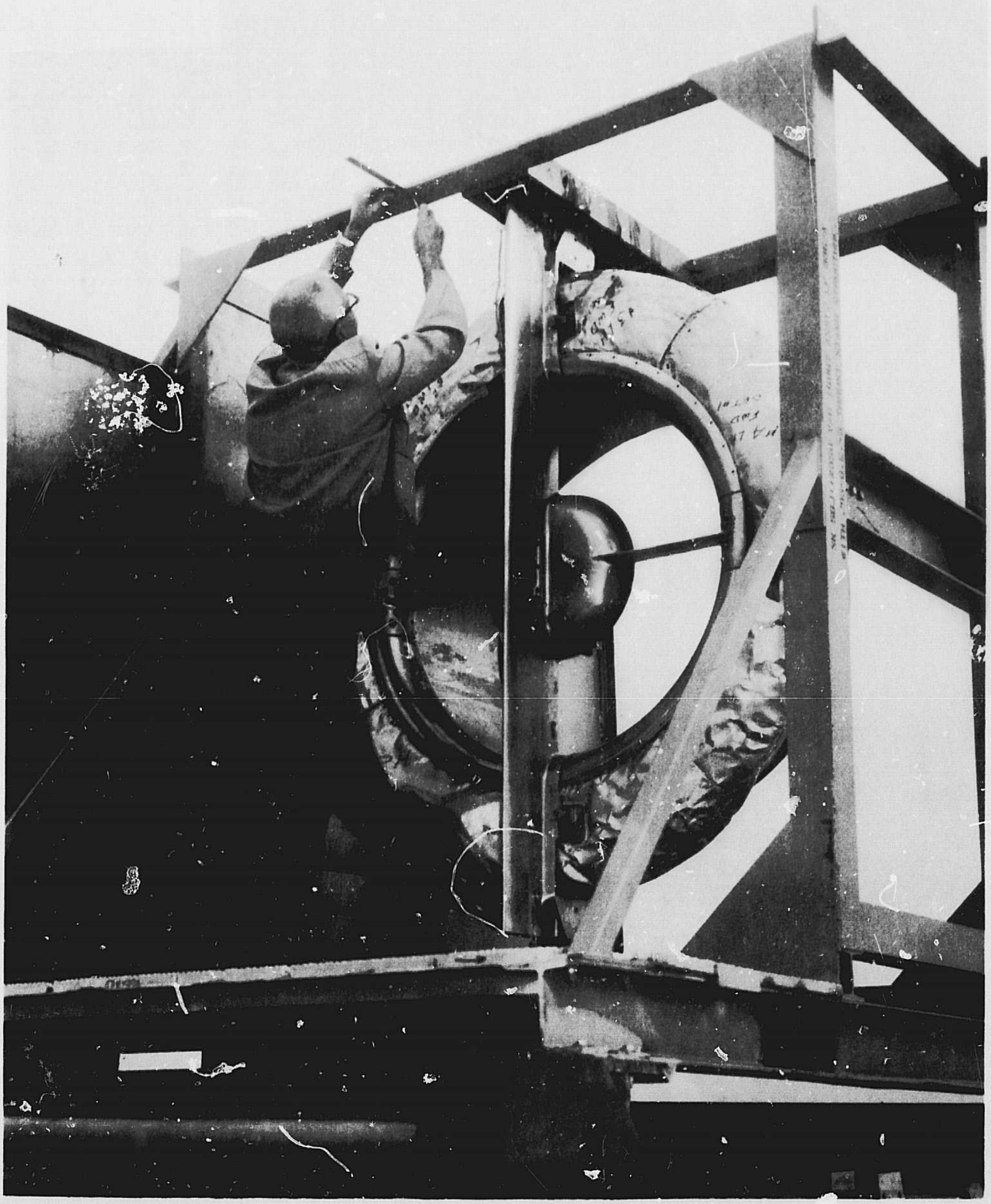


Figure 18. Scroll Mounted For Blow-Down

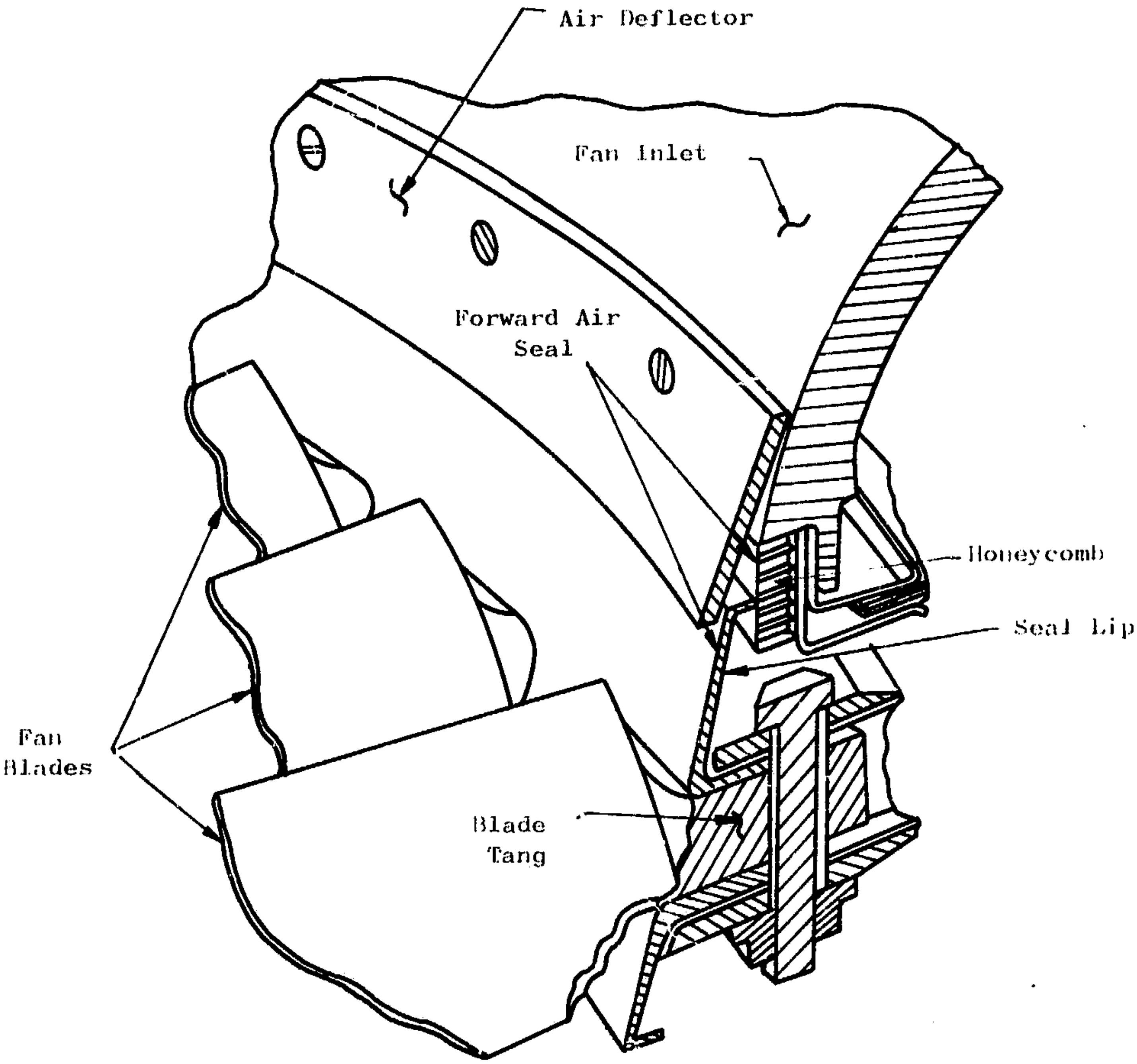


Figure 19. Air Deflector And Forward Air Seal

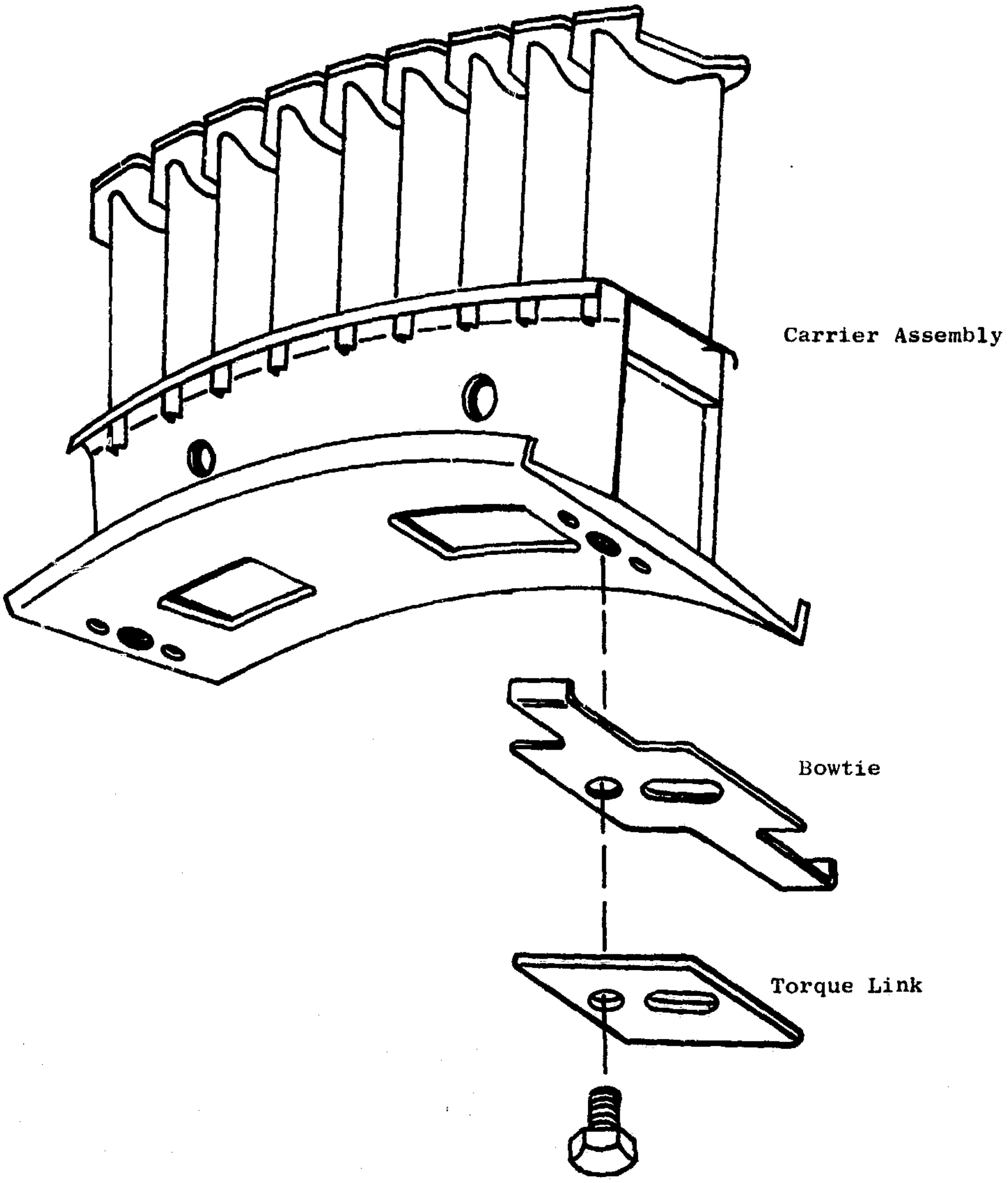


Figure 20 Bowties for Sealing the Gaps Between Adjacent Carriers

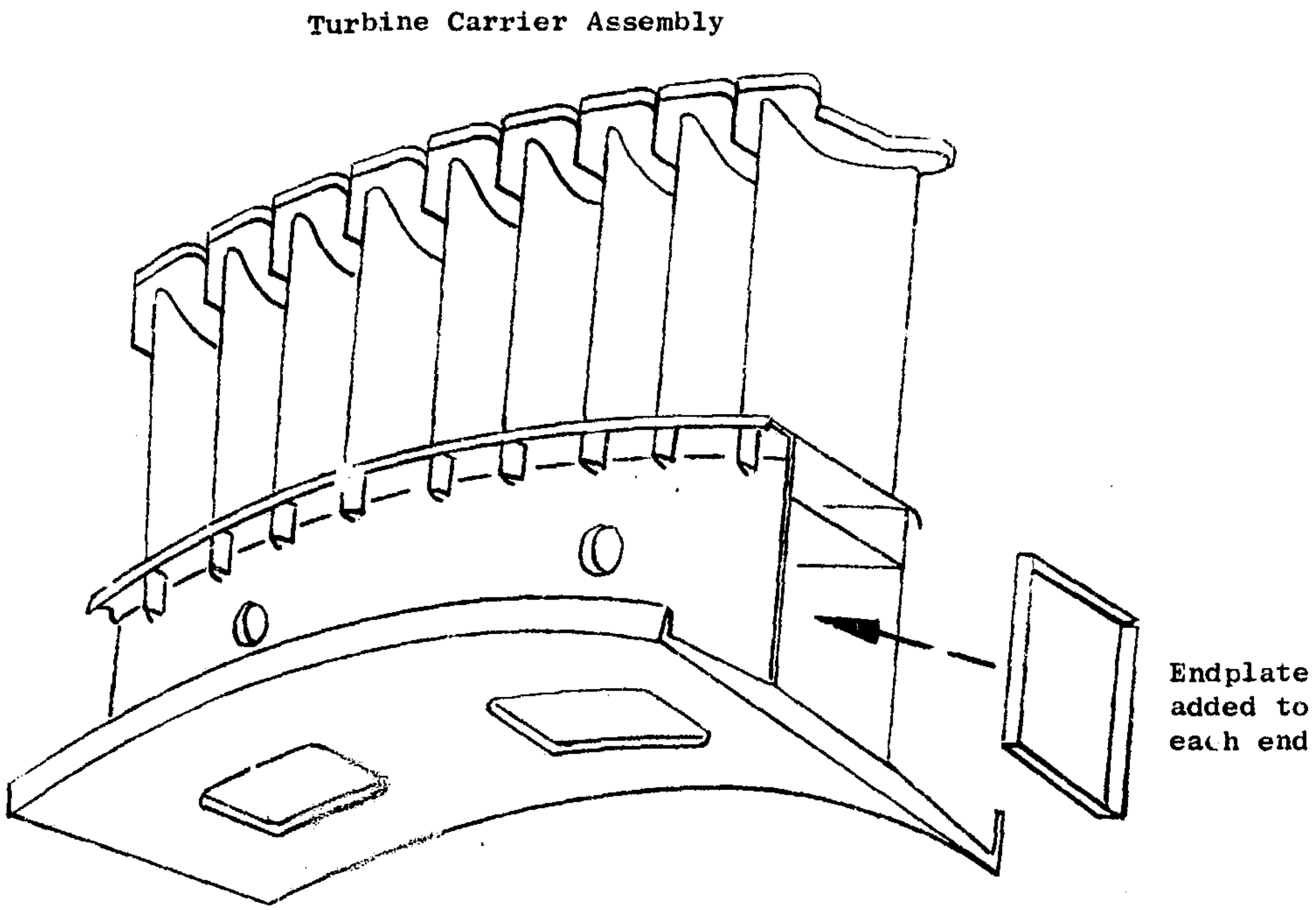


Figure 21 Turbine Carrier Endplates.

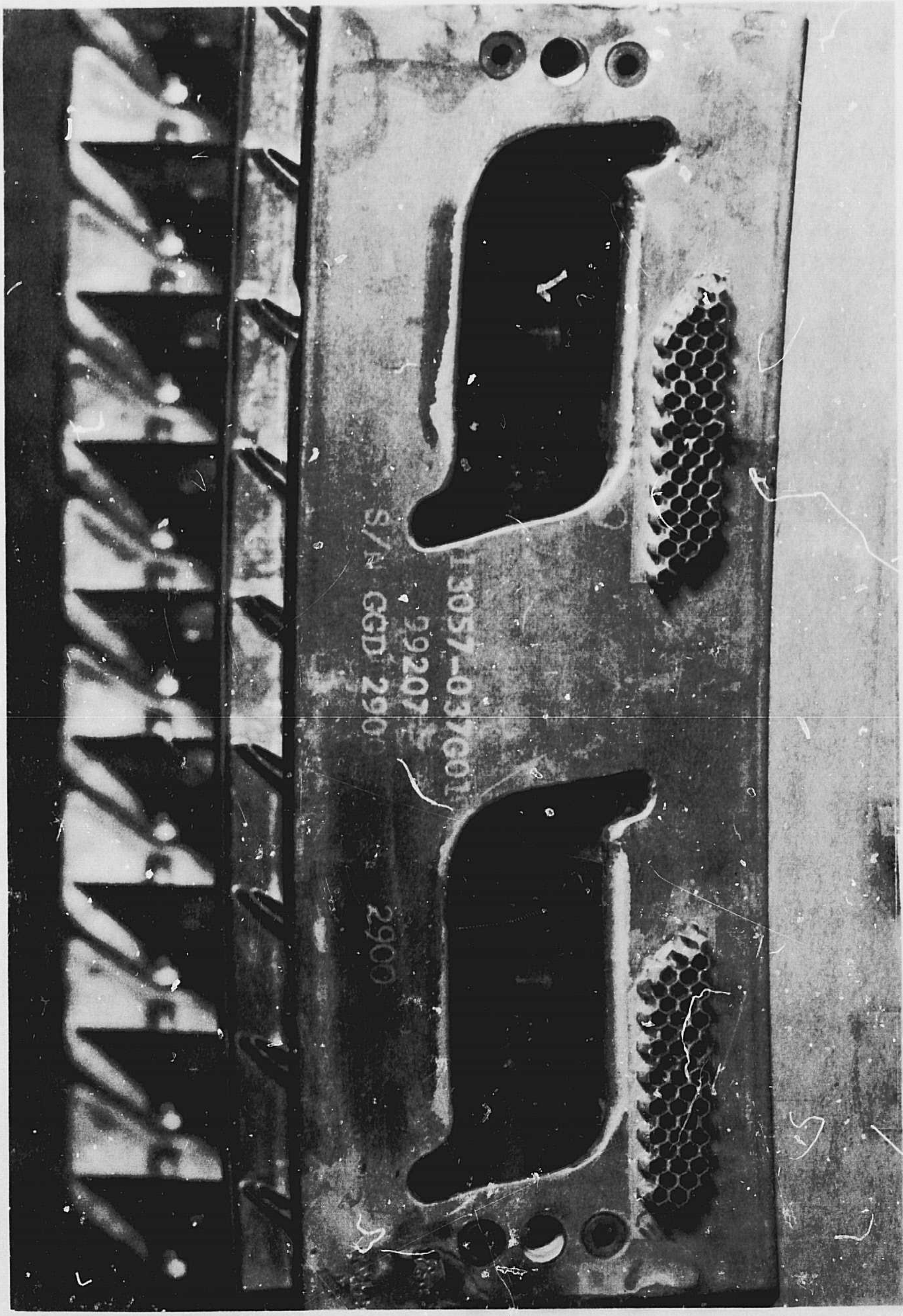


Figure 22. Turbine Carrier Modifications - Dams And **Enlarged** Cooling Holes

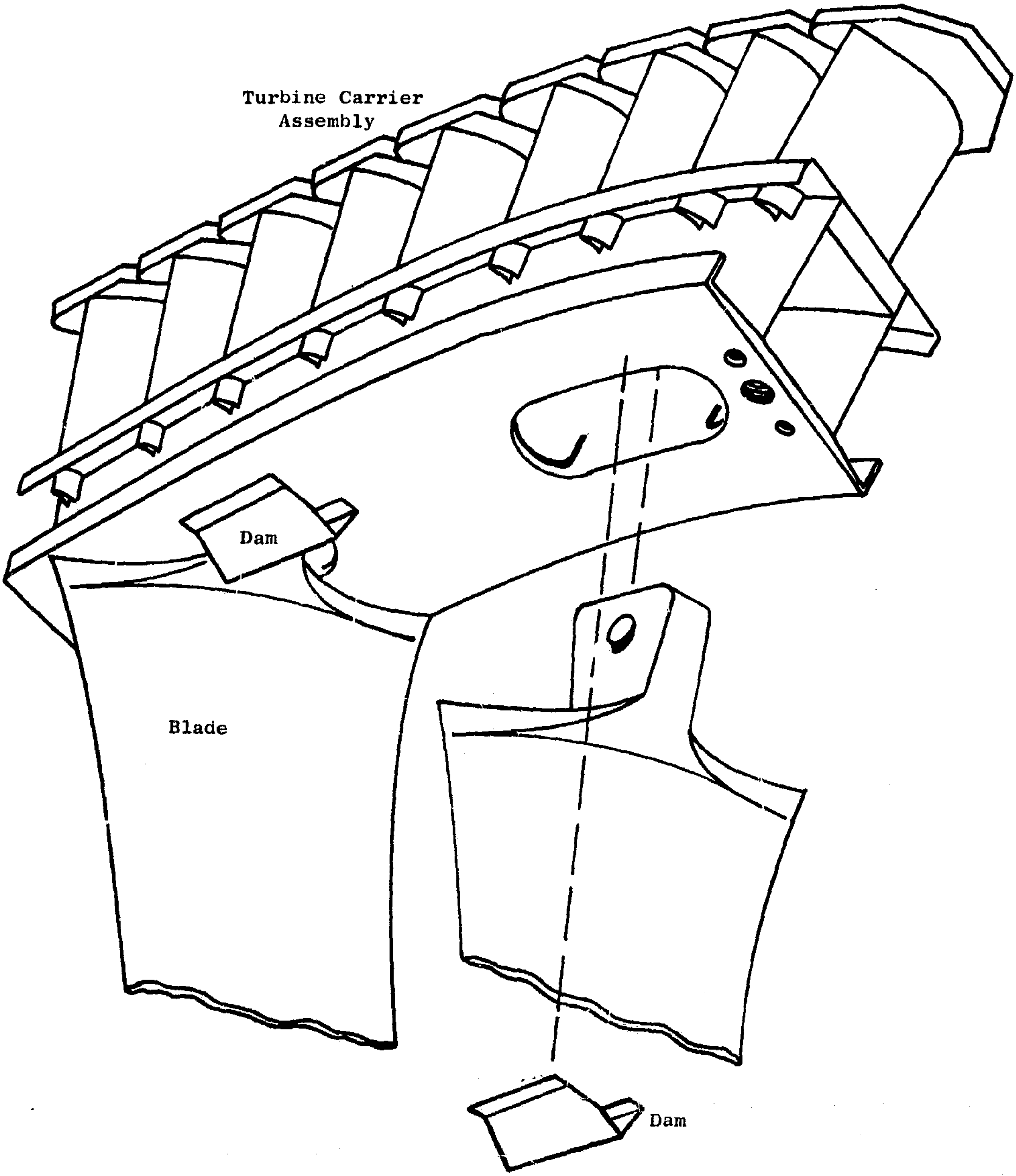


Figure 23 Cooling Air Dams to Increase Flow of Cooling Air Into Tang Slot

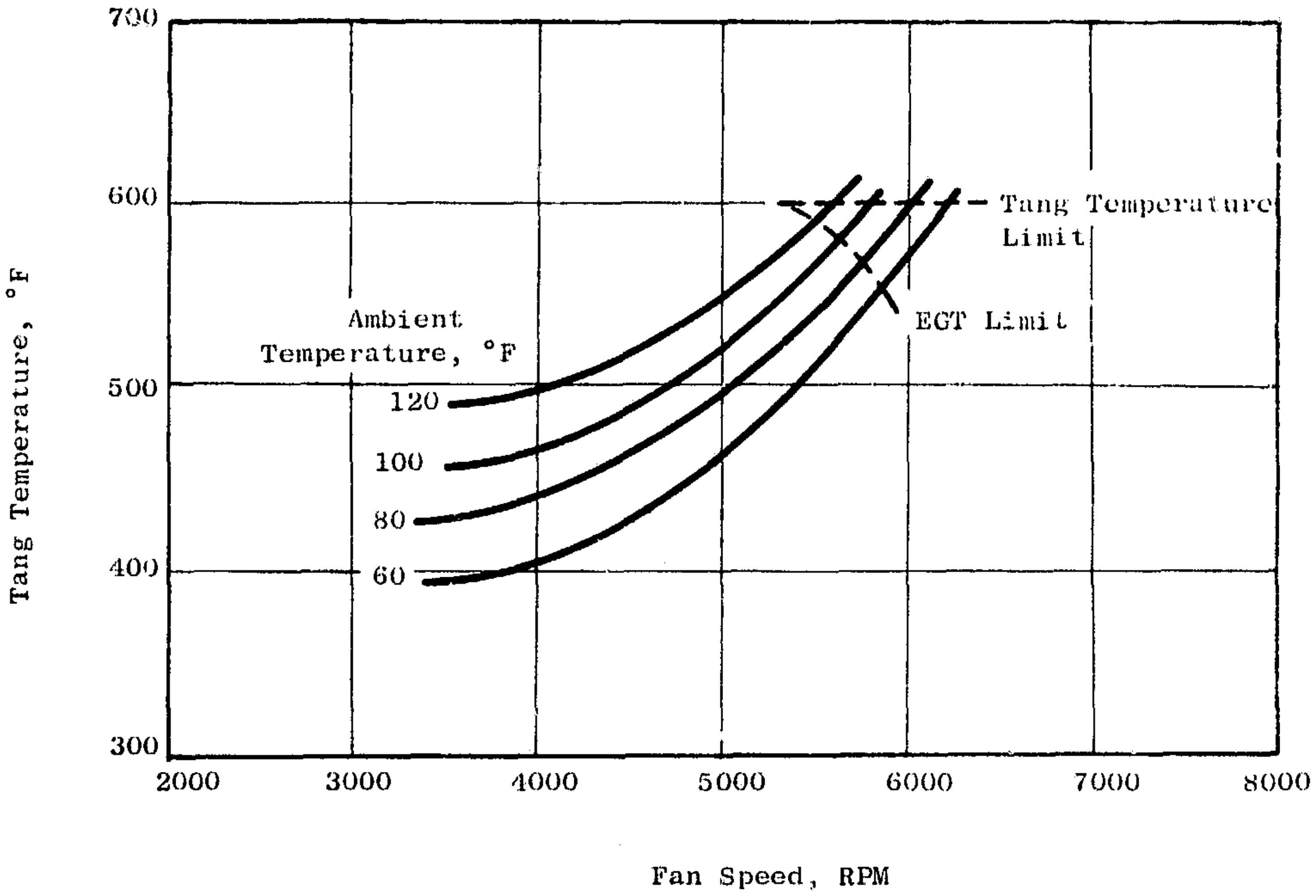


Figure 24. Blade Tang Temperature as a Function of Fan Speed and Ambient Temperature

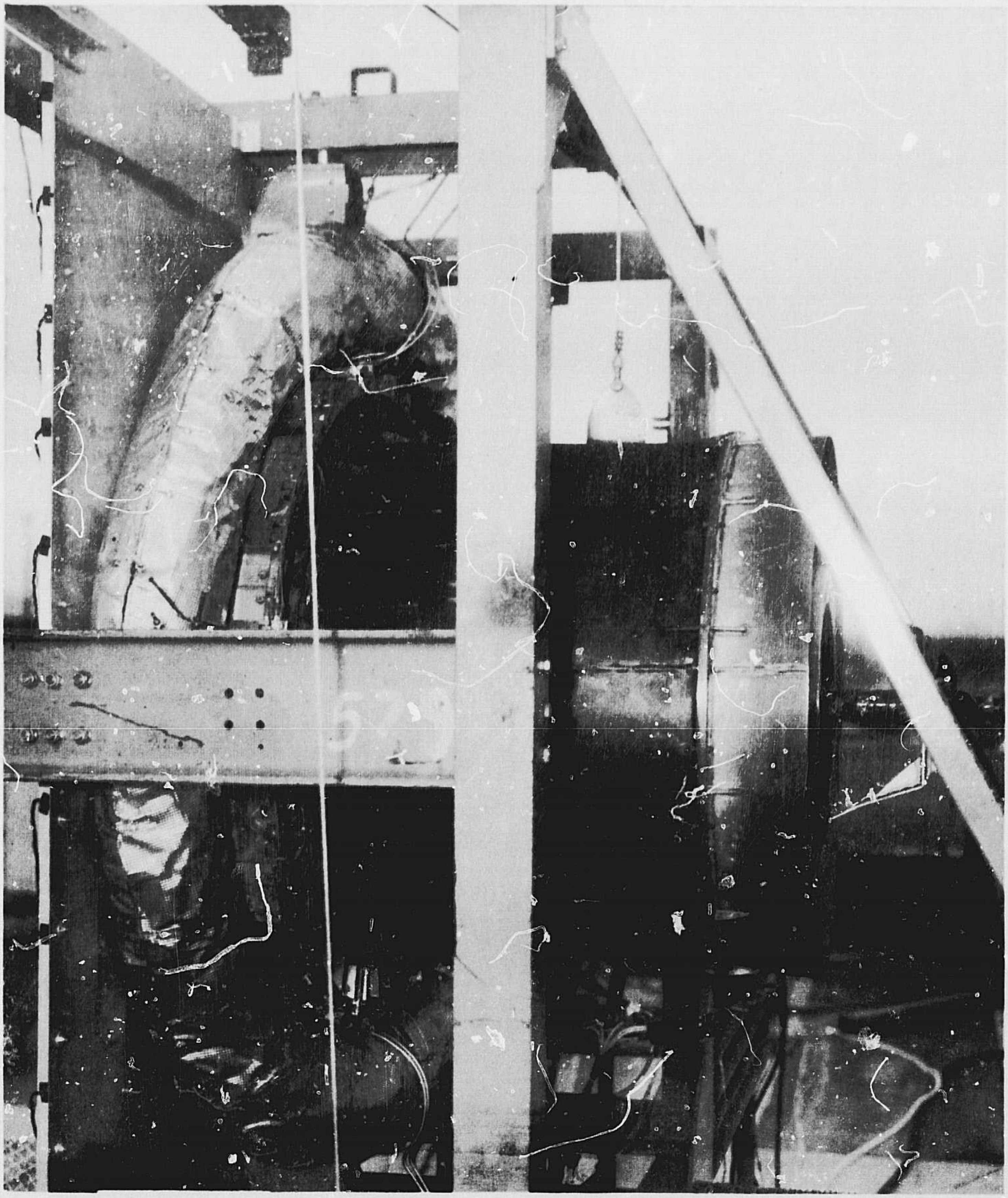


Figure 25. Measuring Section Installed - Side View

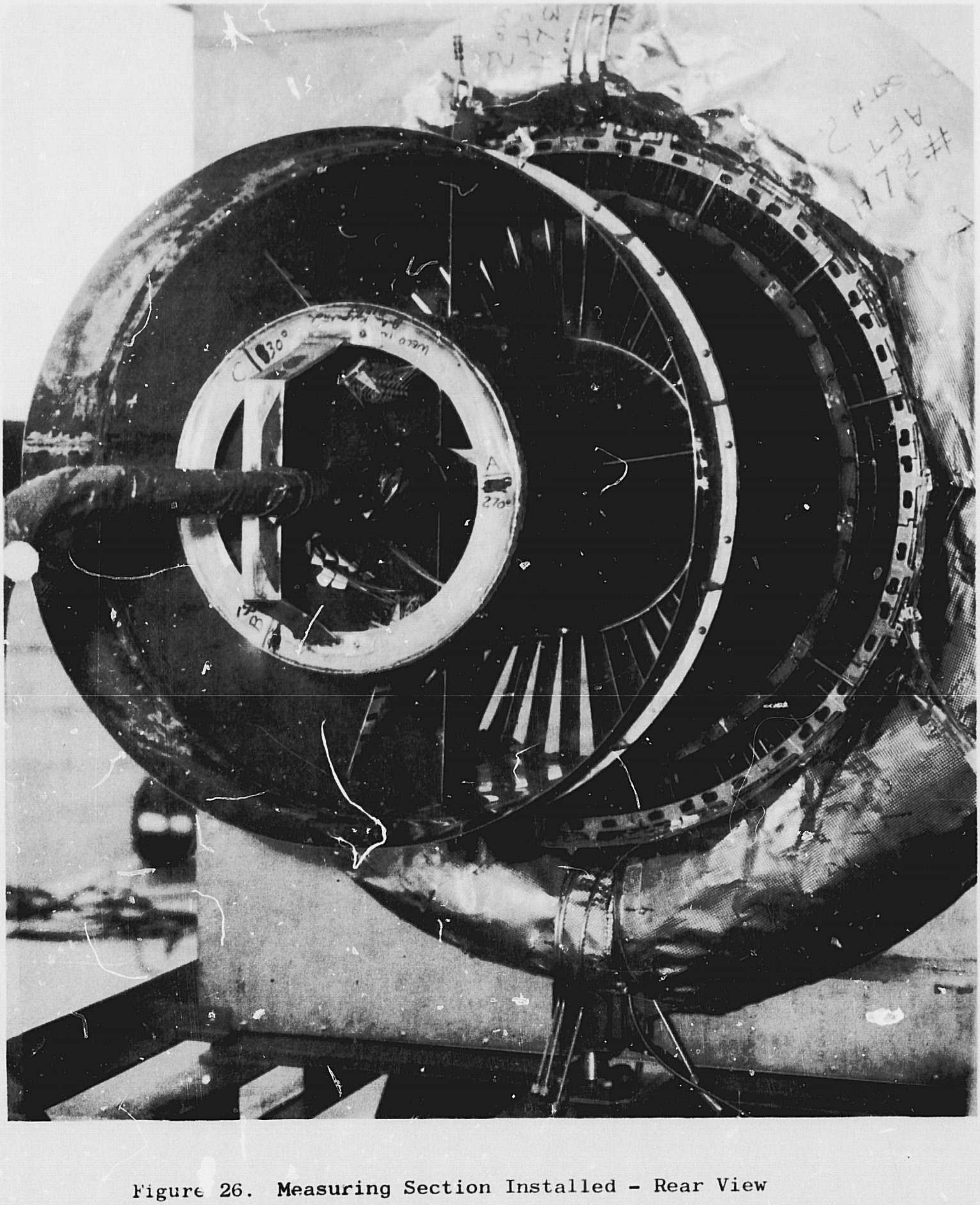


Figure 26. Measuring Section Installed - Rear View

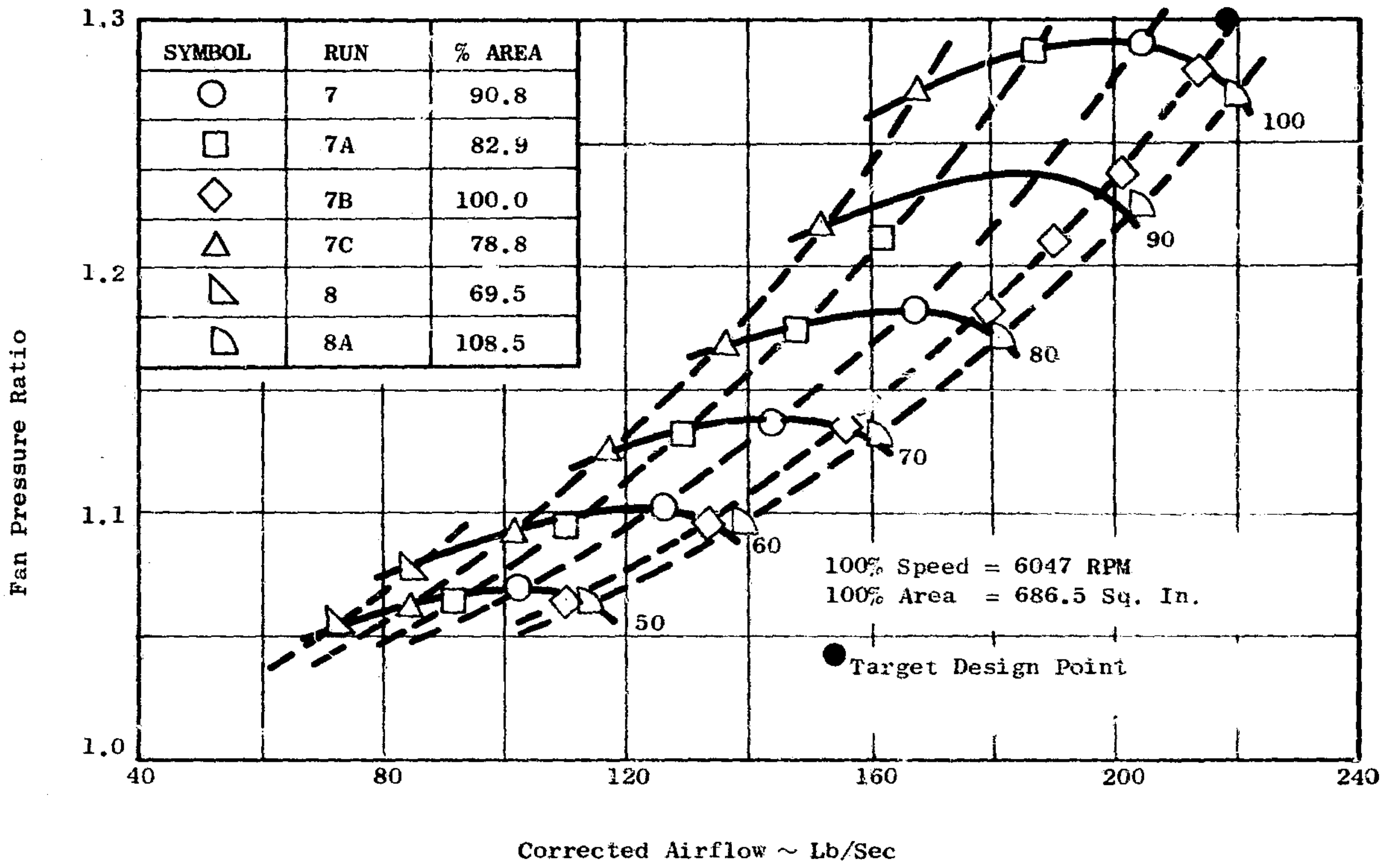


Figure 27. Measured Fan Map Characteristics

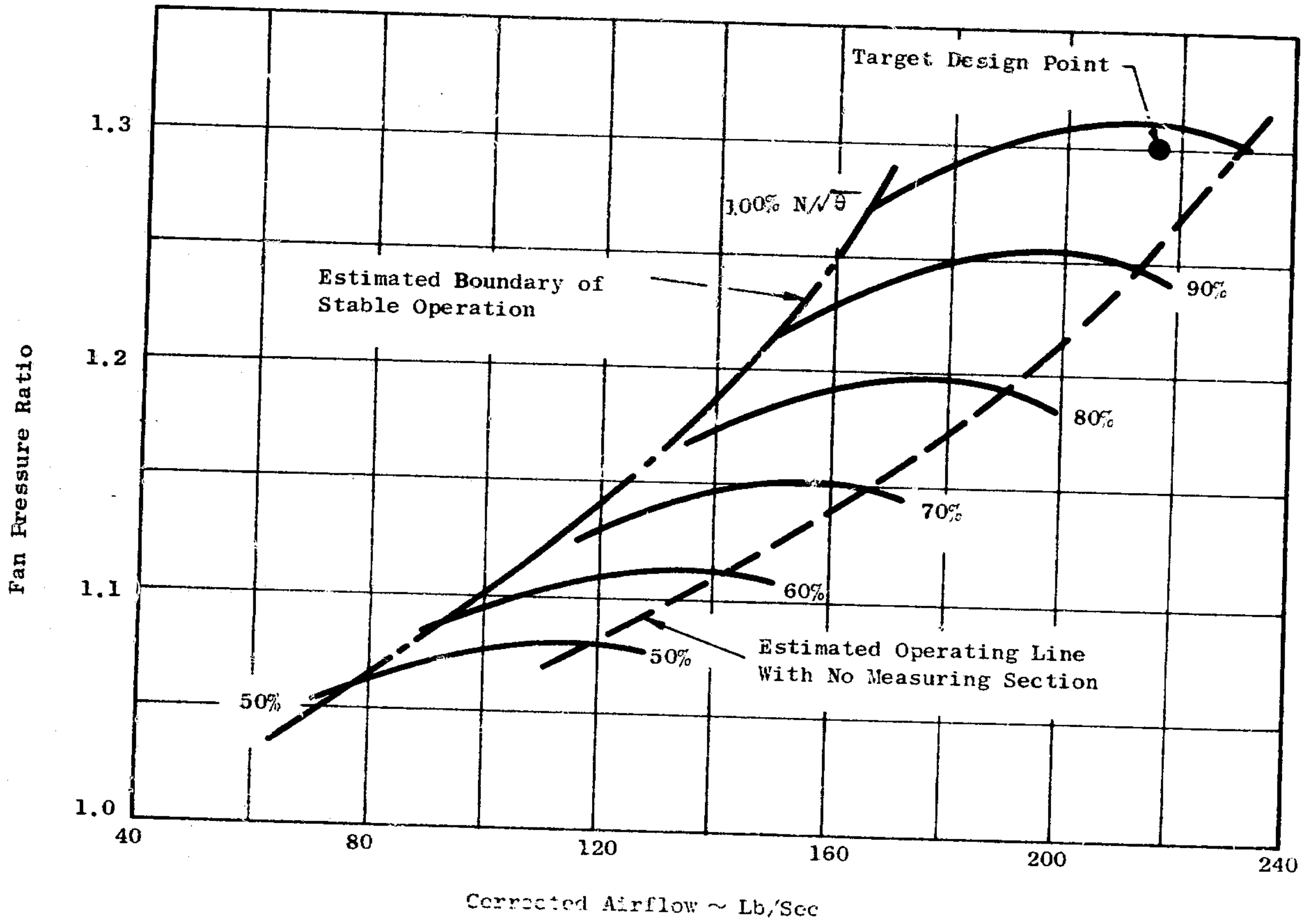


Figure 28. Estimated LF336A Map Characteristics Based on Fan 002 Final Configuration

2

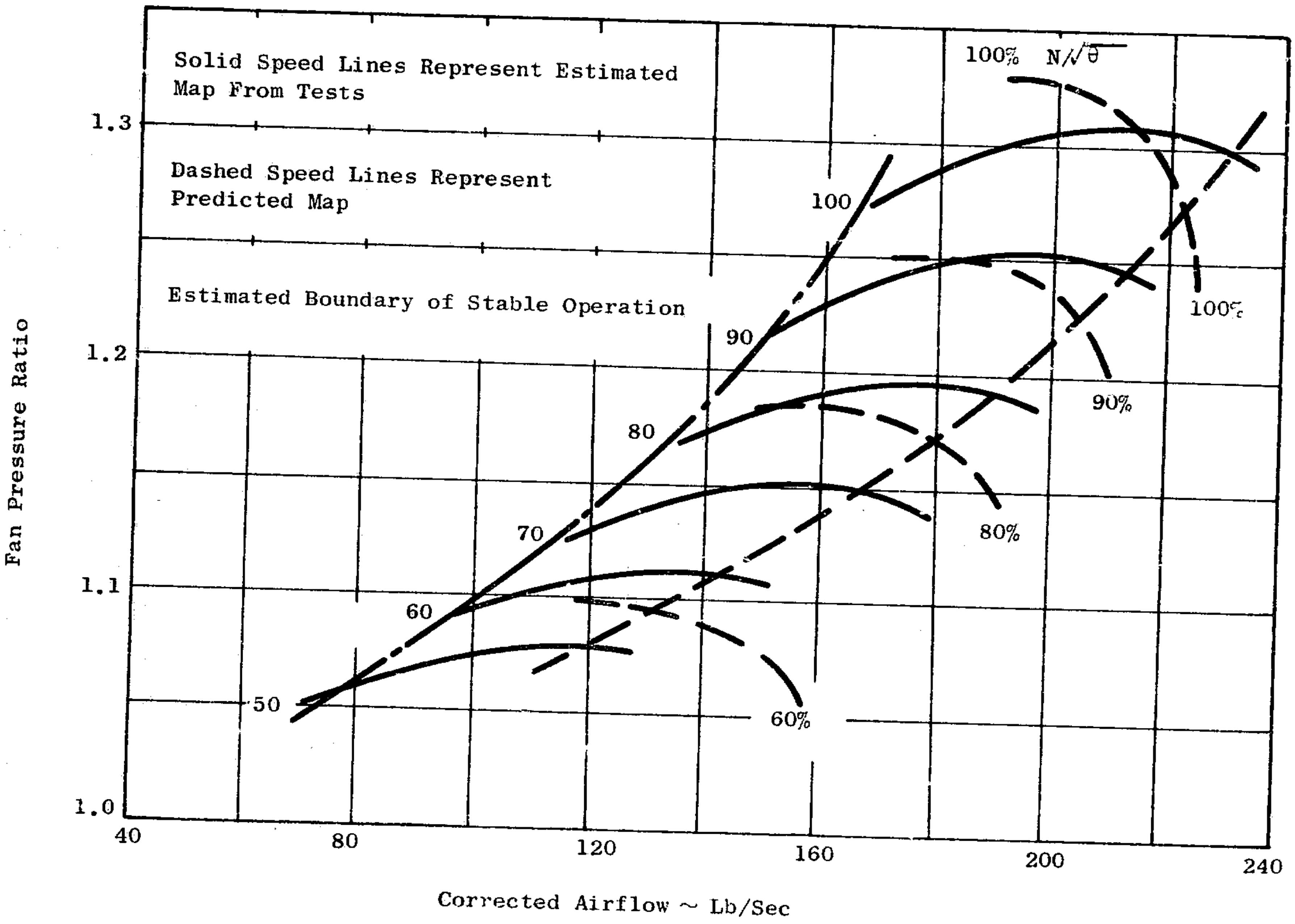


Figure 29 LF336A Estimated Versus Predicted Map Characteristics

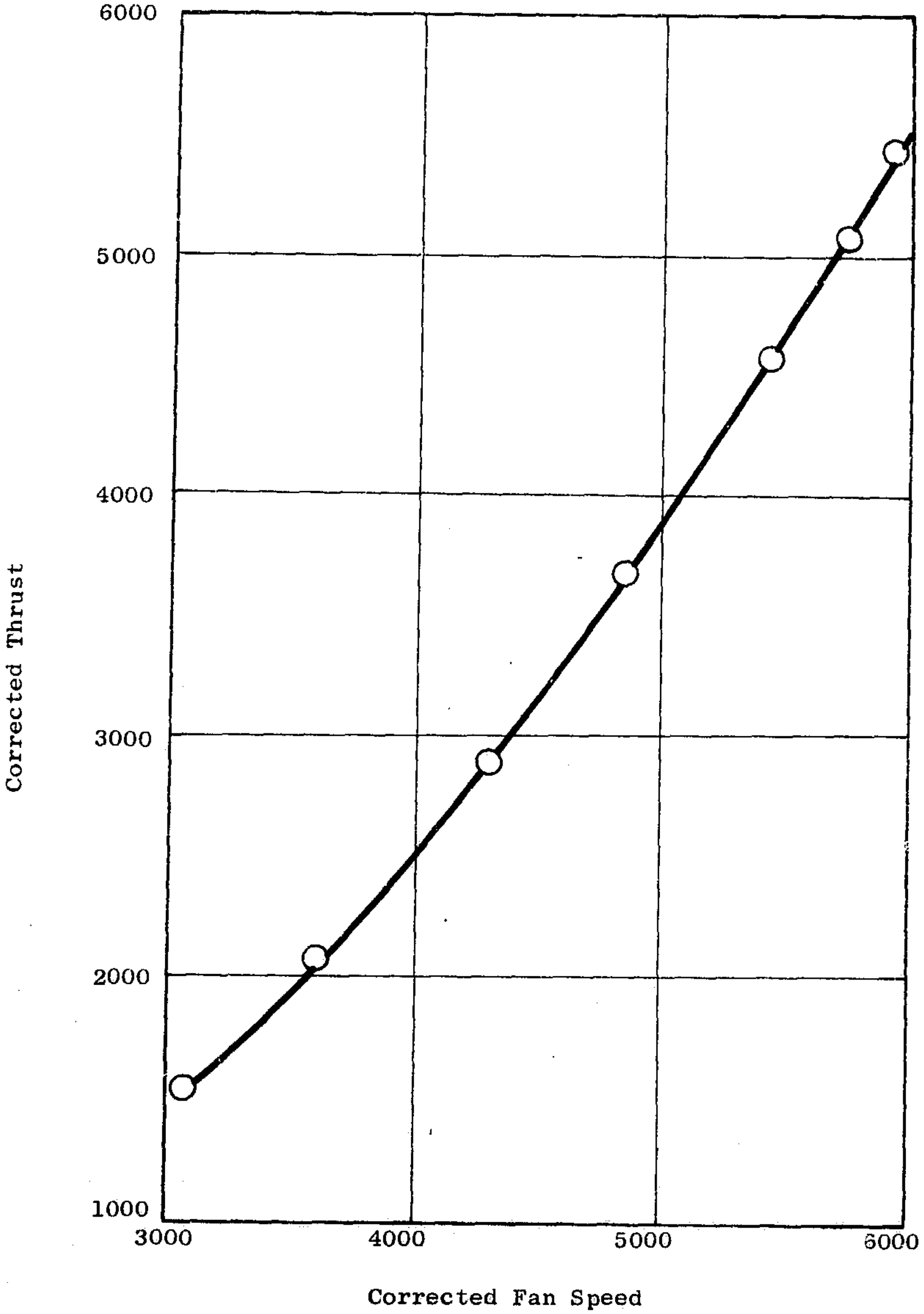


Figure 30 Fan Thrust Versus Speed for Fan 002 from Run 18

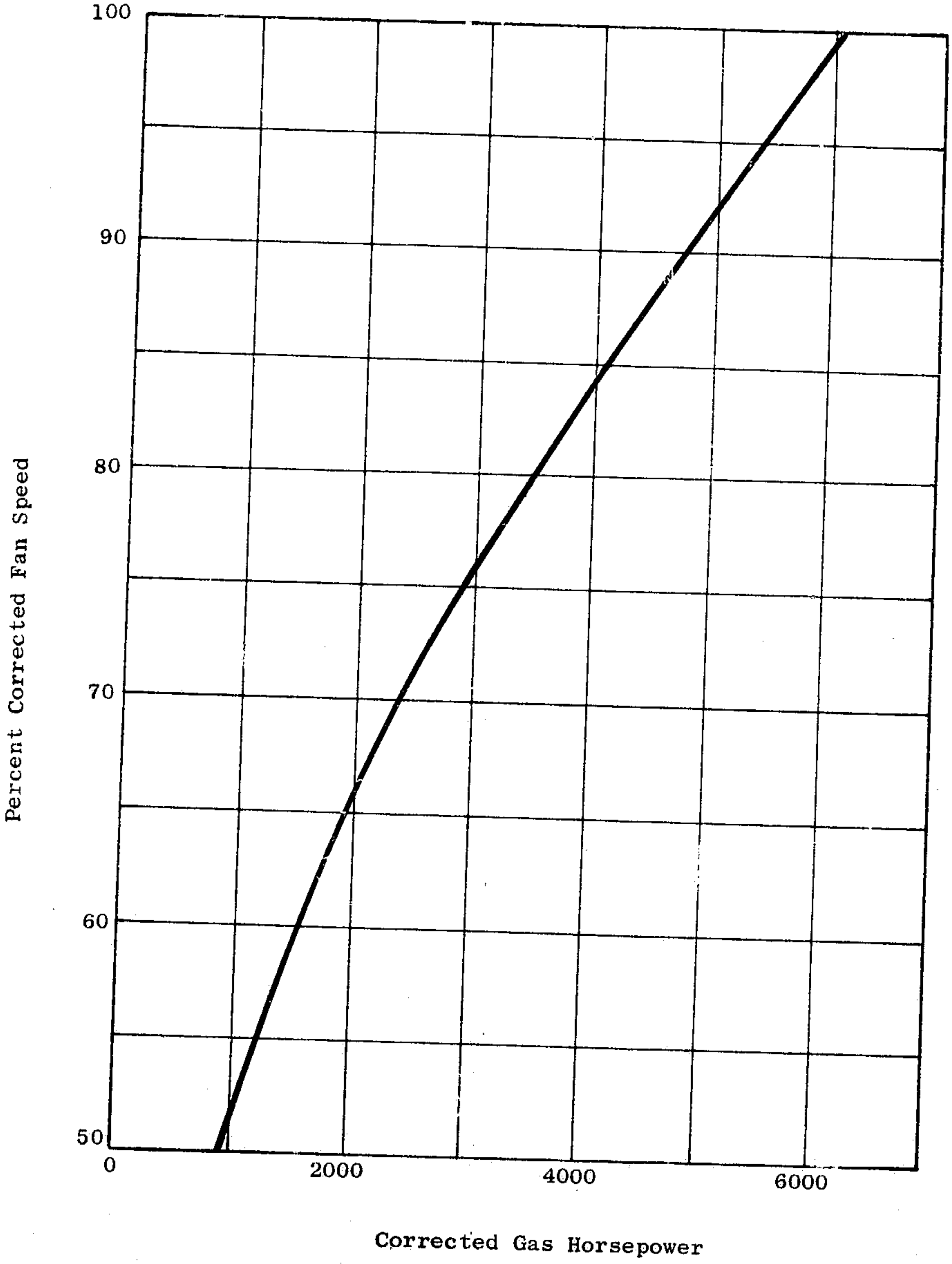


Figure 31 Fan Speed Versus Horsepower, for Fan 002 Final Configuration

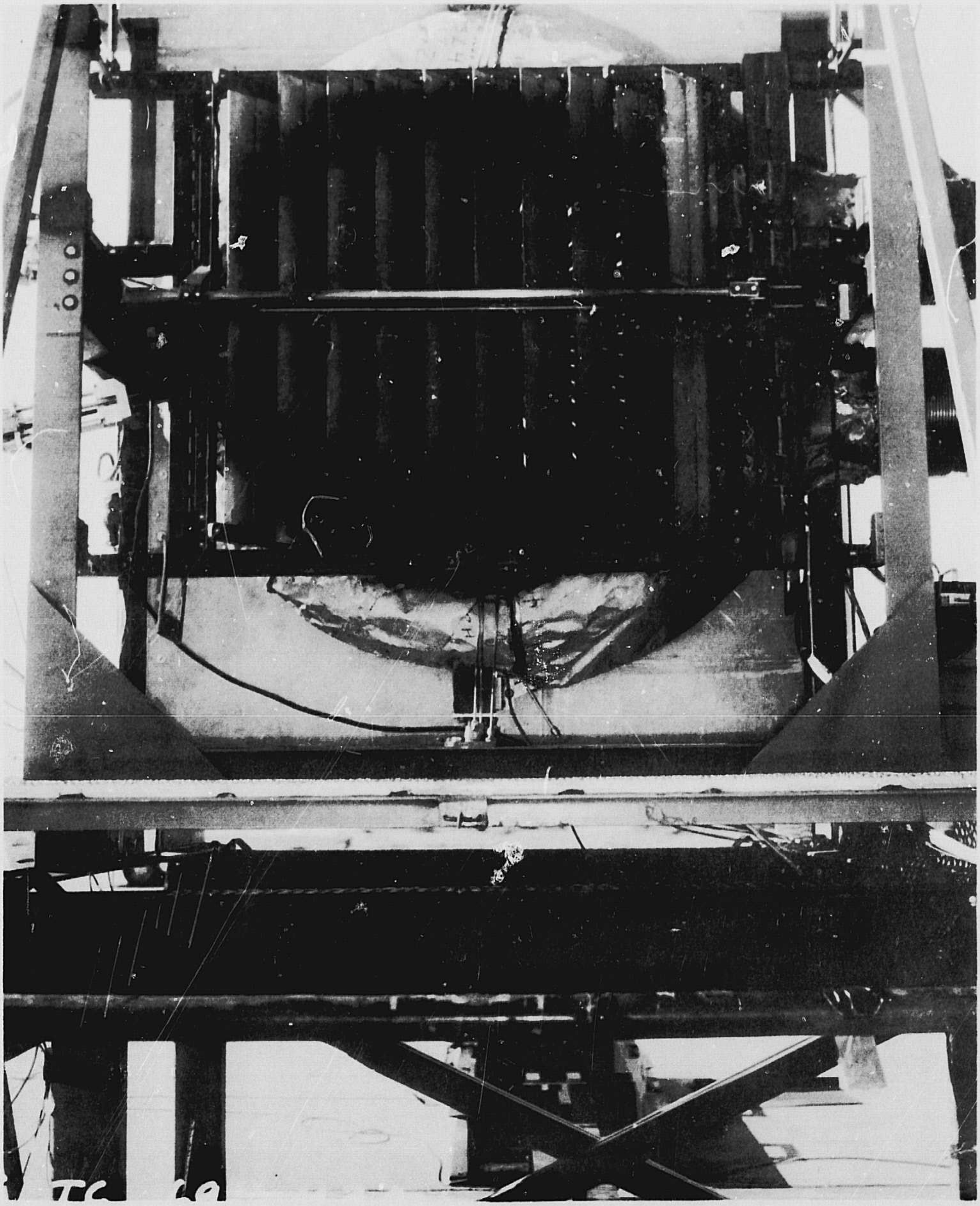


Figure 32. **Exit** Louvers Installed

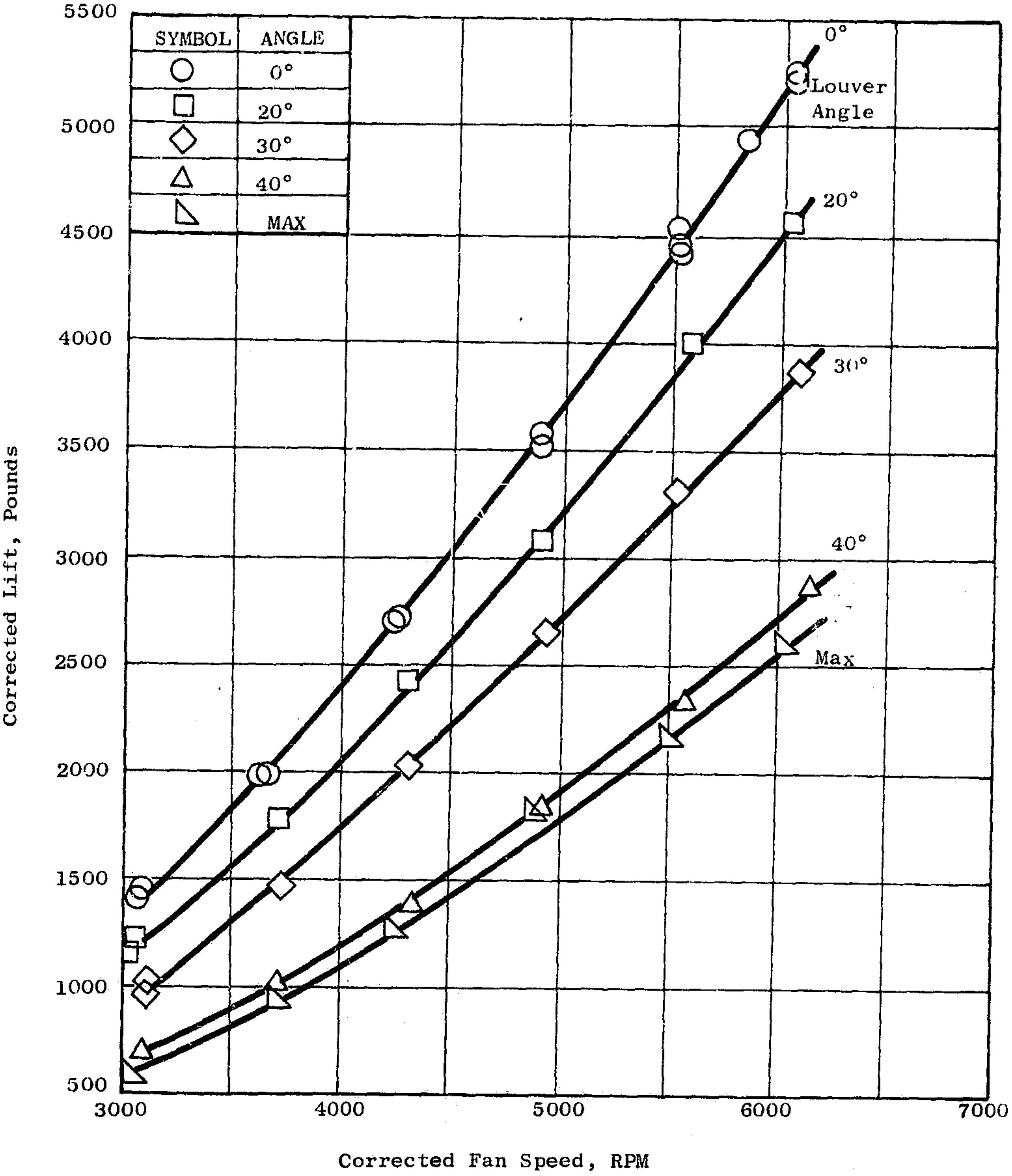


Figure 33 Variation of Fan Lift with Louver Angle

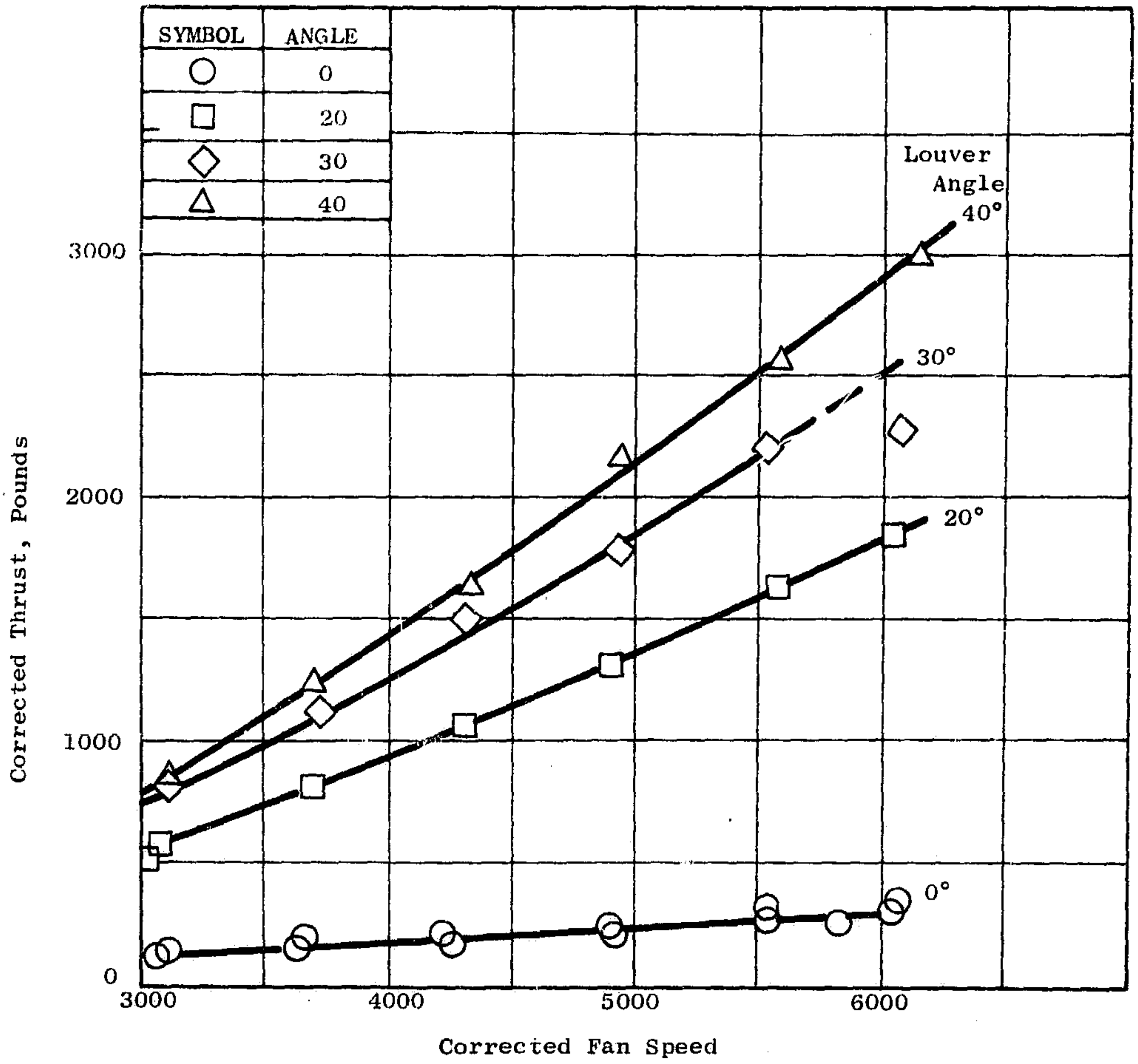


Figure 34 Variation of Fan Thrust with Louver Angle

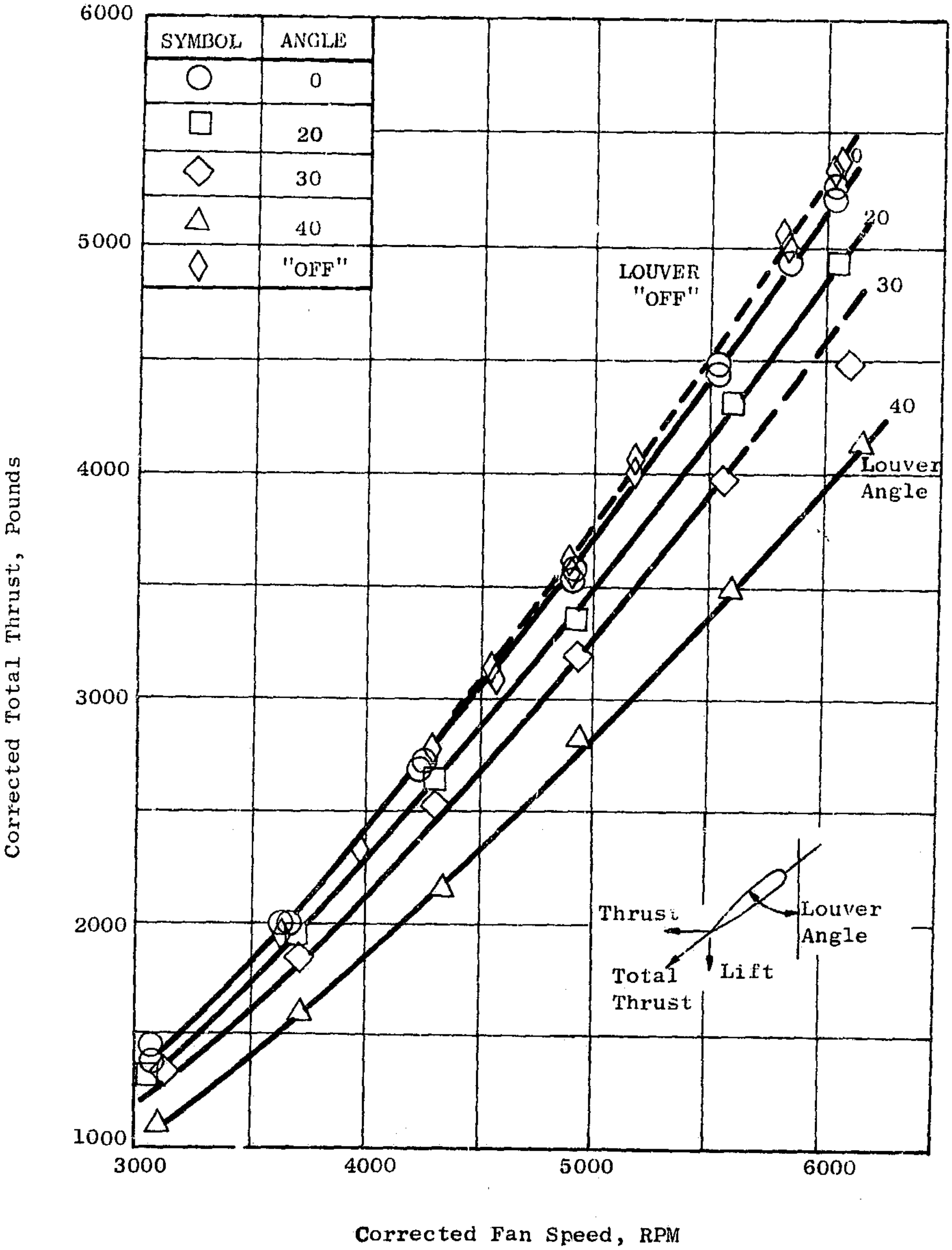


Figure 35. Variation of Fan Total Thrust with Louver Angle

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Title Page

AUTHOR LJ Volk	SUBJECT Lift Fans	NO. R69AEG180
		DATE 4/1/69
TITLE G.E. CLASS GOVT. CLASS LF336A Lift Fan Final Report		G.E. CLASS II
		GOVT. CLASS UNCLASSIFIED
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SUMMARY G.E. CLASS II GOVT. CLASS UNCLASSIFIED

Two 36" diameter, 1.3 pressure ratio lift fans were built under contract NAS2-4130 for use in wind tunnel tests of large-scale aircraft models. This report briefly describes the fan design and summarizes the static test program.

The LF336A fan is a single stage, turbotip, rotor-stator design. The primary power source is a non-afterburning J85-5 turbojet engine. The fan, however, is also capable of operation with the J97 engine. The fan is primarily designed to be wing mounted, however, provisions are made for lift pod mounting. Static parts are of non-flight-weight, low-stress design, to lower the design and manufacturing cost and to provide configuration flexibility.

KEY WORDS

Lift Fans, Tip Turbine

CONTRACT NUMBER NAS2-4130 SPONSORING ORGANIZATION NASA

TESTS MADE BY V/STOL Propulsion Systems Operation (ORGANIZATION)

COUNTERSIGNED E.F. Beeler, Acting Manager, V/STOL Propulsion Systems Operation
(AUTHOR'S SUPERVISOR) (TITLE) (ORGANIZATION)

DEPT./OPERATION AE&TRO LOCATION Evendale, Ohio 45215