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SECURITY CLASSIFICATION Open

SUBJECT Lifting Fans for VTOL Aircraft: Mechanical Development of A Gear-Driven Model Fan Installed in a Wing

PREPARED BY G.G. Levy, R.J. Rimmer, T.W. Hopson

ISSUED TO

Table of Contents

	Page
SUMMARY	3
LIST OF ILLUSTRATIONS	4
1.0 INTRODUCTION	5
2.0 DESCRIPTION OF WING	5
3.0 DESCRIPTION OF FAN AND DRIVE TRAIN	6
3.1 Fan	6
3.2 Spiral Bevel Gears	6
3.3 Turbine	6
3.4 Drive Shaft and Bearing Cartridges	7
3.5 Speed Increasing Gearbox	7
3.6 Lubrication Systems	7
3.7 Instrumentation	8
3.8 Control System	8
4.0 MECHANICAL PERFORMANCE	9
4.1 Preliminary Running	9
4.2 Strip Inspection	10
5.0 TURBINE PERFORMANCE	10
6.0 CONCLUSIONS	11
7.0 REFERENCES	12

SUMMARY

A 12 inch diameter gear driven fan, having a gross disc loading of about 450 $\mathrm{lb/ft^2}$, was installed in a wing for wind tunnel studies on the fan inlet.

The mechanical arrangements of the fan and drive, which included a turbine mounted at one end of the wing, are described.

Preliminary mechanical testing was carried out in the Engine Laboratory, after which the wing and fan were installed in a 10' x 20' wind tunnel for aerodynamic studies. Problems relating to oil seals and oil leakage are discussed.

About 20 hours of running were completed on the rotating machinery. A strip inspection of components then showed them to be in good condition.

LIST OF ILLUSTRATIONS

	Figure
Leading and Trailing Edge Views of Wing Frame	1
(Taken with wide-angle lens)	1A
Upper Surface of Wing	2
Lower Surface of Wing	3
Wing Mounted in Test-Stand Trunnions	4
View of Wind Tunnel Trunnion Mounting and Turbine Lubricating System	5
Fan Rotor	6
Section Through Fan Hub	7
Turbine Cross-Section	8
Fan and Drive Train	9
Cross-Section of Bearing Cartridge and Flexible Couplings	10
Main Lubricating System	11
Control Valve	12
Drive Train Temperatures	13
Spiral Bevel Pinion - After 20 Hours Running	14
Turbine Horsepower	15
Turbine Torque	16
Turbine Air Flow	17
Turbine Temperature Drop	18
Turbine Inlet Pressure	19

1.0 INTRODUCTION

A programme of analytical and experimental studies of fan-in-wing inlets is currently under way in the Engine Laboratory of the National Research Council. This programme represents one phase of a general investigation into the powerplant aspect of the fan-in-wing concept for VTOL aircraft.

Earlier inlet testing was carried out on a model wing using suction from a remote source to simulate the fan flow (Ref. 1). It was recognized that this method imposed some limitations, in that any effects due to the tunnel air flow on the fan efflux were not felt, and that the flow field around the inlet plane may well be modified by the presence of a fan. Thus, to complete the inlet studies, it was necessary to provide a fan and wing combination that would enable these effects to be assessed. For this purpose, two basic fan requirements were indicated:
(1) a high disc loading and (2) the absence of physical obstructions in or around the fan efflux.

As described in References 2 and 3, a considerable amount of work had been done (under static inflow conditions) on 12 inch diameter model fans to establish design criteria for fans operating under conditions of high loading and a non-uniform inlet velocity profile. As a result of this work it was possible to select an existing fan design, to be driven by bevel gears mounted in the hub, with a suitable connecting shaft running along the wing semi-span to a turbine mounted at the wing tip.

This report contains a description of the mechanical arrangement of the fan and drive train, together with preliminary performance results. The aerodynamic testing of the inlet and wing will be the subject of a separate report.

2.0 DESCRIPTION OF WING

As shown in Figures 1 and 1A, the 10 ft. span 40 in. chord NACA 0015 profile wing consisted basically of a welded steel frame to which was attached a sheet metal trailing-edge section. The wing was skinned with moulded fibreglass panels to give the required profile and surface finish (Figs. 2 and 3). Trunnion mountings were bolted to pads at each end of the wing frame, with provision for the shaft drive at one end and for instrumentation and lubrication lines at the other. For preliminary running in the Engine Laboratory, the trunnions were each located in the mounting pedestals by four swivel pads to simulate the mounting system used in the wind tunnel balance (Figs. 4 and 5).

3.0 DESCRIPTION OF FAN AND DRIVE TRAIN

3.1 Fan

The aerodynamic design of the fan blading was similar to that used in the model fan described in Ref. 3, although a different number of stator blades was used. This fan gave a gross disc loading of about 450 lb/ft^2 at a rotational speed of 15,000 RPM and was mechanically designed for speeds up to 18,000 RPM.

The 18 fan rotor blades were machined from series 410 stainless steel and provided with a conventional fir-tree root fixing (Fig. 6). Axial movement of the blades was controlled by an integral lip on one side and by light peening on the other.

Structural support for the rotor assembly was provided by eleven stator blades, one of which was made thicker than the others to accomodate the quillshaft drive between gearbox and fan.

3.2 Spiral Bevel Gears

The fan driving gears were required to transmit about 300 horsepower and had to be contained within a 6 in. diameter hub having limited axial depth. A 22 x 43, 11 D.P. spiral bevel ratio was chosen. Both pinion and gear were made of A.I.S.I. 9310 (AMS 6260) material, heat treated to a tooth surface hardness of Rockwell C-62 min. and a core hardness of C32/C42. Both the pinion and rotor were supported on angular contact ball bearings (Fig. 7) lubricated by oil jets. Because of space limitations, the bearing loading was high and hence it was necessary to accept an estimated full-duty life of only seven hours for the inboard pinion bearing.

3.3 Turbine

The turbine assembly was adapted from a General Electric

Type B22 Turbosupercharger. This unit consisted basically of a shaft carrying a turbine wheel at one end and a centrifugal impeller at the other. The turbine was normally driven by hot gas from the exhaust of a reciprocating engine. For the use under consideration, only cold air was available hence it seemed convenient to eliminate the turbine wheel and use the centrifugal compressor as a radial inflow turbine.

Apart from a few minor modifications to the casing for attachment purposes, conversion of the oil pump gear drive to an externally mounted electric motor drive and new windback seals, the compressor assembly was unchanged (Fig. 8).

3.4 Drive Shaft and Bearing Cartridges

The driveshaft was split into three main segments, each connected by gear-type flexible couplings (Figs. 9 and 10). The shaft segments were carried on angular contact ball bearings lubricated by oil jets and a suction scavenge system. Carbon end-face seals were incorporated into each bearing assembly.

3.5 Speed Increasing Gearbox

In order to match the maximum permissible turbine speed of 24,000 RPM with the desired maximum fan speed of 18,000 RPM (through the 22 x 43 spiral bevel ratio), it was necessary to provide a speed increasing gearbox. The helical gearset consisted of a pinion, idler gear and output gear giving an overall ratio of 1.5 (i.e. output shaft speed approximately 36,000 RPM). The 23° helix angle gears were made of heat treated A.I.S.I. E9310 material.

Lubrication was by oil jet, using the same suction scavenge system as for the driveshaft cartridges.

3.6 Lubrication Systems

The main lubrication system consisted of a 15 gallon tank, electric motor driven supply and scavenge pumps, cooler, filters and a system of bypass valves for control purposes (Fig. 11). All bearings and gears in the fan drive were lubricated by oil jets with a suction scavenge return. After preliminary testing (see Section 4.1) a second scavenge pump was installed.

The lubricating oil was Castrol 98 to U.K. Spec. DERD 2487.

The turbine bearings were lubricated by a separate system comprising a reservoir, electrically driven pumps, cooler and filter (Fig. 5). Tellus 41 oil was used.

Pressure switches were installed in both systems to provide an automatic shut down signal in the event of oil supply failure.

3.7 Instrumentation

Temperatures

Bearing and lubricating oil temperatures were measured by means of iron-constantan thermocouples connected in groups through switches to Bristol pyrometers.

Turbine inlet and outlet air temperatures were measured by iron-constantan thermocouples connected to a manually balanced potentiometer.

Pressures

Lubricating oil pressures and air line pressures were read on Bourdon tube gauges.

Measuring orifice pressures were read on manometers filled with a fluid having a specific gravity of unity.

R.P.M.

Turbine speed was measured by a magnetic proximity pick-up and toothed-wheel arrangement, reading out both on dual-range meters that incorporated an overspeed trip, and a digital counter. The former instrument is described in detail in Ref. 4.

Turbine Air Flow

A B.S.I. orifice with corner taps was used to measure turbine air flow.

3.8 Control System

The turbine air supply, and thus turbine speed, was controlled by an 8 in. diaphragm valve (Fig. 12). By varying the air pressure in the diaphragm chamber, using a pressure regulator valve, very sensitive speed control was obtained. In addition, a solenoid operated air bleed provided an emergency shutdown capability, initiated either automatically through an overspeed trip or low-oil pressure, or manually from a switch on the control panel.

4.0 MECHANICAL PERFORMANCE

4.1 Preliminary Running

Preliminary running was carried out in the Engine Laboratory with the objective of identifying mechanical problem areas before the wing and fan were installed in the wind tunnel for aerodynamic work. Incremental running was first carried out at turbine speeds up to 9000 RPM as part of the running-in process.

During this phase, two problems appeared:

1. The bearing cartridges ran at much higher temperatures than had been anticipated.

2. Lubricating oil was leaking from the fan hub into the fan air stream.

The high temperatures in the cartridge assemblies were generated by the end-face carbon seals. It was noted that although the optically flat, 4 micro-inch finish mating rings showed appreciable wear marks, those from the helical gearbox assembly, which had a ground finish only, were practically unmarked.

After some experimental work, the trouble was cured by reducing the spring load on the seals and improving the lubrication in the rubbing face areas. All mating rings were provided with a ground finish.

Figure 13 shows some representative temperatures before and after these modifications.

Oil leakage from the hub was controlled by a combination of a slinger around the bevel gear, a labyrinth seal at the outer periphery of the hub, and the suction scavenge system. To encourage more rapid scavenging of the oil from the vicinity of the gears, the existing drain holes were enlarged into slots and a separate scavenge pump was provided for the fan hub. These changes resulted in a marked improvement and no discernible oil traces could then be found in the fan efflux.

After further check runs up to a turbine speed of 17,500 RPM (13440 RPM fan speed) the wing was moved to the Propulsion Tunnel for aerodynamic testing. This work involved operation of the fan from zero speed up to an arbitrarily imposed limit of 12,000 RPM, with the wing set at zero incidence and at plus and minus 12.5°. Tunnel air speed varied from zero to about 120 ft/sec.

Operation of the fan presented no problems at wing incidences of -12.5 and zero degrees. However, at a positive incidence of 12.5°, with the fan at zero or very low RPM, there was a small leakage of oil from the fan hub on to the upper surface of the wing. Although the quantity of oil involved was very small, it was sufficient to block several inlet and wing surface pressure taps. It would appear that reversal of the normal direction of flow through the fan resulted in the entrainment of this oil and subsequent spreading of part of it on to the wing surface.

During this part of the programme, the fan was in operation for 14 hours, bringing the total running time up to 20 hours.

4.2 Strip Inspection

Strip examination of the fan and drive train after this period revealed no abnormal wear patterns. The bevel gears were still in good condition (Fig. 14) and apart from slight discolouration of the pinion boss due to the oil seal, no signs of distress were evident.

5.0 TURBINE PERFORMANCE

For the preliminary running described herein, instrumentation for measuring fan performance directly was not scheduled. However, some turbine instrumentation was installed, primarily to measure air flow and temperature drop across the turbine. From these readings, turbine horsepower and torque were calculated and are plotted, together with air flow, temperature drop and turbine inlet pressure in Figures 15, 16, 17, 18 and 19 respectively.

A few points taken from the horsepower-fan speed curve shown as Fig. 7 in Ref. 3 are also plotted in Fig. 15. Quite good agreement is shown although the points tend to diverge at the higher power settings. It should be noted that the estimated turbine powers also include drive train losses. This may account, in part, for the apparent differences in power requirements between the two configurations.

6.0 CONCLUSIONS

1. The end-face carbon seals should be installed with the minimum face loading necessary to effect a seal. The ground seal faces gave superior results to those with highly polished faces, in the relatively short period of running described herein.

2. Turbine/fan power matching appears to be quite satisfactory.

3. Oil leakage from the fan hub was still a problem under conditions of high positive wing incidence and zero or very low fan speeds. Further modifications are being made to the hub scavenge system to minimize this trouble.

REFERENCES

1.	Schaub, U. W. Cockshutt, E.P.	Analytic and Experimental Studies of Normal Inlets with Special Reference to Fan-In-Wing VTOL Powerplants. Part A: Analytic Investigation. Part B: Experimental Investigation. ICAS Paper No. 64-572 4th Congress of the ICAS, Paris August 24-28, 1964.
2.	Fowler, H.S.	Some Tests of 12 in. Dia. Model VTOL Ducted Fans. NRC LR-367, February 1962.
3.	Schaub, U. W. Bassett, R.W.	Analysis of the Performance of a Highly Loaded 12-inch VTOL Z-Axis Fan-In-Wing Model at Zero Forward Speed. NRC LR-439, September 1965.
4.	Harron, R.J.	R.P.M. Indicator and Overspeed Trip. NRC MI-819, 8 May 1959.

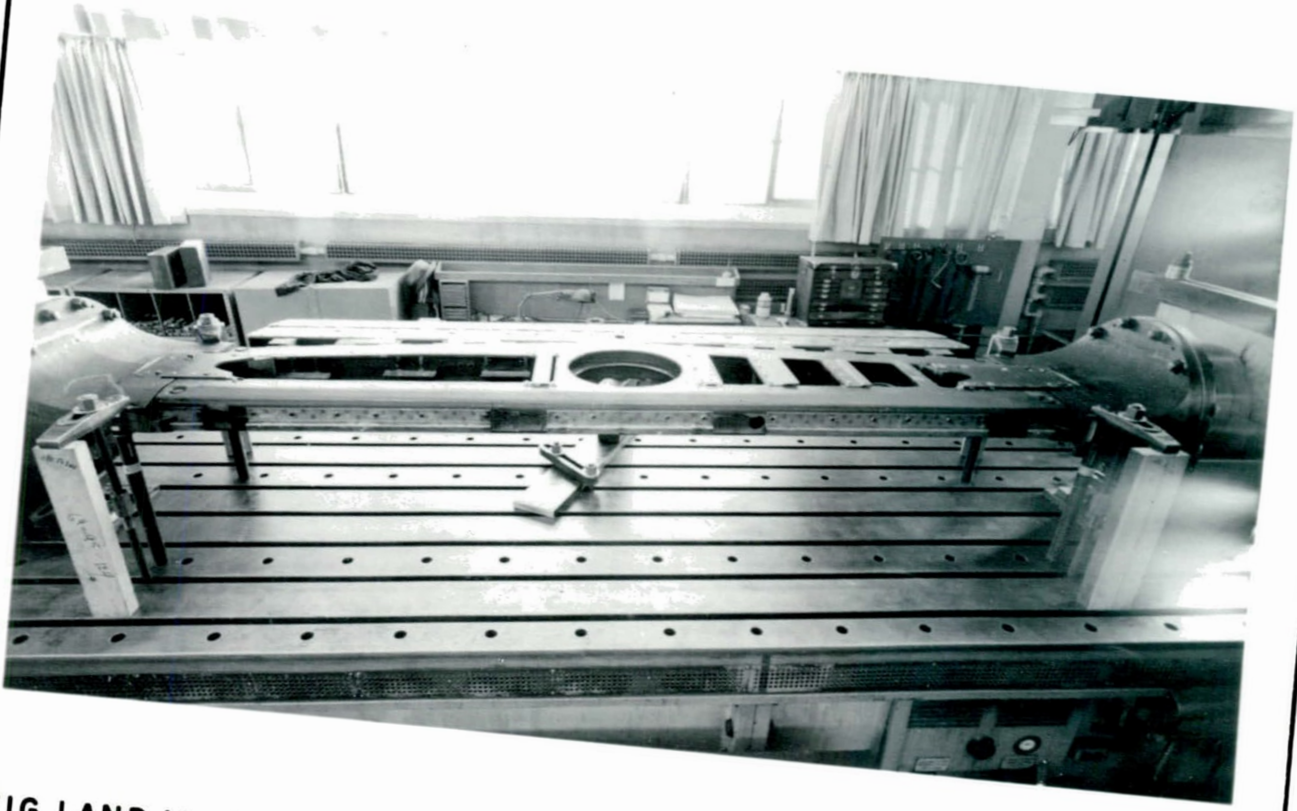
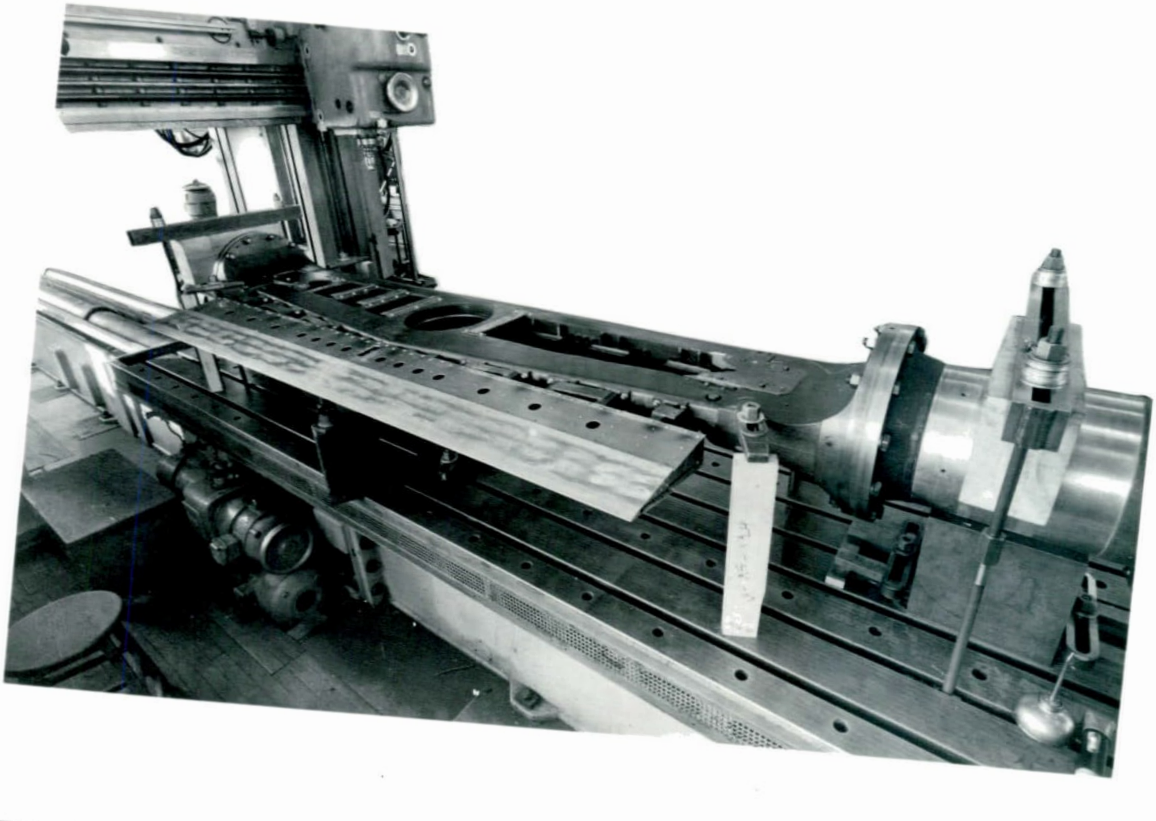


FIG. 1 AND 1A LEADING AND TRAILING-EDGE VIEWS OF WING FRAME (TAKEN WITH WIDE-ANGLE LENS)



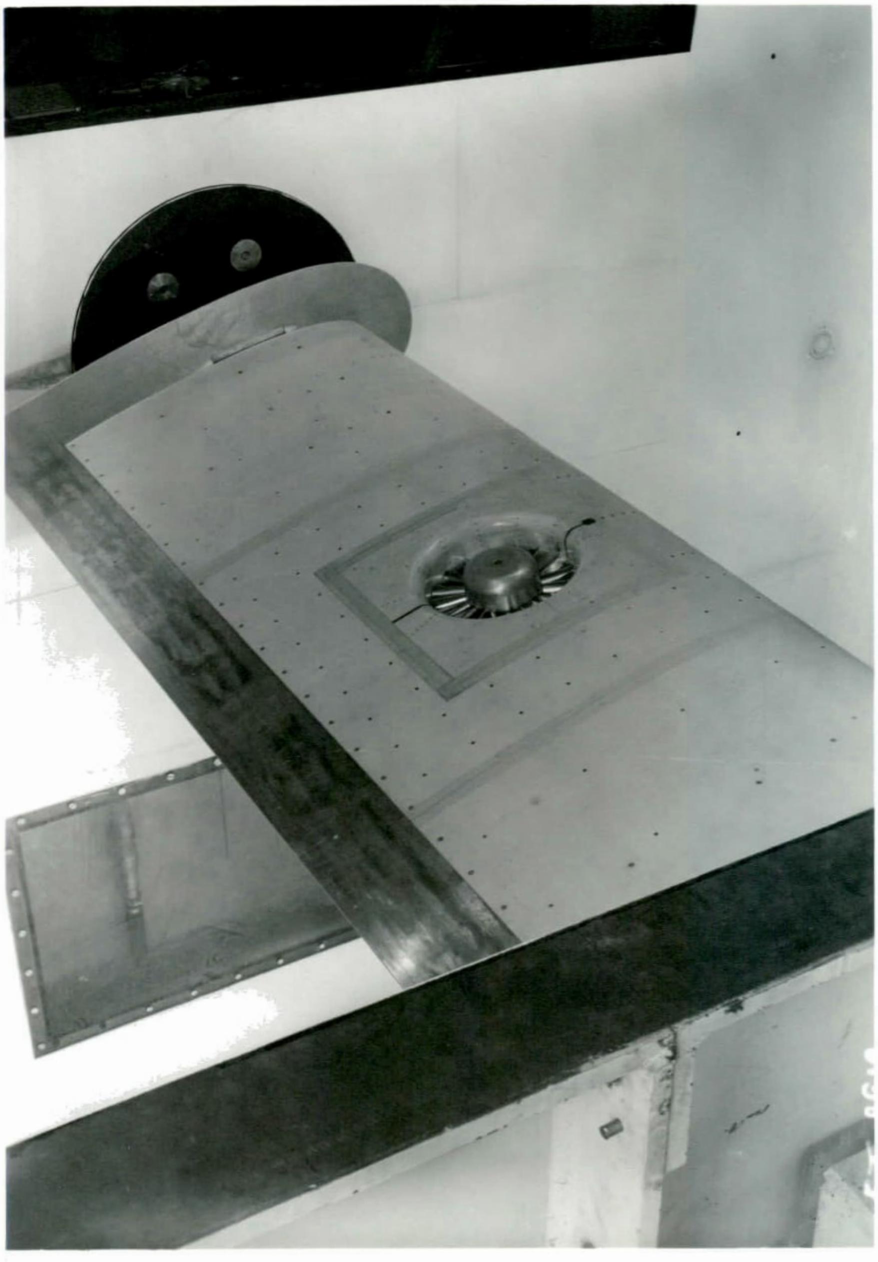


FIG. 2 UPPER SURFACE OF WING

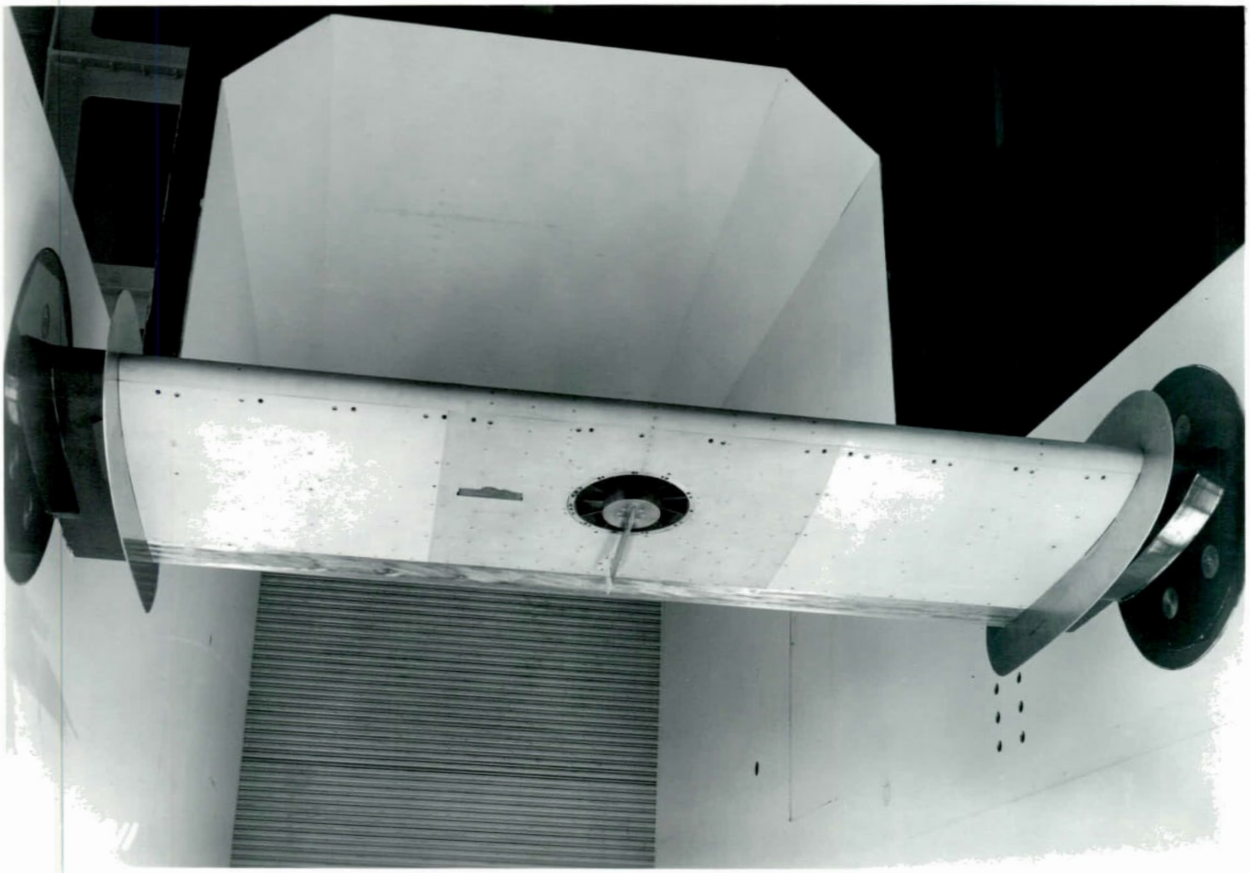


FIG.3 LOWER SURFACE OF WING

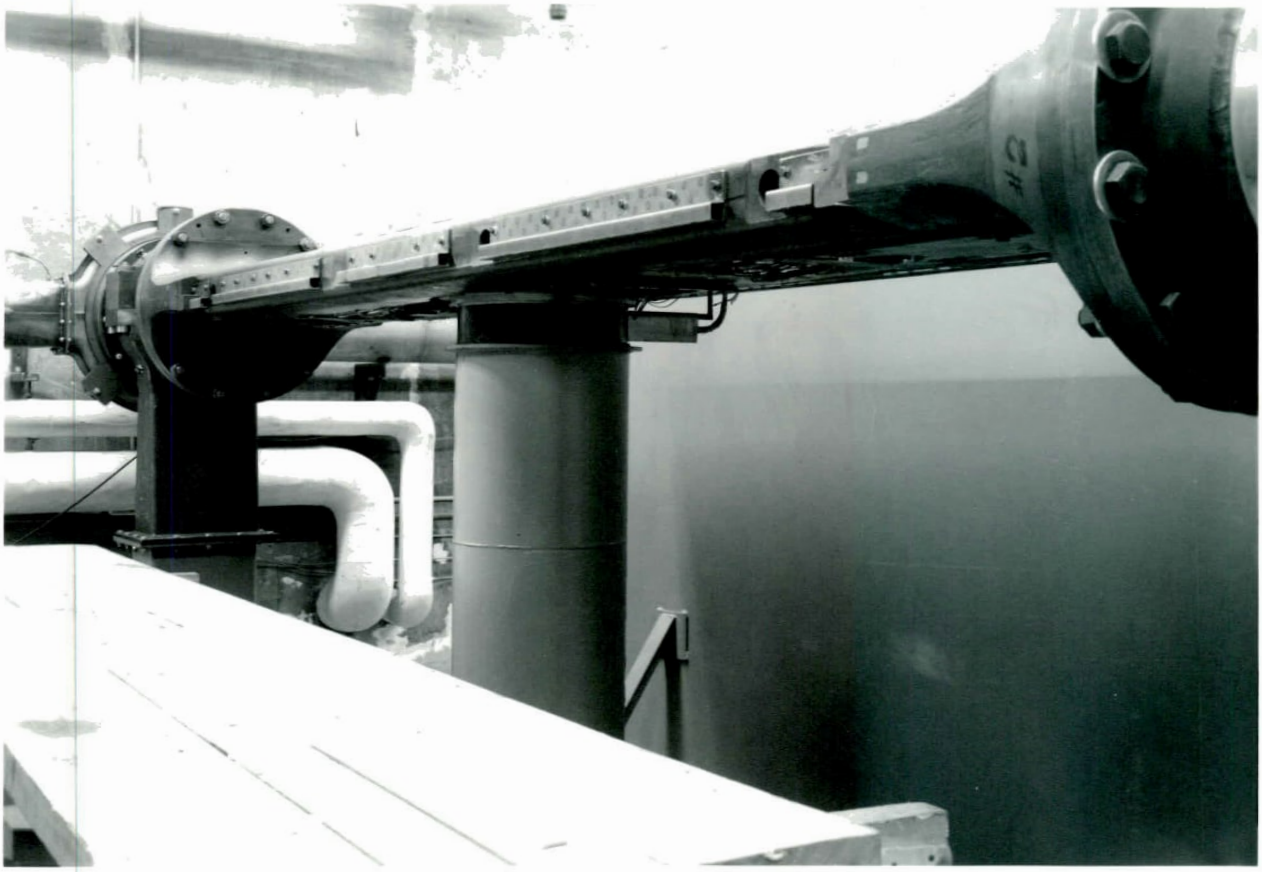


FIG. 4 WING MOUNTED IN TEST STAND TRUNNIONS

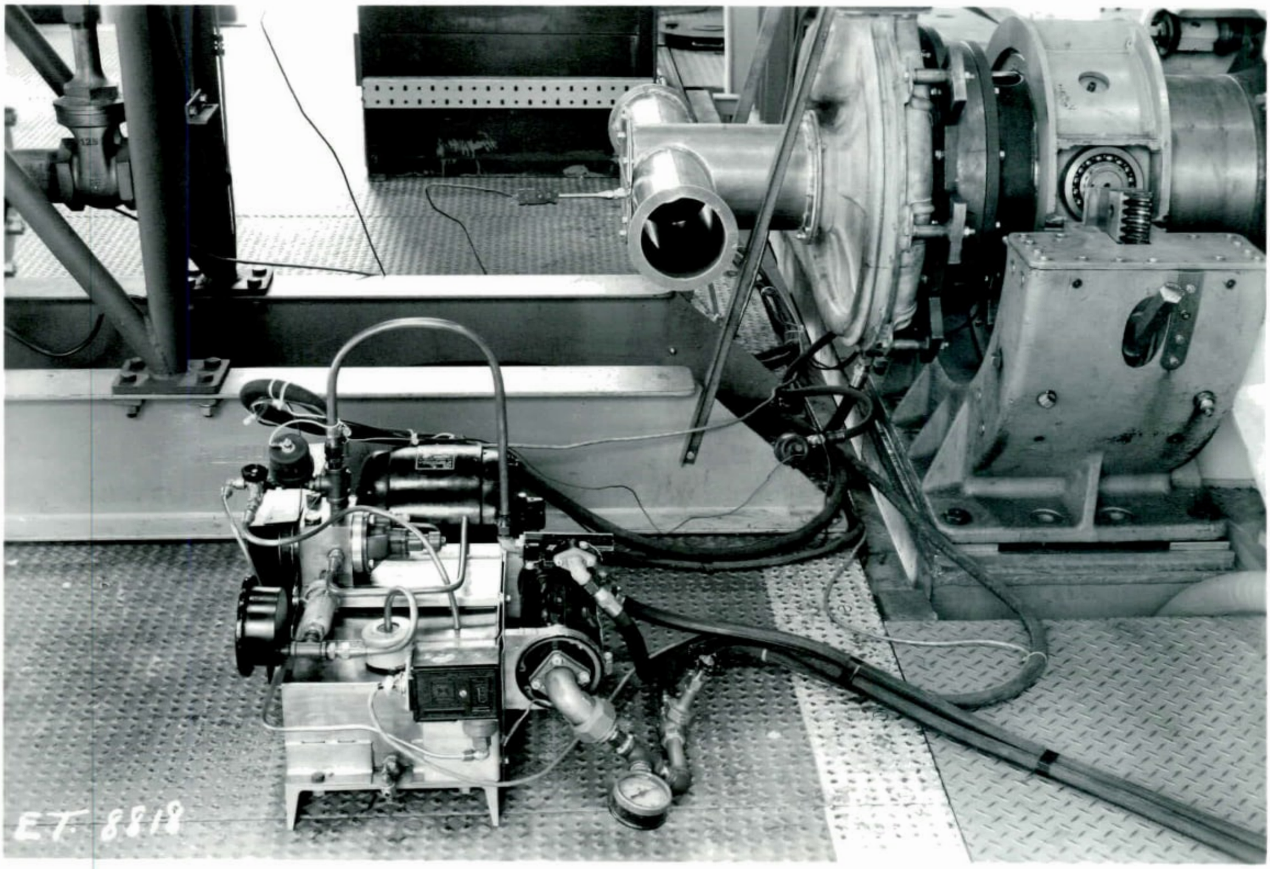


FIG. 5 VIEW OF WIND TUNNEL TRUNNION MOUNTING AND TURBINE LUBRICATING SYSTEM

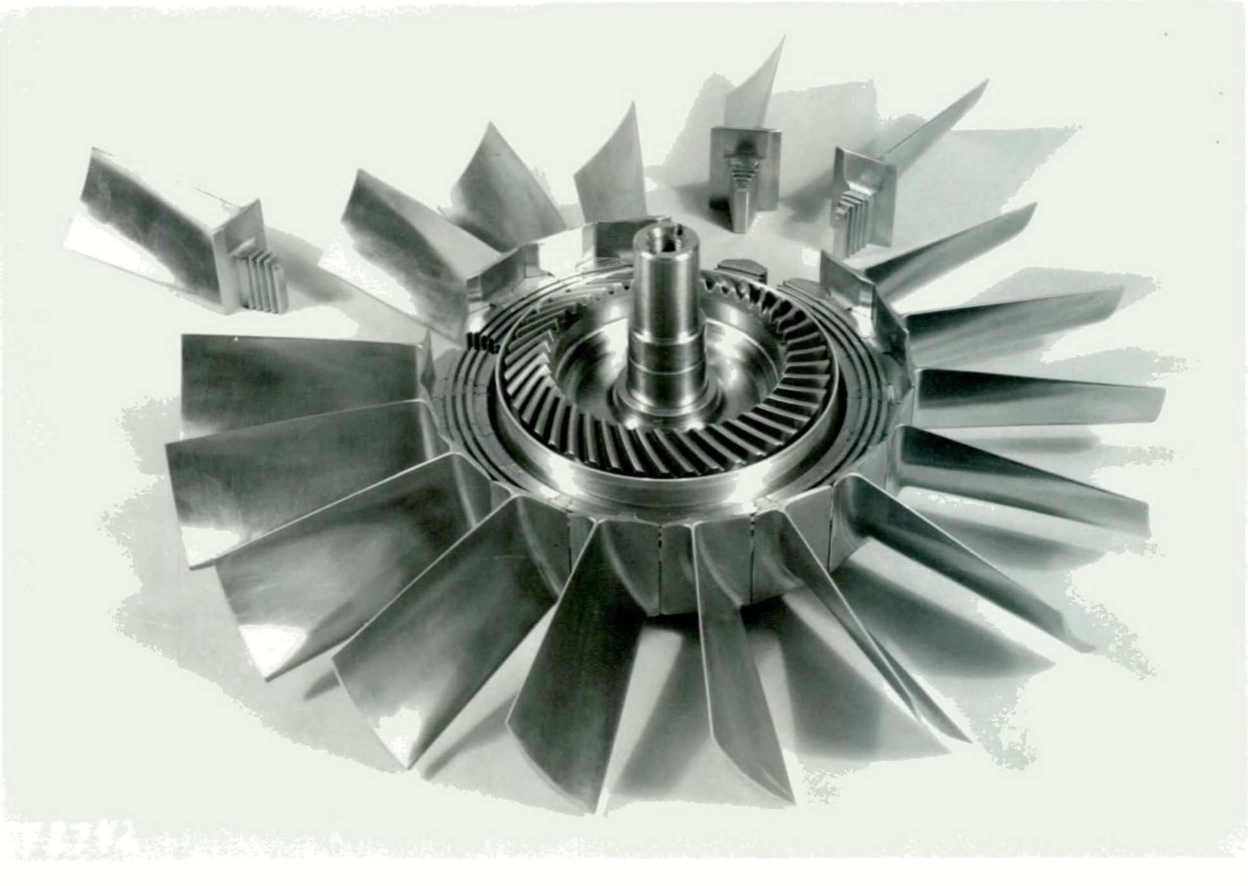
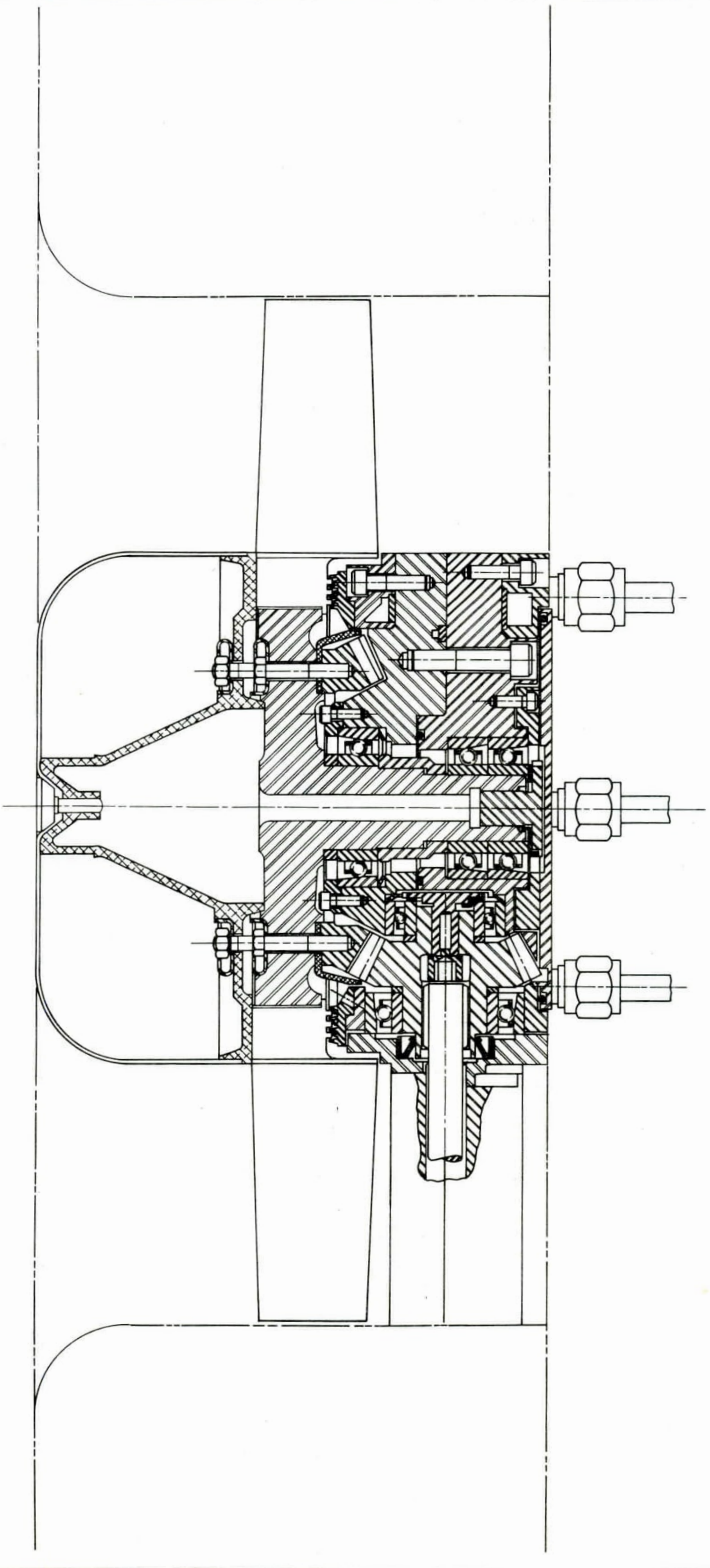


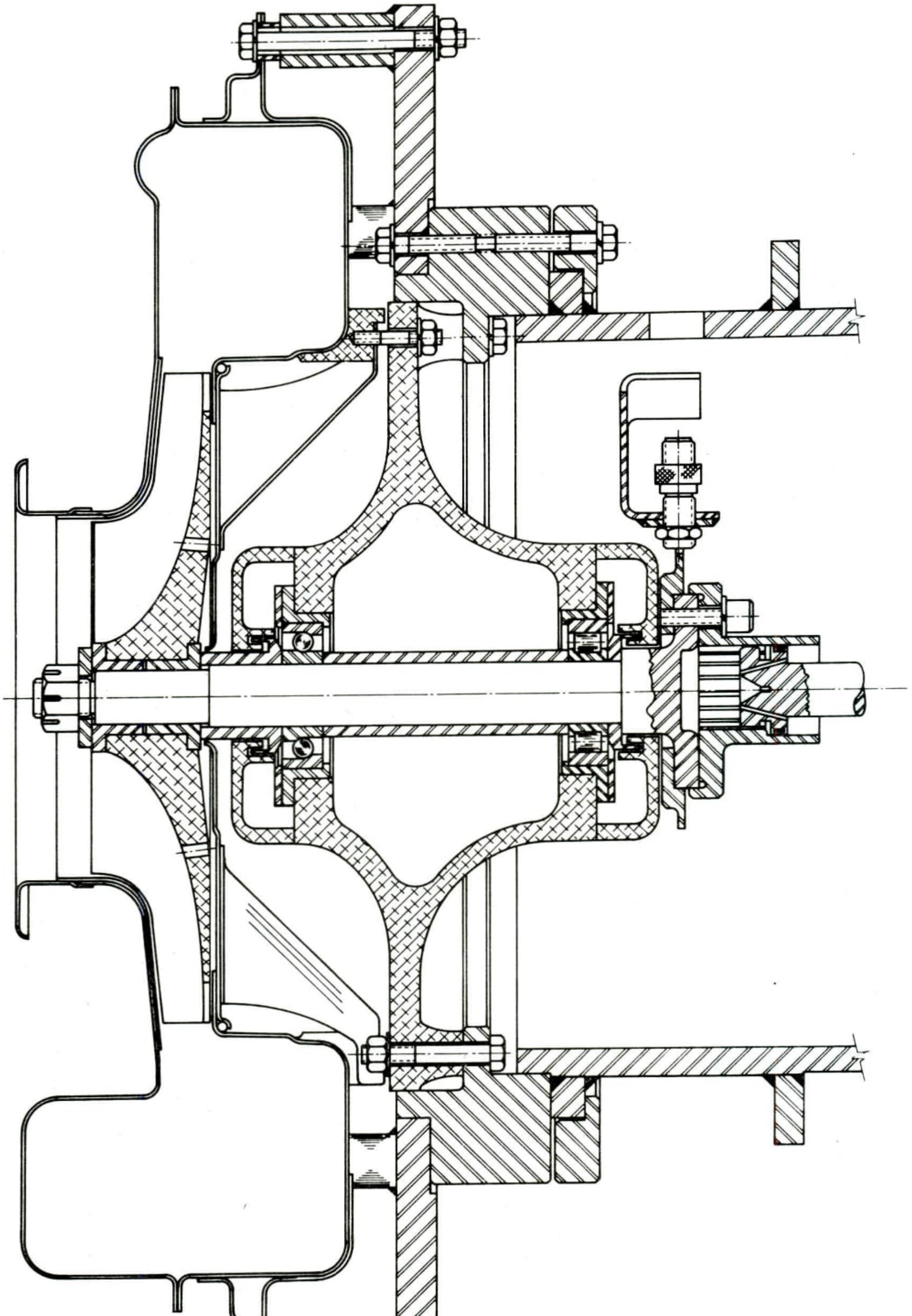
FIG.6 FAN ROTOR

FIG.7



SECTION THROUGH FAN HUB

FIG. 8



TURBINE CROSS-SECTION

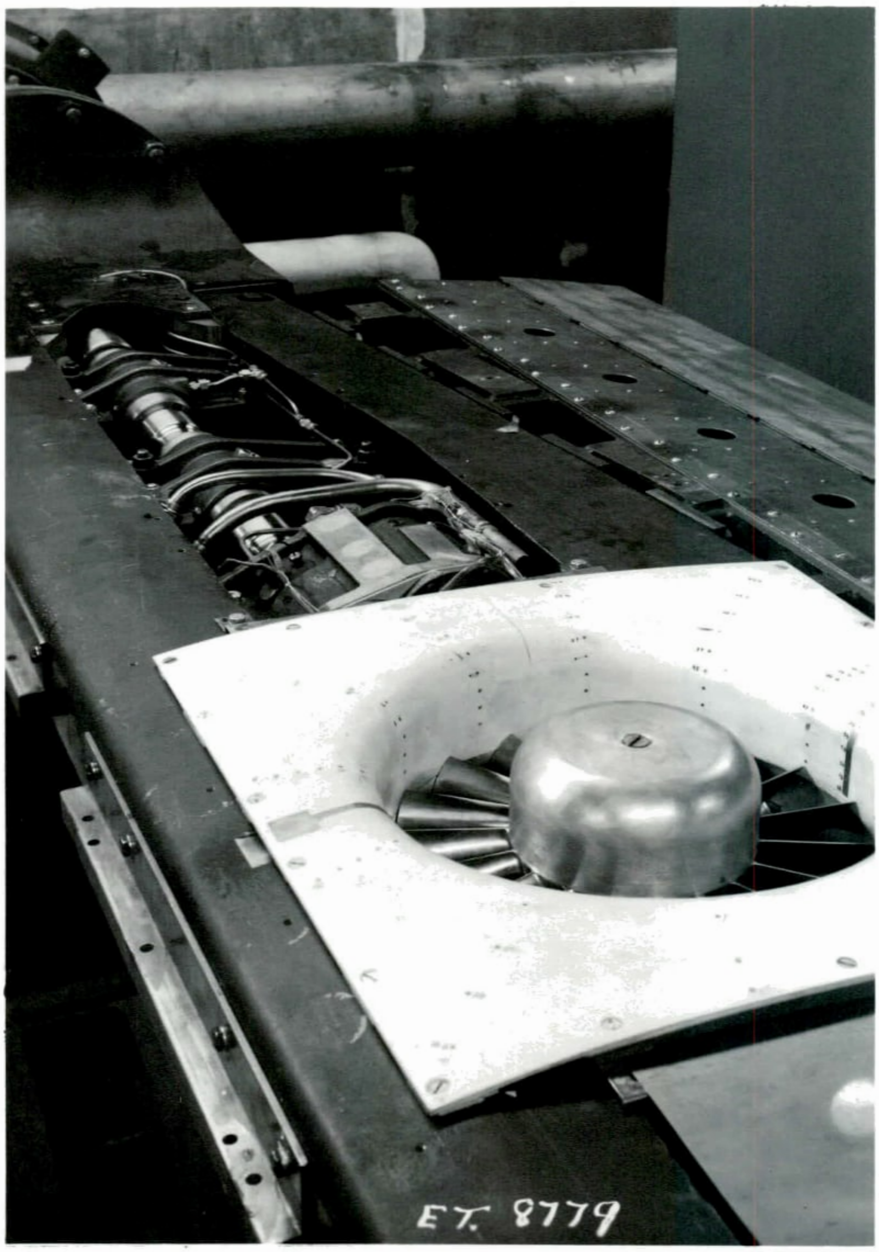
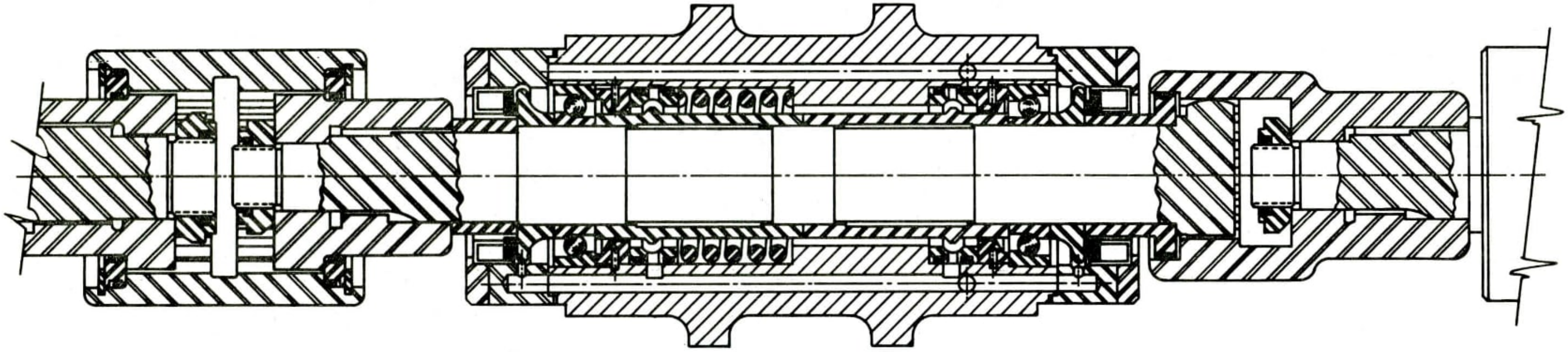


FIG. 9 FAN AND DRIVE TRAIN



CROSS-SECTION OF BEARING CARTRIDGE
AND FLEXIBLE COUPLINGS

FIG. 10

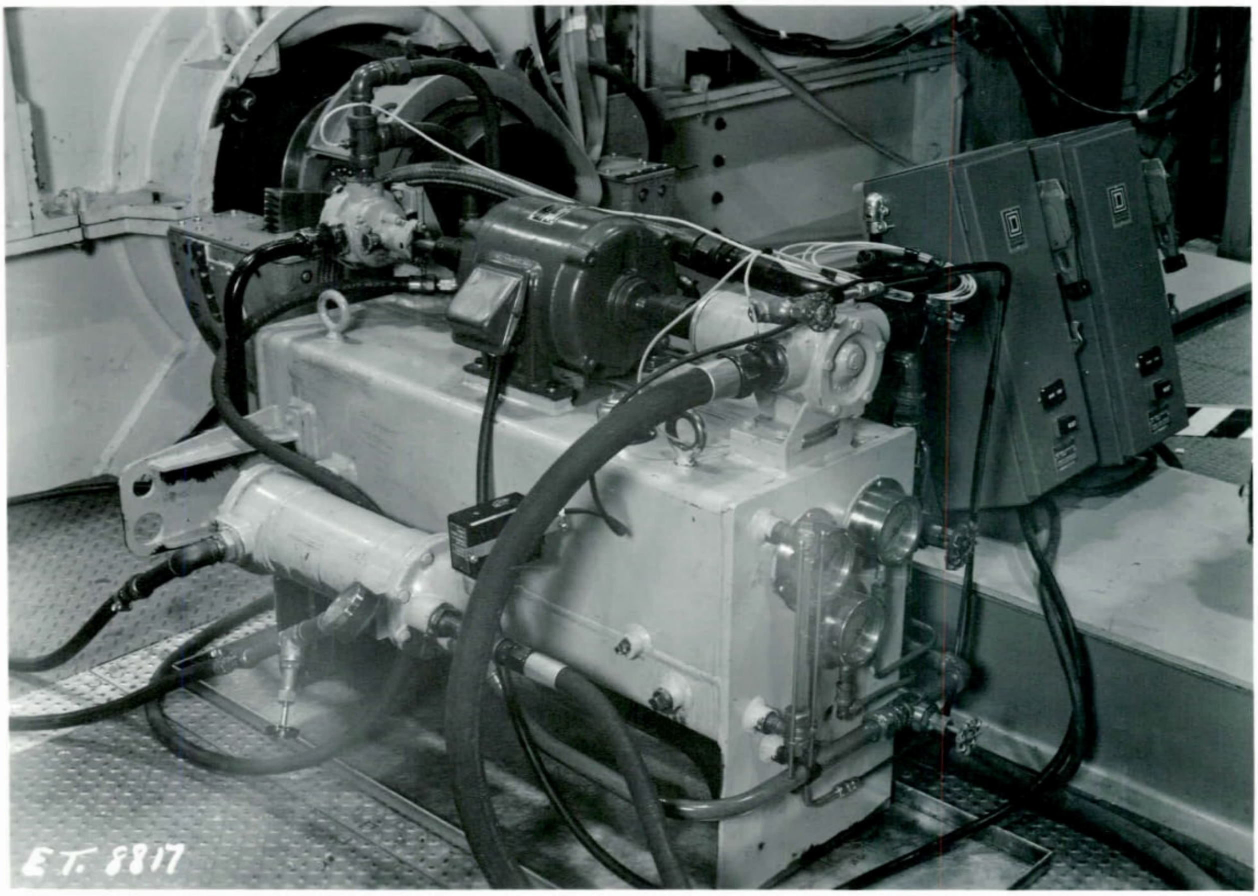


FIG. 11 MAIN LUBRICATING SYSTEM

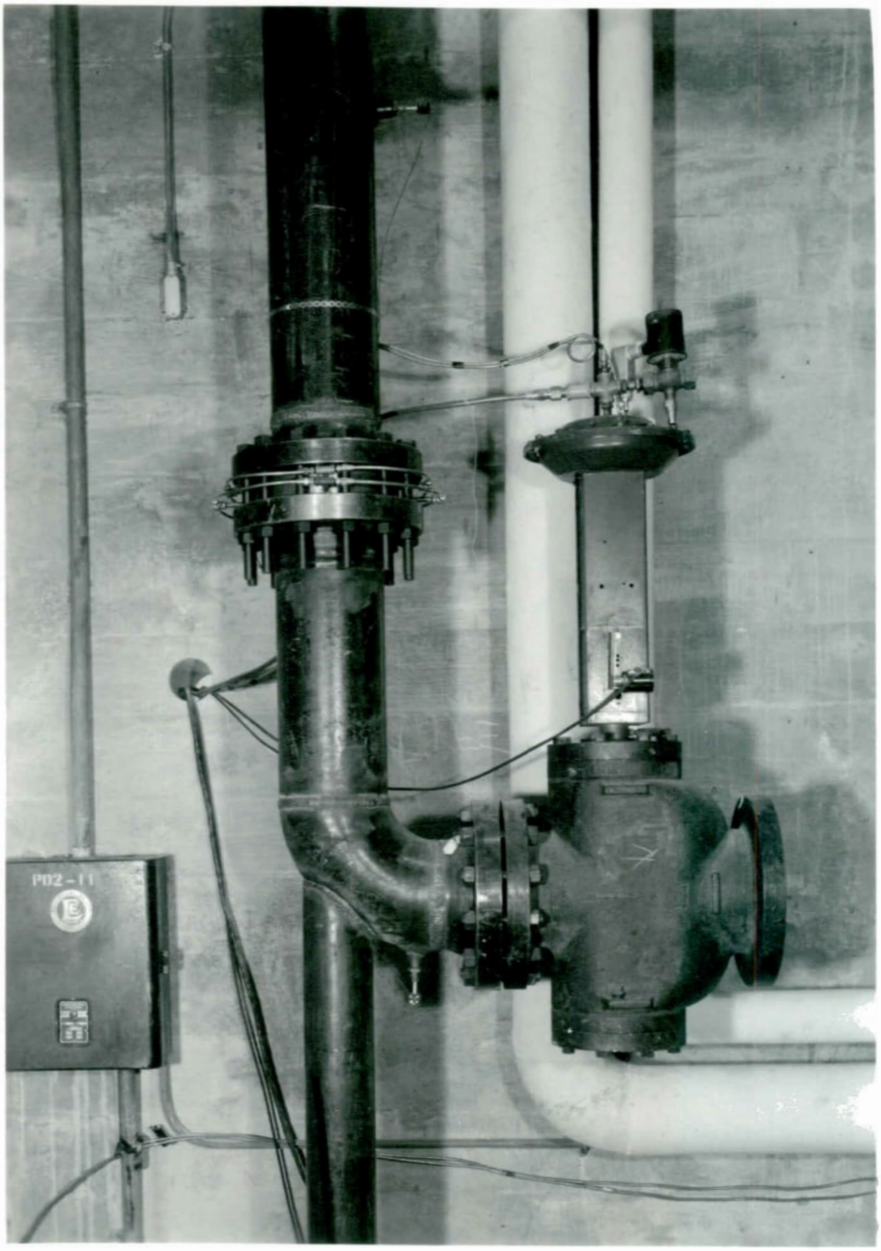


FIG. 12 CONTROL VALVE

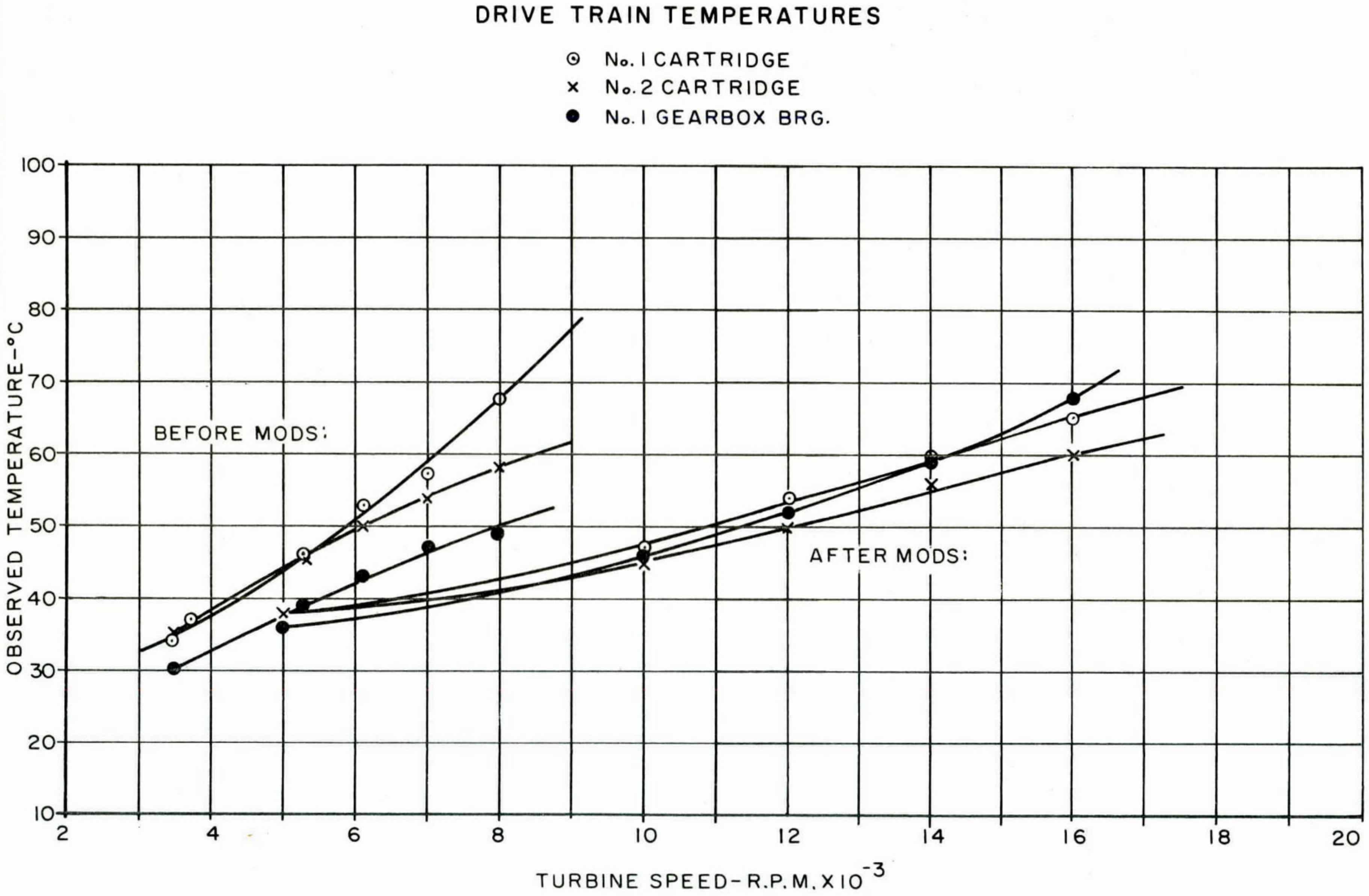

DRIVE TRAIN TEMPERATURES
⊙ No. 1 CARTRIDGE
× No. 2 CARTRIDGE
● No. 1 GEARBOX BRG.
OBSERVED TEMPERATURE - °C
100
90
80
70
60
50
40
30
20
10
2
4
6
8
10
12
14
16
18
20
BEFORE MODS:
AFTER MODS:
TURBINE SPEED - R.P.M. X 10^{-3}

FIG. 13

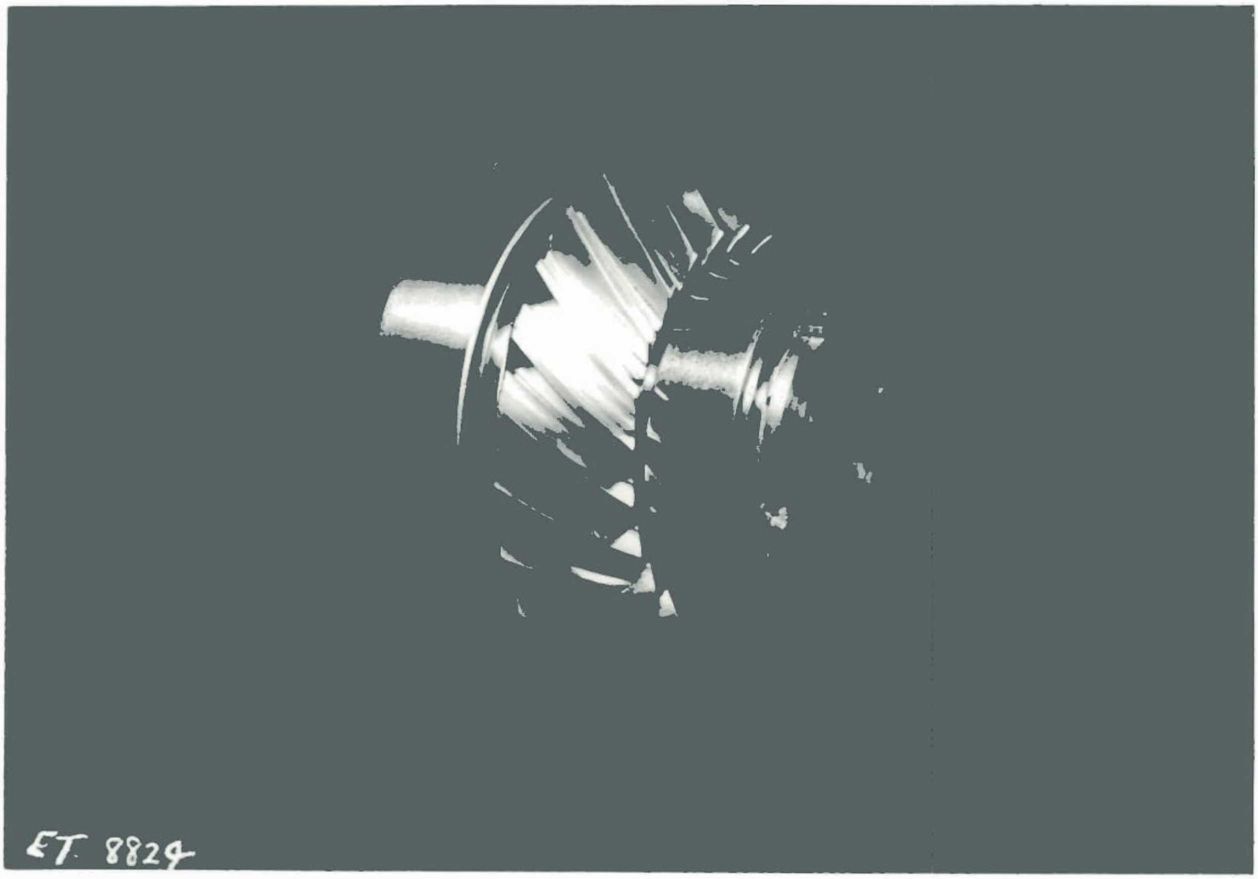
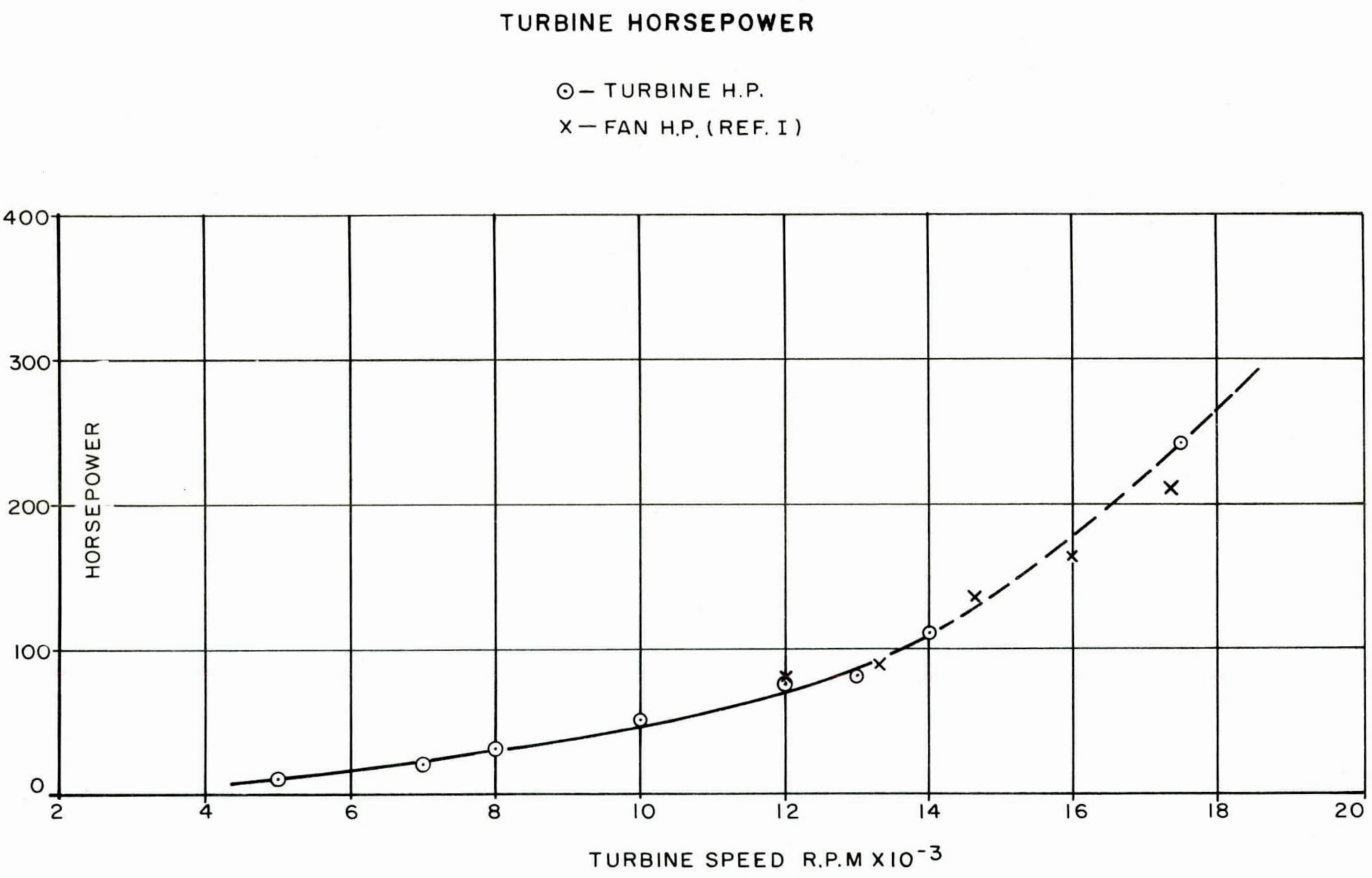


FIG.14 SPIRAL BEVEL PINION-AFTER 20 HOURS RUNNING



TURBINE HORSEPOWER

FIG. 15

TURBINE TORQUE

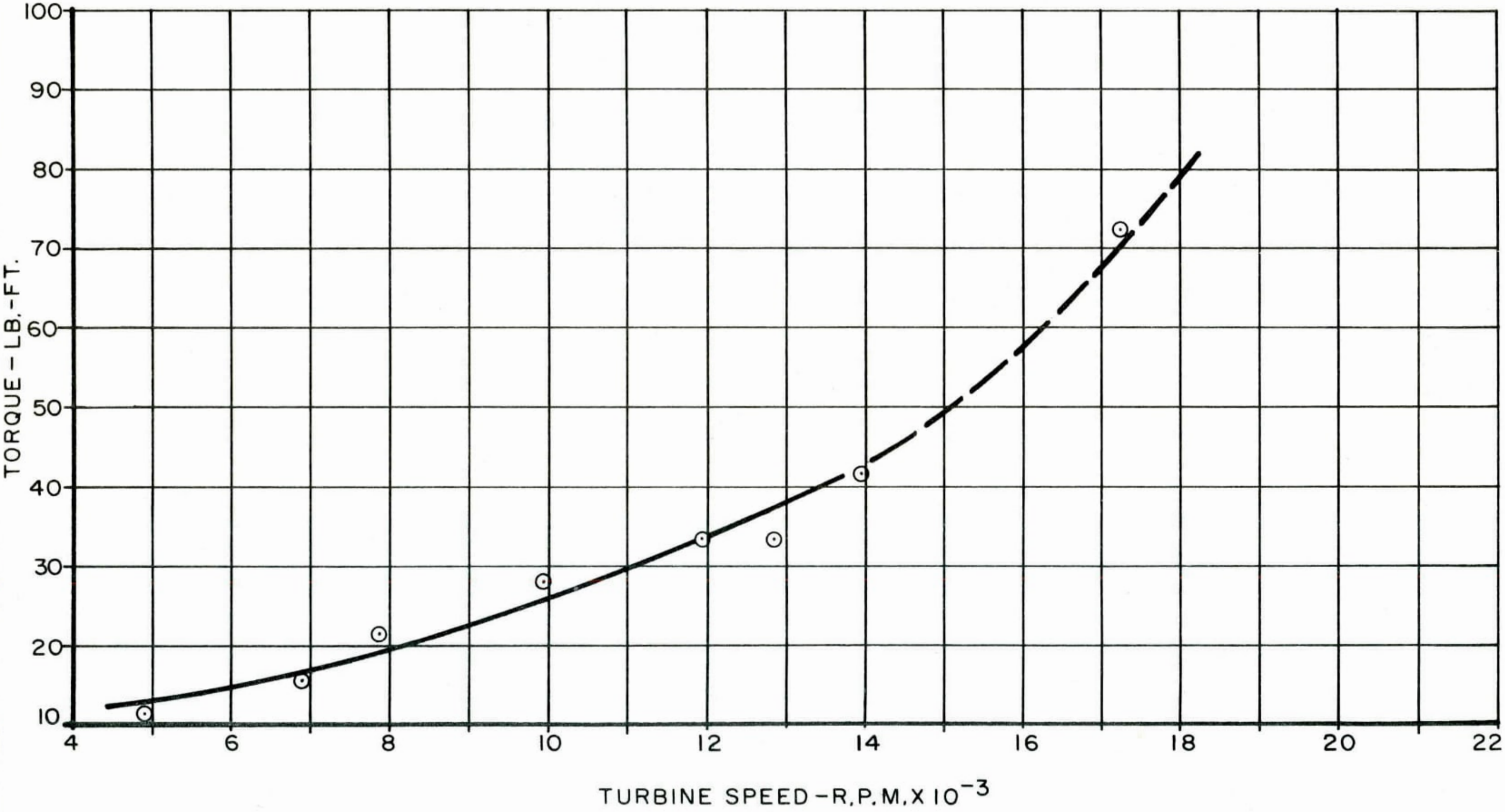


FIG. 16

TURBINE AIR FLOW

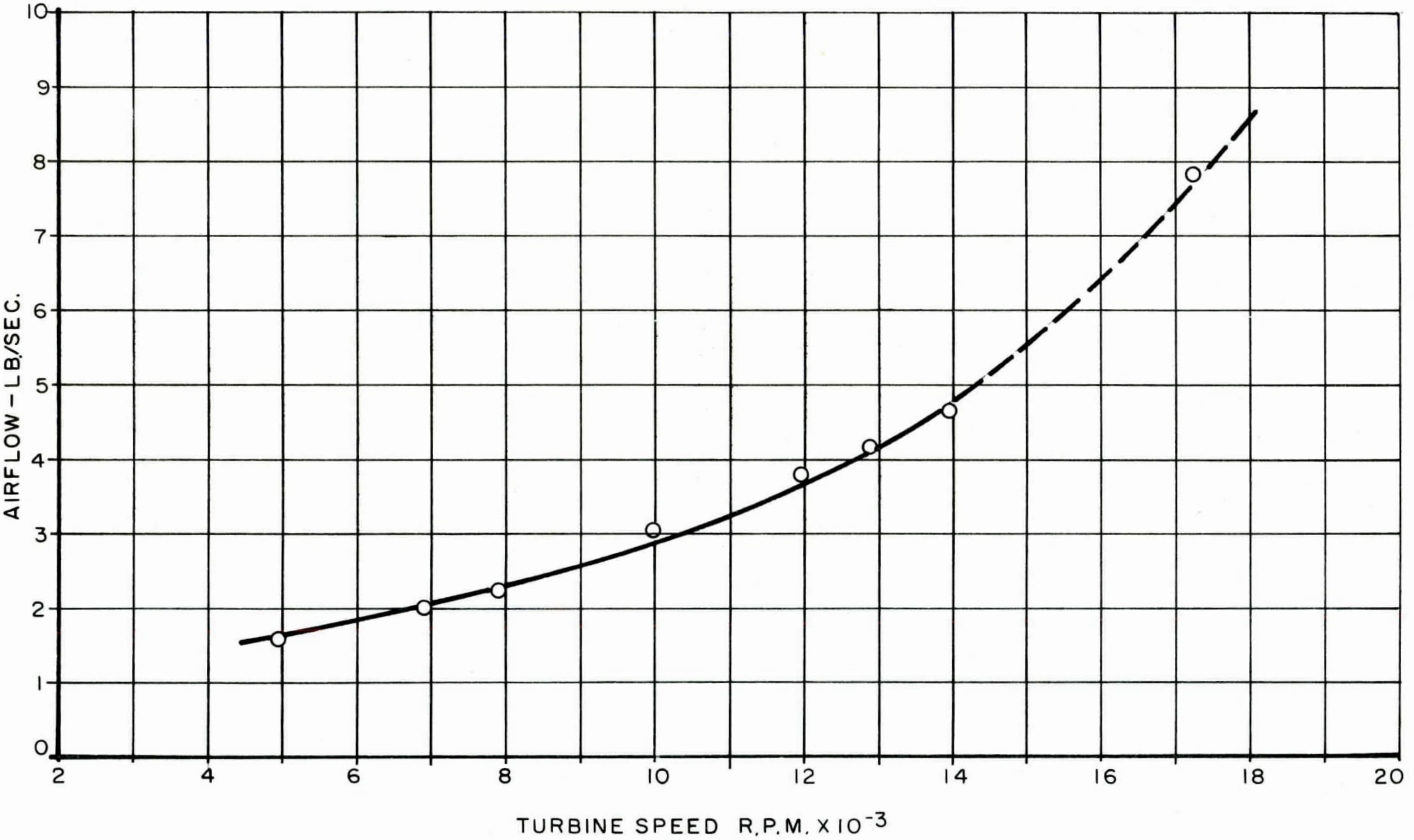


FIG. 17

TURBINE TEMPERATURE DROP

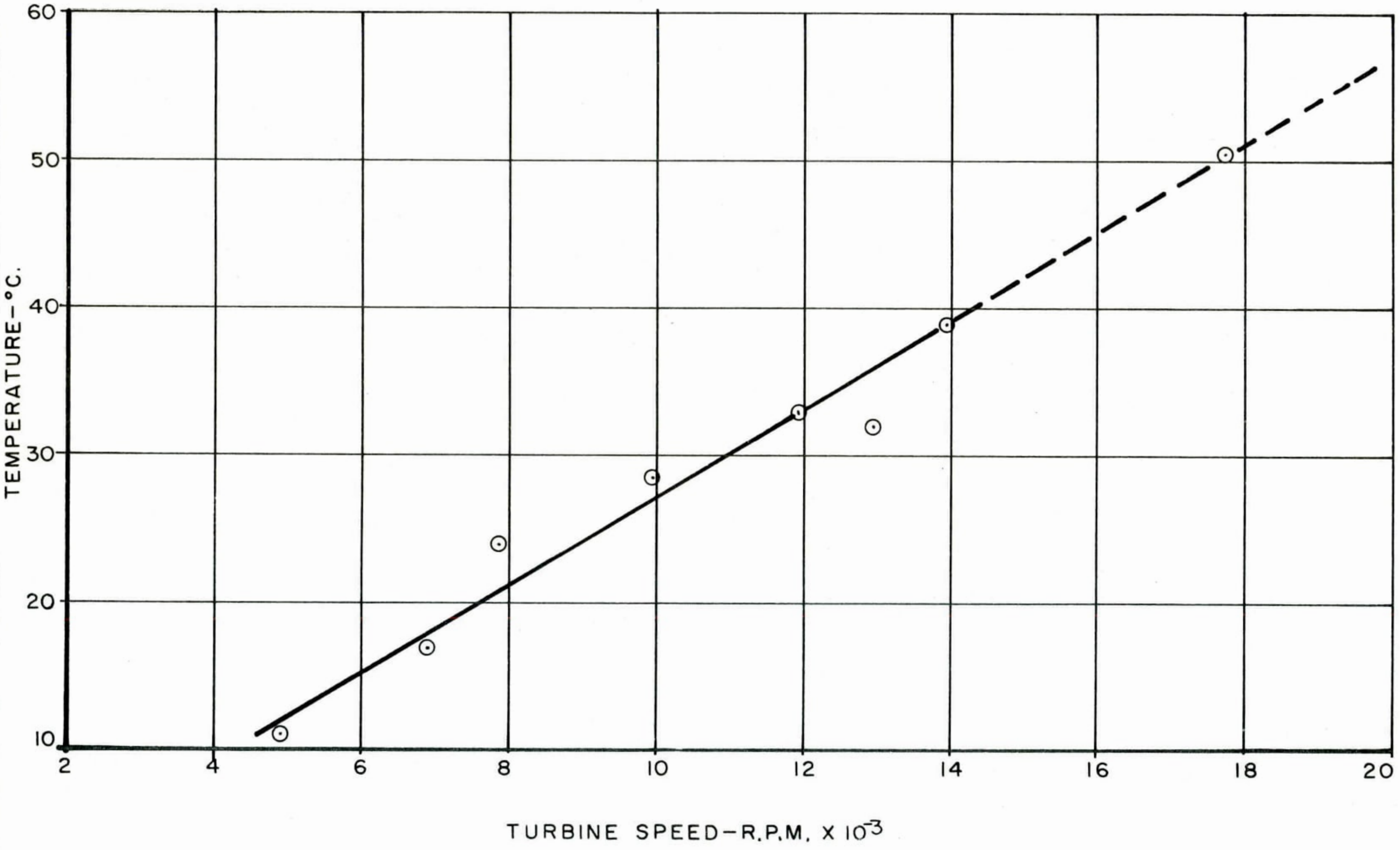


FIG. 18

TURBINE INLET PRESSURE

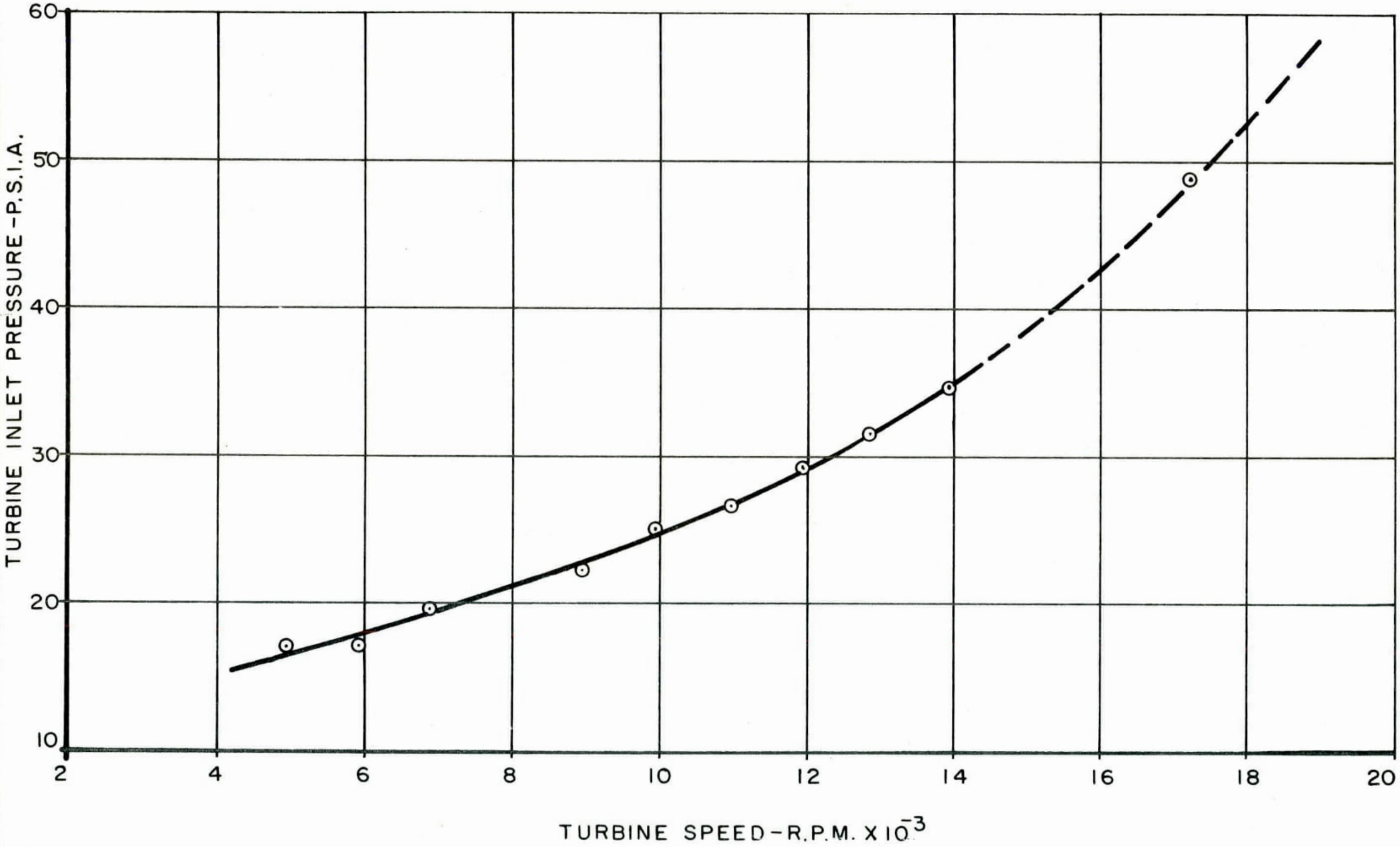


FIG. 19