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AERONAUTICAL REPORT

LR-366

THE DEVELOPMENT OF RIG AND INSTRUMENTATION FOR TESTING 12-IN. DIA. MODEL VTOL DUCTED FANS

BY

H. S. FOWLER

DIVISION OF MECHANICAL ENGINEERING

OTTAWA

JANUARY 1962

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NATIONAL RESEARCH LABORATORIES

Ottawa, Canada

REPORT

Division of Mechanical Engineering

Engine Laboratory

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Subject: THE DEVELOPMENT OF RIG AND INSTRUMENTATION FOR TESTING 12-IN. DIA. MODEL VTOL DUCTED FANS

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Approved by: D.C. MacPhail
Director

SUMMARY

In order to obtain design data for highly loaded ducted fans suitable for installation buried flat in the wing of a VTOL aircraft, it was decided to carry out a programme of experiments on 12-in. O/D model fans. These were to be tested at true Mach number, and disc loadings of the order of 500 lb./ft^2. were to be sought, requiring a rotational speed of about 15,000 r.p.m.

A test rig capable of driving these fans was built, and instrumentation to measure their performance developed for use with it. Most of the running carried out was without any forward-speed effect across the fan inlet, but a later version of the rig was capable of simulating forward speeds up to 250 ft./sec.

The rig and instrumentation are described, and the method of manufacturing fan blades is also outlined.

The testing carried out on this rig is reported and analyzed in N.R.C. Aeronautical Report LR-367.

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1.0 INTRODUCTION

In 1956 it was decided at N.R.C. that the fan-in-wing concept of a VTOL aircraft should be thoroughly investigated, and the Engine Laboratory was given the task of studying certain aspects of the powerplant. Although the fan size chosen for detailed study was 36 in. O.D., it seemed that much of the work could be carried out far more conveniently at a size of 12 in. O.D. This scale promised an adequate Reynolds number, while greatly reducing the cost, power, and time required.

In order to measure the power absorbed, and to simplify changes in fan geometry, the fan was to be mounted on one end of a shaft, while the turbine was mounted at the far end of the shaft. Power absorbed could be measured by putting a torquemeter into the shaft, and the whole unit could be mounted on a stand to measure the fan thrust. This defined the general form of the test rig, and the requirements were laid down that the designed fan tip speed was to be 750 ft./sec. (corresponding to 15,000 r.p.m.); minimum stage thickness of the fan was required to enable it to fit flat in a wing, and a designed disc loading of 500 lb./ft^2 was to be aimed for. While a large body of basic two-dimensional cascade information was available, there were difficulties in applying this directly to an actual fan of small hub/tip ratio and high disc loading. While axial compressor design is quite a well-explored art, the design of a single-stage fan operating with very unusual inlet profile and with a very short exit duct is not a straightforward matter, largely because of the non-uniform inlet velocity profile, which means that the flow over the blading is no longer two-dimensional.

The philosophy of the programme was therefore to obtain an understanding of the complete unit, detailed enough to assist in designing a closely related family of units in this rather specialized field.

This report describes the development of the test rig and instrumentation, from 1957 to mid-1961.

The running programme is described and the results are discussed, in N.R.C. Report No. LR-367.

2.0 DESCRIPTION OF TEST RIG

2.1 General Description

The rig consists essentially of a shaft, mounted on a thrust measuring stand, and divided to accommodate a torquemeter and r.p.m. counter. On one end of the shaft is the driving turbine, supplied with 90 p.s.i. compressed air from the Gas Dynamics Laboratory air compressors. The experimental fan is mounted at the other end of the shaft, while the stator and duct assembly is located around it by means of the stator blades.

The complete test stand is shown in Figures 1, 2 and 3.

2.2 Thrust Measurement

The whole stand is mounted on the floor rails on a pair of spring flexure pivots vertically beneath the plane of the fan itself, and at the far end, the frame rests on a continuous flow oil thrustmeter. The vertical distance of the fan above the pivots is exactly equal to the horizontal distance from pivots to thrustmeter, so that fan-thrust is read directly as the increase of thrustmeter load. Direct dead weight thrustmeter calibration is also possible by placing weights on the frame above the thrustmeter.

The first type of cell tried was a commercial closed constant-volume oil type shown in Figure 4(a).

This cell was satisfactory at its designed thrust range (0-30,000 lb.) but was being used here over the bottom 7 percent of its range. In this range, the zero-shift due to the expansion of the oil with test cell temperature changes was of the order of 30 lb. of indicated thrust. Since the full load in this application was 350 lb., this error was intolerable. Attempts at temperature stabilization were not successful.

The second standard type of cell considered (see Fig. 4(b)) is supplied with 90 p.s.i. (approximately) compressed air, and blows off through a servo valve. This cell is free from temperature errors, but sometimes suffers from instability. Resonance can be tuned out by proper adjustment of damping constrictions and chamber volumes, but it is difficult to eliminate it over the whole working range, and the required damping may seriously reduce the sensitivity of the cell. It was therefore decided to reject this system.

The third type of cell was of the continuous-flow type, but used oil as the working fluid (see Fig. 4(c)). The valve system used is reduced to the simplest possible, consisting merely of an annular exhaust port extending right round the cylinder bore. The piston movement from minimum to maximum load was of the order of 0.010 in. The only source of trouble observed to date has been a slight zero-shift, apparently due to the change of viscosity of the oil due to temperature rise caused by the pump. A watercooling coil in the small tank in the oil circuit has eliminated this trouble, and a constant viscosity oil is used in the circuit.

A calibration was carried out with standardized 50-lb. weights, using a 100-in. mercury manometer instead of the usual Bourdon gauge. The results are presented in Figure 4(d).

On top of the thrust stand are mounted the fan and turbine shafts, connected by the torquemeter.

2.3 The Turbine

The turbine is a single-wheel impulse unit, of 9-in. mean diameter with 2-in. long blades. In view of the power to be transmitted, it did not seem practical to mount the turbine separately from the thrust stand and transmit the torque through a sliding coupling without any thrust. On the other hand, if the turbine were to be mounted on the thrust measuring stand, it had to have zero thrust of its own, so that all the thrust measured would be that due to the fan. The turbine wheel was therefore given simple impulse passages symmetrical about the plane of the disc, and three air nozzles were placed opposite either face of the wheel, which rotated between the two sets as shown in Figure 5. Thus the blading, as it rotated, was subjected to air alternately from the front and back faces, so that the resultant end thrust on the wheel was zero. This was checked on test, using a zero-thrust paddle-brake, run up to 15,000 r.p.m.

An interesting change in the turbine disc design took place during the evolution of the rig.

The earliest turbine had very thick blades only 1 in. high, and these were machined integral with the 65ST6 light alloy disc. It was realized at the time that the undamped blades produced by integral construction may be prone to vibration fatigue, but these blades were so stout that the design seemed reasonable. In fact, after 50 hours' running, the disc was still in perfect condition. A higher powered turbine was then built. The blades were a little thinner, and 2 in. high, but the same integral construction was used. After less than 5 hours' running, these blades cracked, and only a short life could be obtained when separately machined blades retained by 1/4-in. axial steel pins were used.

A radical change of design was therefore made. The one wheel with 30 blades 2 in. long blown from both sides by six separate nozzles was replaced by two discs, each with about 90 blades 1/2 in. long, and with a 100 percent admission manifold between the two discs, blowing outwards through the two of them. This design greatly reduces the steady blade stresses and preserves the zero end-thrust characteristic, yet the 100 percent admission from the central manifold eliminates the 3 cycles per revolution axial rocking couple on the blades due to the three opposing pairs of nozzles in the older design.

The shaft between turbine and fan is cut in two, and joined by the torquemeter. The two half-shafts are each mounted on two pairs of ordinary class "A" angular-contact ball races. It was found that the best method of lubrication was to clean the bearings with gasoline to remove all traces of grease, and then cool them with an air blast loaded with a faint mist of atomized light spindle oil. The far side of each bearing is scavenged by a vacuum system to prevent any oil build-up. The bearings are selectively assembled to the shaft and housing, allowing a tight hand fit, since the bearings are locked by nuts. The fit must not be so tight that the race is spread enough to take up more than half of the 0.0002-in. radial float in the bearing. Given these precautions, the rig has been run at up to 20,000 r.p.m. for 15-minute periods, with the bearing thermocouples not exceeding 80°C.

Another factor contributing to this performance is the very careful balancing of the rotating parts. The shaft is machined to very tight tolerances of concentricity and straightness, and assumed to be in balance. The turbine and fan rotors are reasonably thin discs, and after a run-out test to close limits are balanced statically on a dummy shaft supported on four knife edged wheels. After a rough balance is obtained, a small piece of clay is put on one blade tip, this blade is put alongside a pointer level with the wheel centre height, and the blade is released. The wheel rotates almost 180 degrees as the weighted blade swings down and up on the opposite side. The point to which it rises is marked by a second pointer. This process is repeated for each of eight equally spaced blades on the rotor, using the same small weight on each, and may also be done with both clockwise and anticlockwise swings. If each blade swings to the same height on the opposite side of the circle, then the rotor is considered to be truly in balance. Experience has shown that this results in a static balance within less than 0.0005 lb. in. error. Rotors weighing 20 lb., assembled with bladed discs balanced in this manner, are run on this rig up to 20,000 r.p.m. without difficulty, and show only small vibrations even while passing through their critical speeds.

The fan rotor, on the other half shaft, is of the same general construction as the turbine rotor, but the blade root pins are retained by easily removable spring rings, to allow frequent changes of blades during testing. The turbine blade-pins are retained by peening the disc.

In the still-air-inlet rig, the inlet side of the fan is towards the turbine, so that the outer duct and bellmouth were supported on the stator blading, which is mounted on a further set of bearings on an extension of the rotor shaft. Rotation of the stator duct is prevented by light struts to the thrust stand base.

The stator blading is made of glass reinforced plastic, cast to the required blade profiles and set into a machined plastic hub (see Fig. 6). The outer duct is of laminated mahogany, with a variety of bellmouths of mahogany or fibreglass bolted on as required. This arrangement holds the duct concentric with the fan rotor so that a 0.018-in. radial blade tip clearance on the 12-in. dia. fan can be maintained with safety.

In the cross-wind rig, the fan is reversed relative to the turbine, so that the bellmouth and outer duct are mounted via the stator blades directly on the main fan shaft housing, without the necessity of an overhung bearing.

2.4 The Torquemeter

As was previously mentioned, the fan and turbine half-shafts are joined by a torquemeter unit. After careful consideration of aerodynamic and electronic torquemeters, it was decided to use an optical method of measuring the power input to the fan.

Three sources of trouble were anticipated; loss of optical accuracy due to mechanical vibration, poor illumination, and loss of illumination due to oil vapour condensing on the mirrors. In fact, the only one of these troubles which showed up was poor illumination, and this was easily remedied.

Description of the Optical Torquemeter

2.4.1 Mechanical System (See Fig. 7)

The main shaft is split 9 in. from the turbine end and has a 3/8-in. dia. 3-in. long tool steel quill shaft let into it. Two 1/2-in. dia. mirrors are mounted at each end of the quill shaft, and an optical system measures the twist in the quill shaft, which varies from zero up to about 10 degrees at full load. By static calibration, the relation is established between this twist and the torque driving the fan.

The heart of the device is the quill shaft, clearly visible in Figure 8. In order to obtain maximum sensitivity over a large range of torque, three sizes of quill shaft have been provided, and the chucks holding them between the two half shafts are designed to be positively self-centering and aligning, allowing shafts to be changed very quickly without any re-calibration or setting up.

The design of the quill shaft is calculated from the torsional deflection characteristics of a cylindrical rod of known elasticity under pure torque loading. A suitable steel, in this case Jessop's superior oil hardening, is chosen, and the maximum permissible surface stress decided. This should be high in the elastic range; a safety factor of not more than 1.5 x yield strength is allowed. The maximum torque which will be measured is calculated, and the equation for maximum surface stress can be solved.

$$F = \frac{2T}{\pi R^3}$$

where F = Max. Surface Stress, lb./in.^{2}

T = Torque, lb. in.

R = Radius of quill shaft, in.

It is absolutely essential for all corners on the quill shafts to be amply radiused, and for the whole part to be polished to a mirror finish all over, to avoid any stress raisers. It is also vital for the keys on the ends of the quill shaft to fit firmly and accurately into the slots in the ends of the fan and turbine half-shafts. Any slack here will lead to vibration and cause fretting and corrosion. This has in fact been observed in some shafts which were a few ten-thousandths of an inch slack.

2.4.2 Optical System (See Fig. 9)

Fundamentally, this is a system by which a continuous beam of light is directed by a mirror on one end of the quill shaft to a mirror at the other end of the shaft, and thence onto a scale. The point at which the beam hits the scale varies according to the twist in the shaft between the two mirrors, thus indicating the torque applied to the quill shaft. This simple system (Fig. 9(a)) suffers from the defect that, although the light source is continuously alight, the first rotating mirror swings the reflected ray round at twice shaft speed, so that it falls on the fixed mirror for only a small fraction of each shaft revolution, thus reducing the amount of light drastically. The small plane fixed mirror has therefore been replaced by a cylindrical mirror; actually, a narrow zone cut out of a spherical mirror is used, for simplicity of manufacture. This cylindrical mirror has its radius of curvature equal to its distance from the shaft so that as the first rotating mirror sweeps its beam around, the cylindrical mirror returns it to the second rotating mirror over a considerable part of the shaft revolution. The diagram makes it clear that, so long as the two rotating mirrors spin together and remain parallel, the light spot on the screen will remain stationary. But, as soon as the quill shaft twists and the rotating mirrors are no longer parallel (Fig. 9(a)), then the final beam reaching the scale will swing by twice the angle of twist in the shaft.

The system, shown in its final form in Figure 10(b), can therefore be run by a simple 1000-watt projector lamp, without any necessity for an intermittent light source.

The lighting efficiency is further doubled by putting two mirrors back to back at each end of the quill shaft, thus getting two pulses of light per revolution, instead of one. More could be added, if necessary. Finally, the small rotating mirrors are actually spherical concave, with their radius equal to the distance from shaft to lamp, cylindrical mirror, and scale. This prevents spreading of the light beam and consequent loss of light, but does not otherwise affect the foregoing argument.

The scale is a translucent strip of roughened Plexiglass, bent to form a circular arc concentric with the rotating shaft. Graduations are engraved deeply into it, and edge lit by a small fluorescent tube at each end. These tubes are blue, while the light spot from the projector lamp is yellow-white, so that the observer is not confused between the illuminated graduations and the light spot.

One difficulty which became apparent in the first mock-up of the torquemeter was that while using a very lightly frosted scale, to allow as much light as possible to pass through to the observer, the spot was only visible when the eye was almost directly in line with the light beam. Since the observer had to view the scale through a periscope from outside the cell, for reasons of safety, as the beam and spot swung across the scale with change of torque, the observer was able to see the spot for only a few degrees of the scale from his fixed eye position. This trouble was overcome by roughening the scale heavily with very coarse sandpaper, the scratches being kept parallel to the axis of rotation. The light was then scattered only in the direction of rotation, up and down the scale, and not lost by sideways scattering. There is now no difficulty in seeing the light spot anywhere on the scale from the one viewing point. The numerals in the scale are engraved reversed to allow for an inversion in the simple viewing periscope.

With reasonable shading of the mirrors and scale from stray light, the reading may easily be seen, although the cell is brightly illuminated for closed-circuit television observation.

2.4.3 Calibration (Fig. 11 shows calibration curves)

While the instrument is designed from calculated torque-deflection characteristics, the constant for each quill shaft is found by calibration in position. By using a dead-weight arrangement pure torque without side-load is applied to the fan shaft through a beam replacing the fan. The turbine shaft is locked by placing a special screw jack under one tooth of the massive notched wheel of the tachometer pick-up. As each increment of load is added to the scale pan, the screw jack is adjusted to return the fan shaft to its original angular position, thus eliminating any change in the lever arm of the applied load. The mirror at the fan end of the quill shaft is therefore held still, while that at the turbine shaft end is rotated as the twist in the quill shaft increases with load.

Readings of the position of the light spot on the scale are taken for each applied torque, on ascending and descending load curves. Provided the shaft is not stressed over its elastic limit, there is no observed hysteresis. If the limit is exceeded, the return curve is a new straight line, parallel to the original but displaced by a constant amount owing to the twist set in the shaft. The quill shaft can be used in this condition provided a zero correction is applied to all readings. In practice, the zero reading is taken at the beginning and end of each test, to check that no set has been put into the bar by momentary fan surge or other unintentional overloads.

2.4.4 Torsional Vibration

It was suggested that vibration might render the instrument useless. No effects of linear vibration have been observed, owing to extremely careful rotor balancing. However, the first indication of fan-blade stall is usually a slight torsional vibration, which shows up as a blurred lengthening of the circular light spot on the scale. This is often cyclic in occurrence. It causes no inconvenience, as it is easy to estimate the mean reading at the centre of the elongated "spot", and is indeed a useful warning of increasing severity of stall and blade flutter, which might fatigue and wreck the fan if allowed to persist.

2.5 Speed Measurement

In the photographs of the torquemeter, the toothed wheel and pick-up coil of the combined tachometer and overspeed trip are visible. This unit was made by the Instruments and Control Systems Laboratory of N.R.C. and has been found ideal for its purpose.

Briefly, a six-toothed wheel on the turbine shaft excites six pulses per revolution in the coil surrounding the magnetic pole piece of a standard proximity pick-up, which allows a simple conversion from pulses per second to r.p.m. The output from the pick-up is fed into two circuits, one to provide a speed indication for the driver and to operate an adjustable overspeed trip, and the other a standard digital EPUT meter which displays counts of r.p.m. revised at about 2-second intervals, for recording as performance data.

The driver's speed indication and overspeed trip relies on the fact that the R.M.S. voltage generated in the pick-up is proportional to r.p.m. This voltage is amplified in a solid state amplifier and used to saturate the core of a transformer. The transformer output is rectified, and fed into a d.c. meter calibrated in r.p.m., which has an accuracy of better than 0.1 percent.

On the dial of the indicator there is a second pointer, set by the driver to any desired maximum speed, and should the indicator pointer make contact with this, the overspeed trip relay closes. This opens a solenoid air valve, which closes a pneumatically-operated gate valve in the main 8-in. air line to the rig turbine. In this connection, it is essential to mount the toothed wheel of the tacho pick-up on the turbine half-shaft, so that if the torquemeter quill shaft fails, the turbine is shut down.

2.6 Airflow Measurement

In order to provide data for pressure rise, velocity profile, and air mass flow measurements, various arrangements of total and static pressure measuring points were used.

2.6.1 Fan Inlet Measurement

The inlet to the fan, while operating in still air, was assumed after early calibrations to have circumferentially symmetrical air flow. The problem therefore reduced to finding the radial distribution of velocity over the inlet. This was done by using cylindrical total and quasi-static probes.

A diagram of the pressure on the surface of a cylinder at right-angles to the airstream (Fig. 12(a)) shows that a small hole on the leading edge will measure total pressure, while true free-stream static pressure is detected at a point some 46 to 48 degrees round from the leading edge, the precise angle depending on speed and Reynolds number. The pressure gradient in this region is so steep, however, that in practice the quasi-static pressure on the trailing edge is used. The calibration of quasi-static to true free-stream static pressure is shown in Figure 12(b) for a typical unit. This calibration depends upon Reynolds number, but a particular unit, calibrated at the required air conditions, is reliable and simple to make and use.

For further simplicity in the small size required, total and quasi-static taps were made in separate tubes, so that to measure total and static pressures at seven radial stations in the inlet annulus, fourteen tubes were used. The completed assembly is shown in the fan inlet plane in Figure 13.

2.6.2 Fan Exit Measurement

At the fan exit, just downstream of the end of the outer duct wall, the static pressure was assumed to be equal to atmosphere, and the total pressure was measured by a rake of simple pitot-tubes. The static pressure was checked by wall-static points.

Various total pressure rakes were made, including the one shown in Figure 14, which had 27 tubes. Nine of these tubes covered a complete stator blade-pitch, closely spaced across the blade-wake region in the middle of the pitch chosen, and there was one of these three groups of nine tubes at each of three radial stations. The tubes were approximately aligned with the mean exit swirl, at 15 degrees to the fan axis.

2.6.3 Recording

All pressures were read off from a bank of single-tube manometers, filled with oil of specific gravity 1.00 or 2.95, or with mercury.

Since the fan speed could not be held precisely constant, owing to changes in the turbine air supply pressure, the manometer readings were usually photographed on 4-in. x 5-in. cut film, or 5-in. aerial survey film, with the serial number of the shot displayed in the manometer array and photographed onto the negative.

2.7 Cross-Wind Rig

In concluding this description of the rig, the cross-wind development should be mentioned. It was realized from the start that the behaviour of the fan would be affected by the change of inlet velocity profile due to the forward motion of the wing during transition to horizontal flight. Until the end of 1960, no tests had been made with cross-wind in this laboratory.

Since then, however, some preliminary work has been done on a fan mounted in a wing subjected to various forward speeds, and the fan test rig has been rebuilt over the cross-wind jet.

In the preliminary tests, no direct power or thrust measurements could be made, although fan mass flow was measured, both at open exit and with various degrees of throttling.

The arrangement of the second cross-wind rig is shown in Figure 15. The 700-h.p. blower on the floor below gives a cross-wind speed of up to 250 ft./sec. over a 3-ft. x 4-ft. open jet. The wing, a 5-ft. span x 3-ft. chord x 18-percent thick laminated spruce unit, is carried rigidly on the thrust measuring stand, but the drag is not recorded. The wing is a symmetrical section, mounted at zero incidence, so that any lift recorded is either direct fan lift, or wing lift induced by the fan. Since the centre of pressure of the wing moves forward as fan lift is increased, there will be an uncompensated pitching moment recorded but this has been minimized by the positioning of the pivot, and will be allowed for in computation. Apart from this, the rig is the same as the previous fan rig, except that the turbine volute and air supply line have been improved. This should boost the available horsepower to over 300, and an all-steel turbine rotor now being made should allow uncooled air to be used, with a consequent further increase in power.

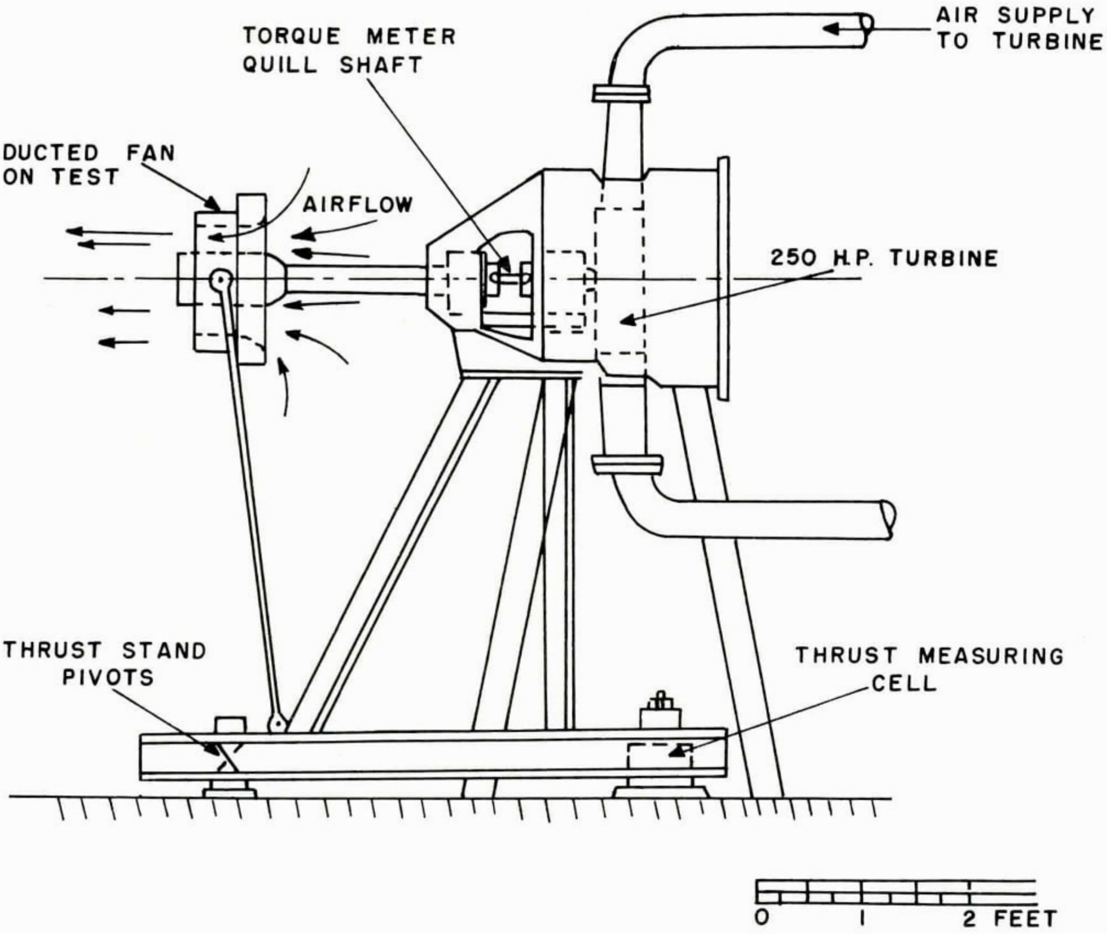
2.8 Fan Rotor Blade Manufacture

The remaining feature of interest is the method of rotor blade manufacture.

A profile-copying machine was rebuilt for this specific purpose and a special method of detailing blade drawings was evolved. Given a supply of blade-blanks with finished roots, which can be ordered fairly well in advance, it is now possible to draw a blade in about 3 days, make the master in one week, and immediately start turning out finished blades at the rate of 3 to 5 per day. Thus, given a supply of blanks, a 20-blade set can be completed in 3 weeks from putting pencil to paper. If further sets of the same profile at different stagger angles to the root are required, the same master is used and production of blades starts immediately.

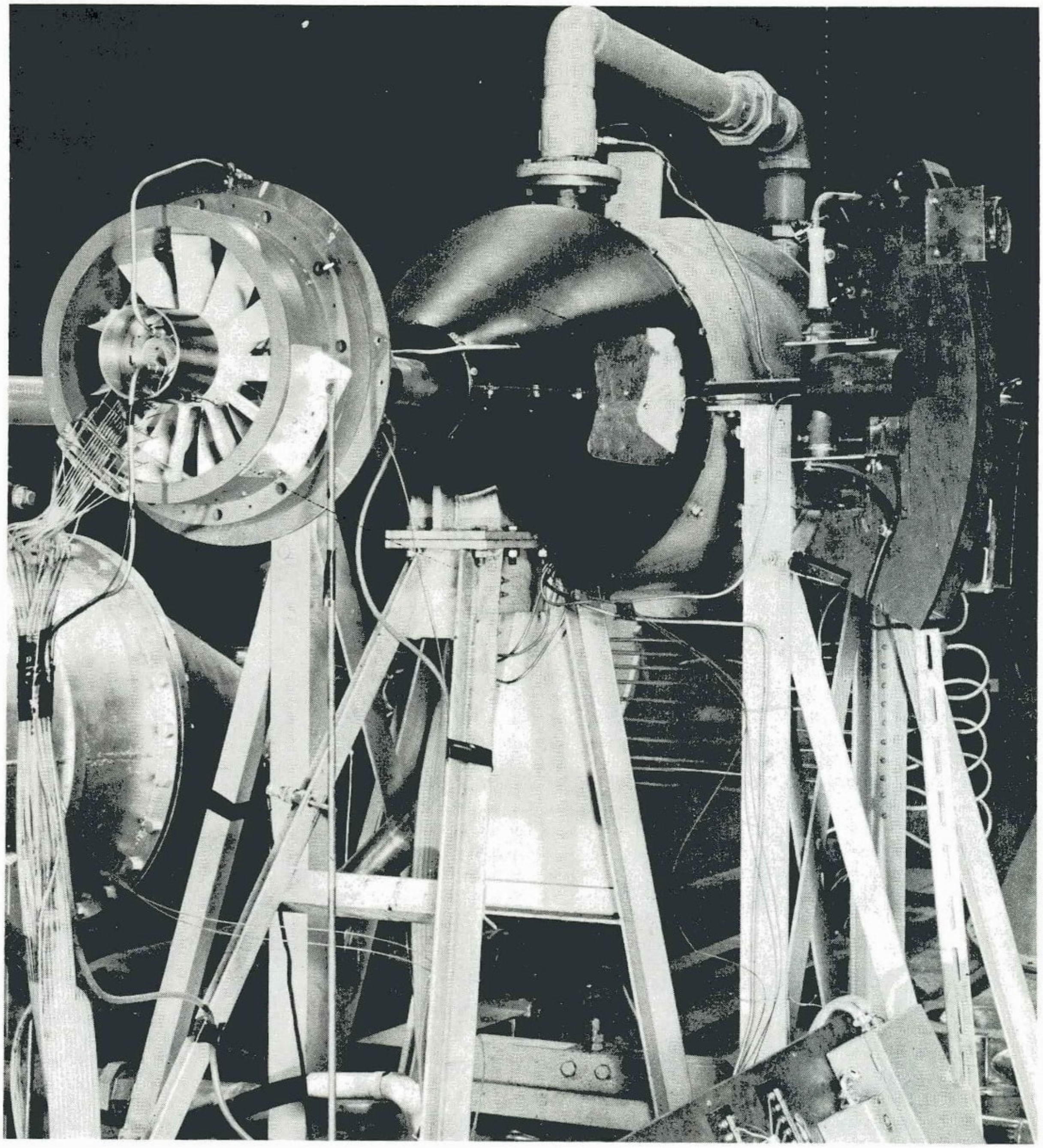
A copying machine in its final form is shown in Figure 16. The master and work piece are rotated in exact synchronism by a spring loaded split gear train driven by an electric motor. At the same time, the follower is kept in contact with the master by a pneumatic jack loaded with about 16 lb. thrust so that the cutter, mounted on the same swinging arm as the follower, traces and cuts the form of the master into the workpiece. At the same time, the arm carrying the master and cutter is slowly traversed spanwise along the blade by a lead screw drive.

Since the follower swings at twice the radius swung by the cutter, the master is made twice the size of the finished blade, in the chord and thickness directions, although the spanwise dimension of master and blade is the same. This increases the attainable blade accuracy by a factor of 2. The master is further strengthened, specially at the sharp leading and trailing edge regions, by adding a 1/4-in. thick envelope all round the master, and reducing the follower radius 1/4 in. from nominal. Normally two cuts are needed, a rough cut with the follower oversize, followed by a finishing cut with the correct size follower. After this only light hand rubbing with fine emery cloth is required. The leading and trailing edges are finished to the required profile and sharpness in the second cut in the machine, and no subsequent trimming is needed. The blades themselves are made from rolled 65ST6 having a yield strength of 45000 p.s.i.

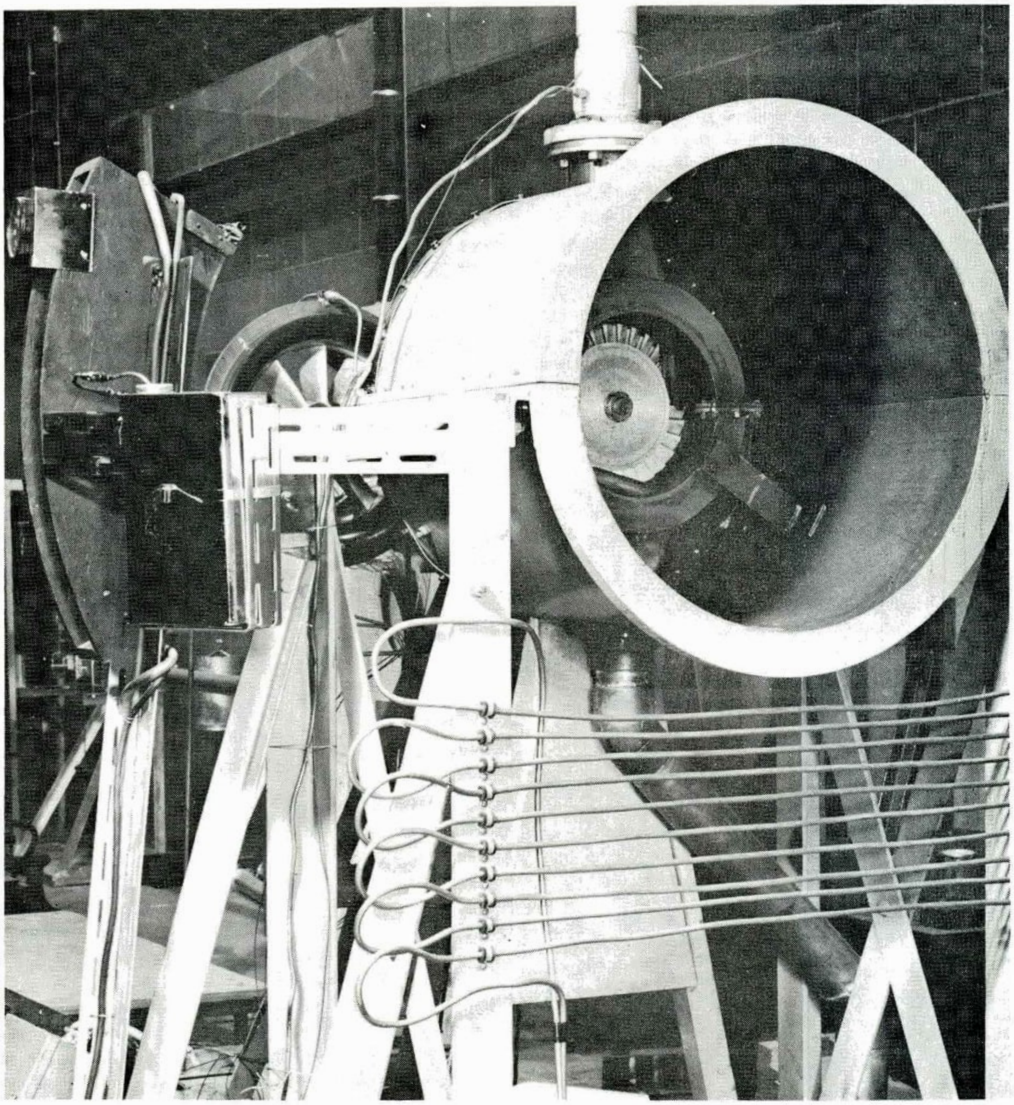


12-IN. VTOL DUCTED FAN TEST RIG

FIG. 2
LR-366



VIEW OF FAN END OF TEST RIG



VIEW OF TURBINE END OF TEST RIG

FIG. 4a,b
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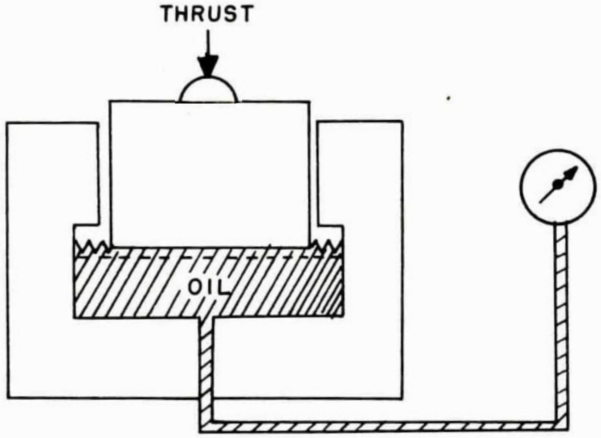
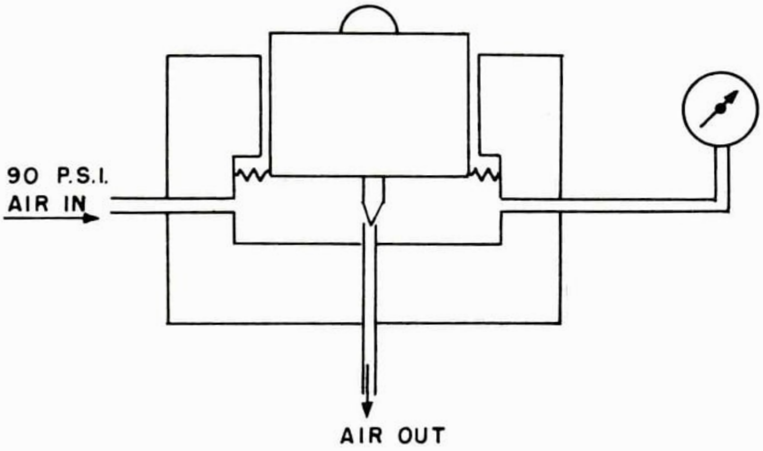
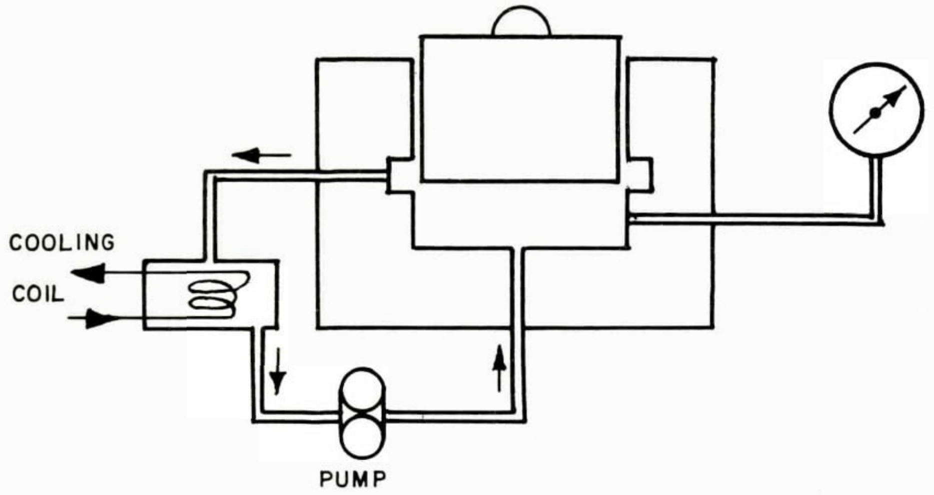


(a) CONSTANT-VOLUME OIL THRUSTMETER

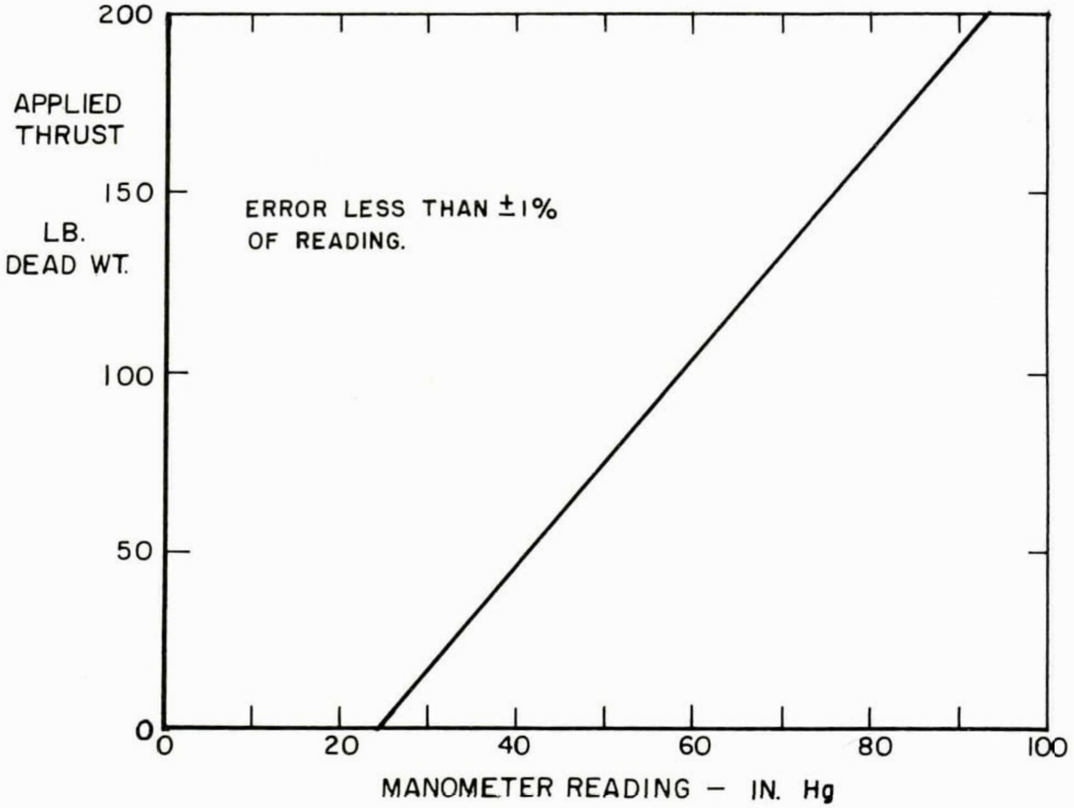


(b) CONTINUOUS FLOW (AIR) THRUST CELL

TYPES OF THRUST CELL



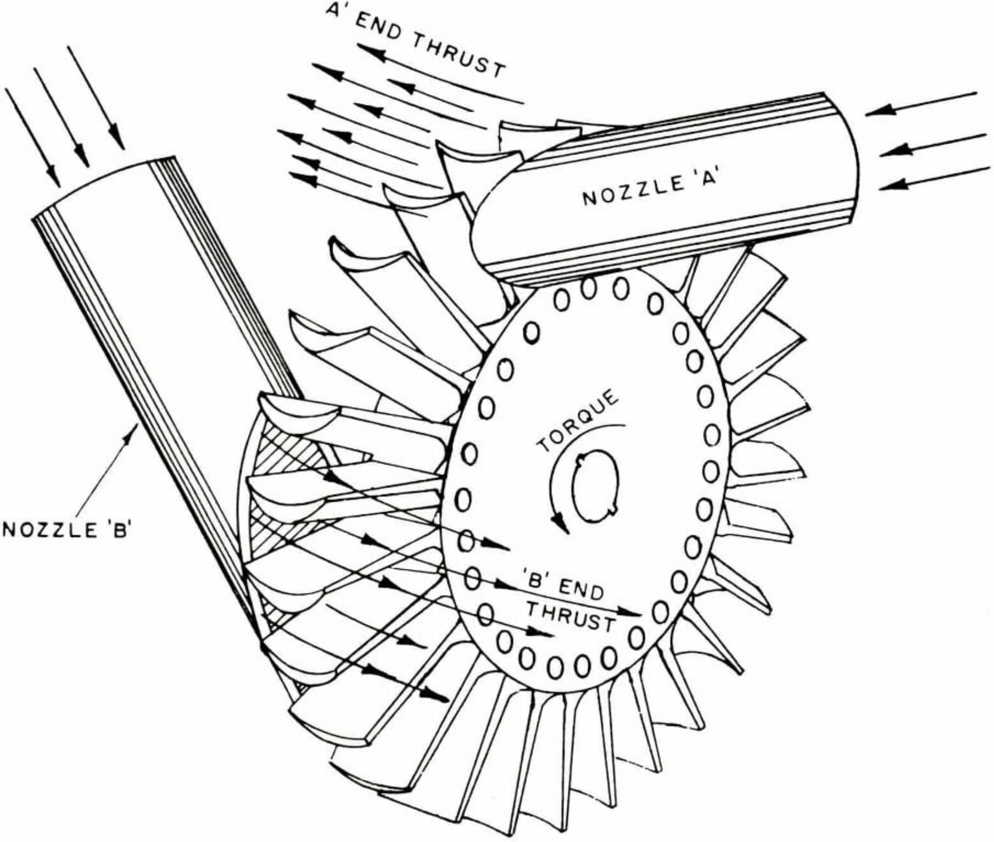
(c) CONTINUOUS FLOW (OIL) THRUST CELL



(d) CALIBRATION OF THRUST CELL

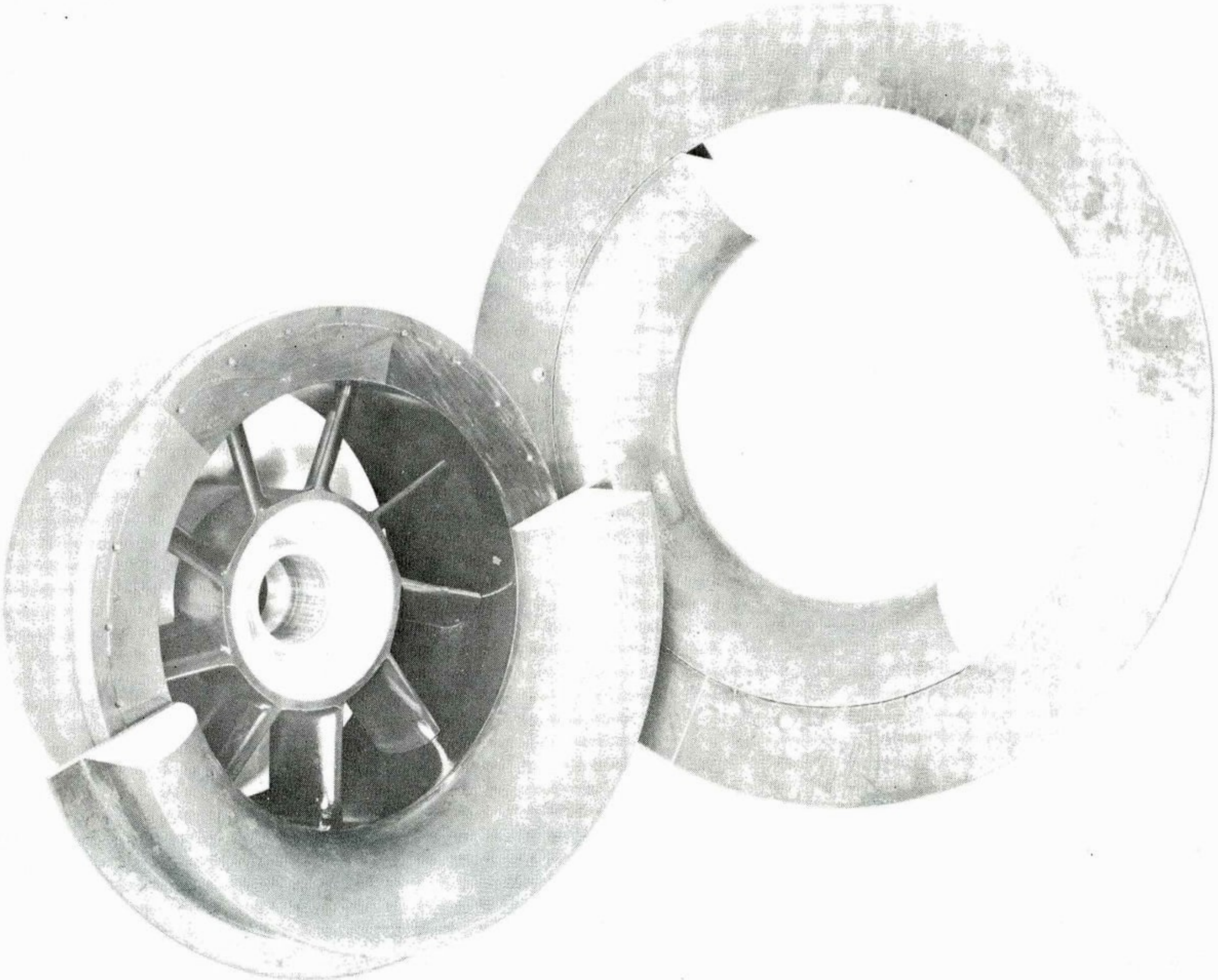
TYPES OF THRUST CELL (CONT'D)

FIG. 5
LR-366



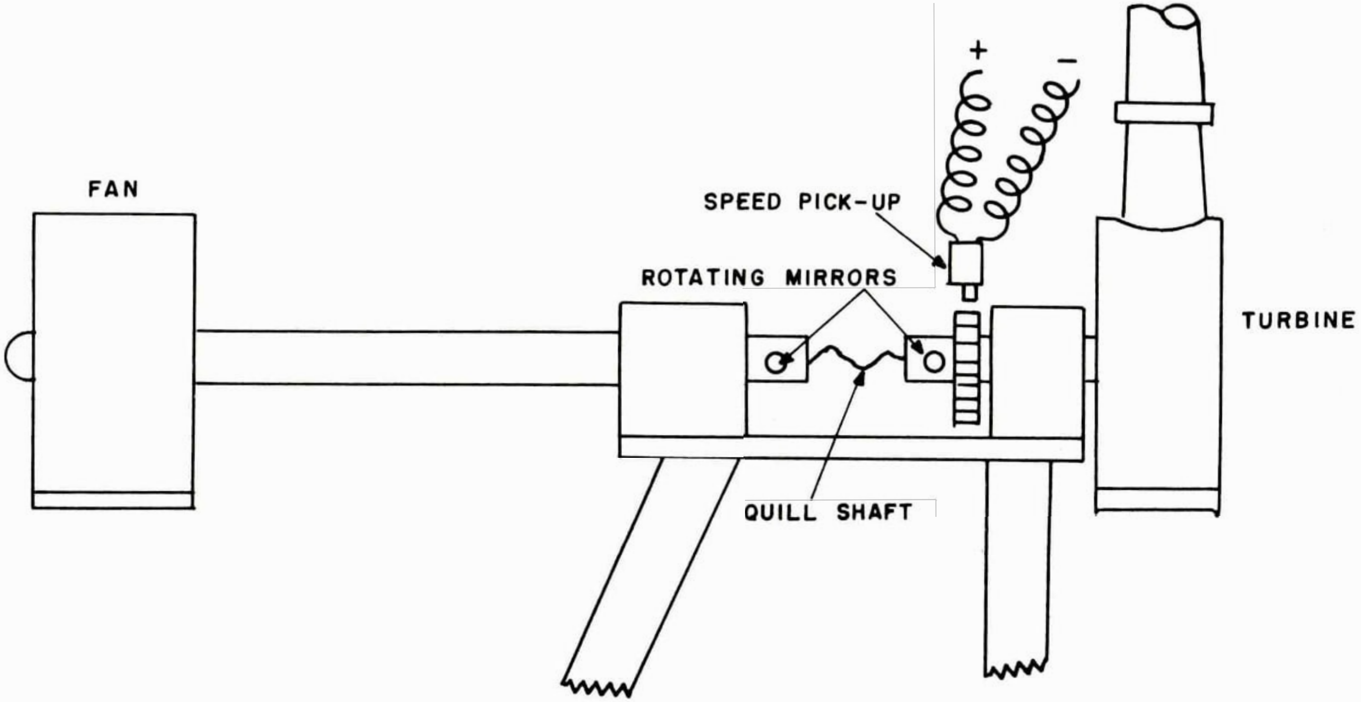
RESULTANT END THRUST = 'A' − B = O

PRINCIPLE OF OPPOSED-NOZZLE TURBINE



INLET BELLMOUTH, DUCT AND STATOR ASSEMBLY

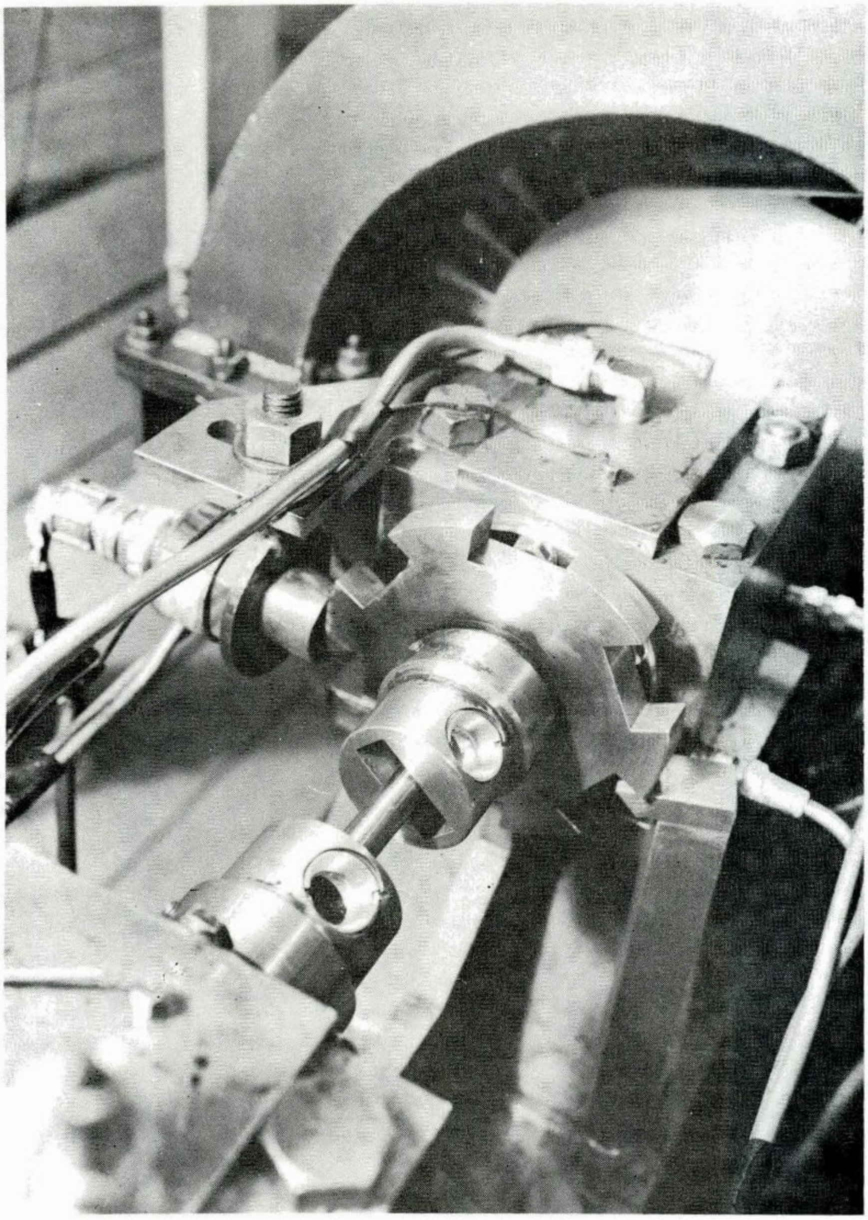
FIG. 6
LR-366



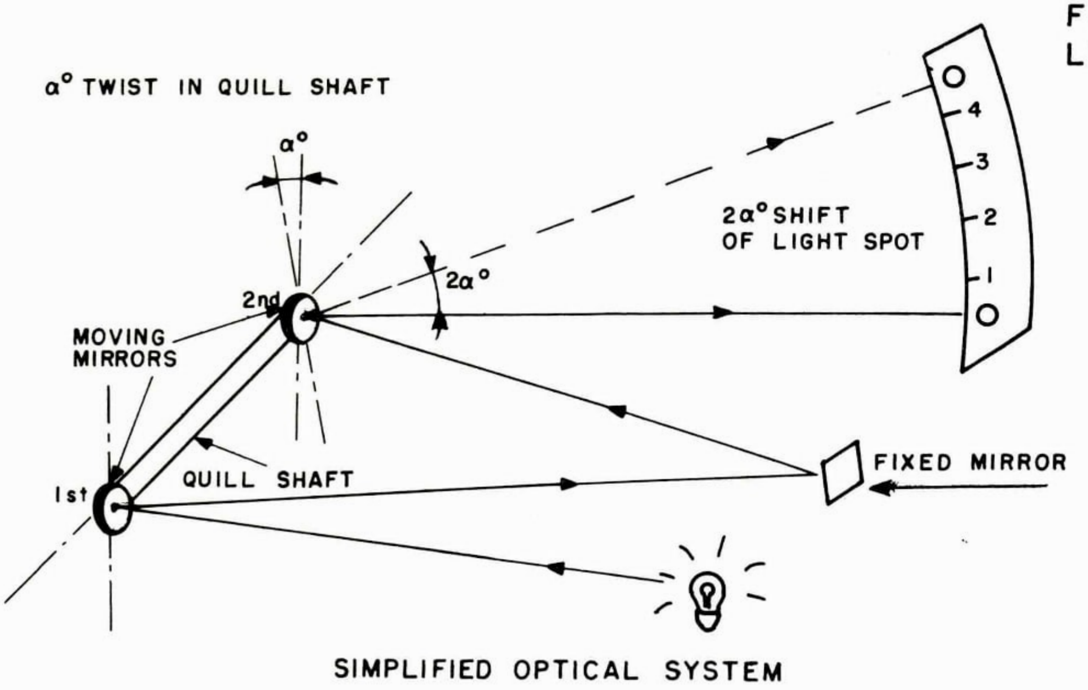
LAYOUT OF TORQUEMETER

FIG. 7
LR-366

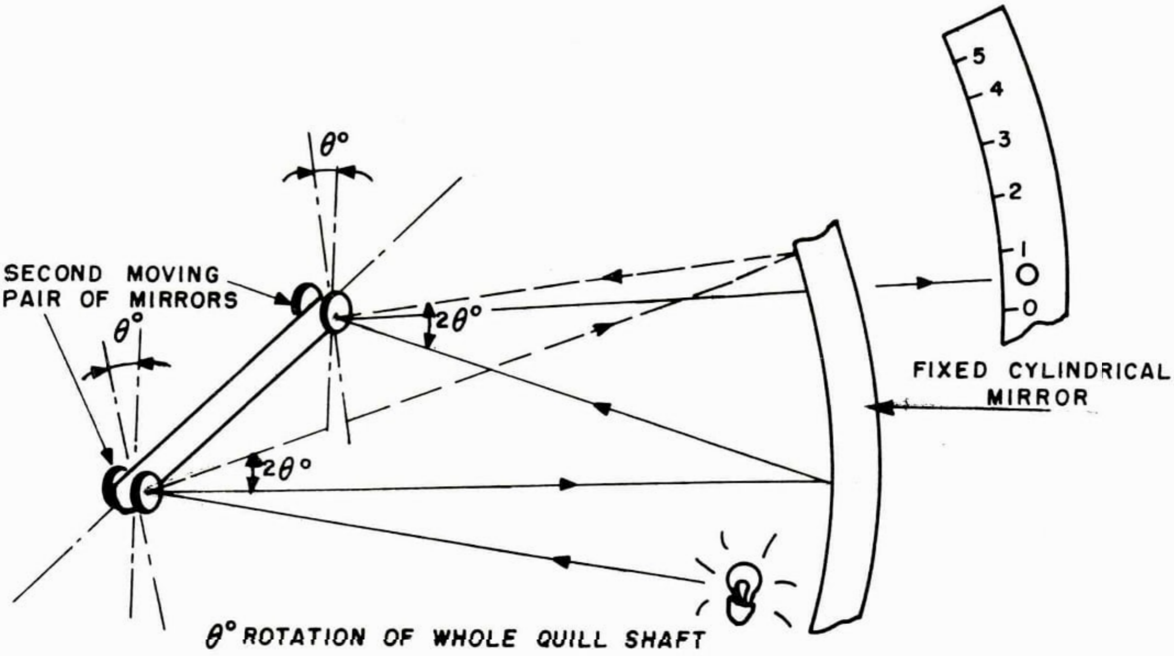
FIG. 8
LR-366



TORQUEMETER, SHOWING QUILL SHAFT, MIRRORS, AND TOOTHED WHEEL AND PICKUP COIL OF TACHOMETER

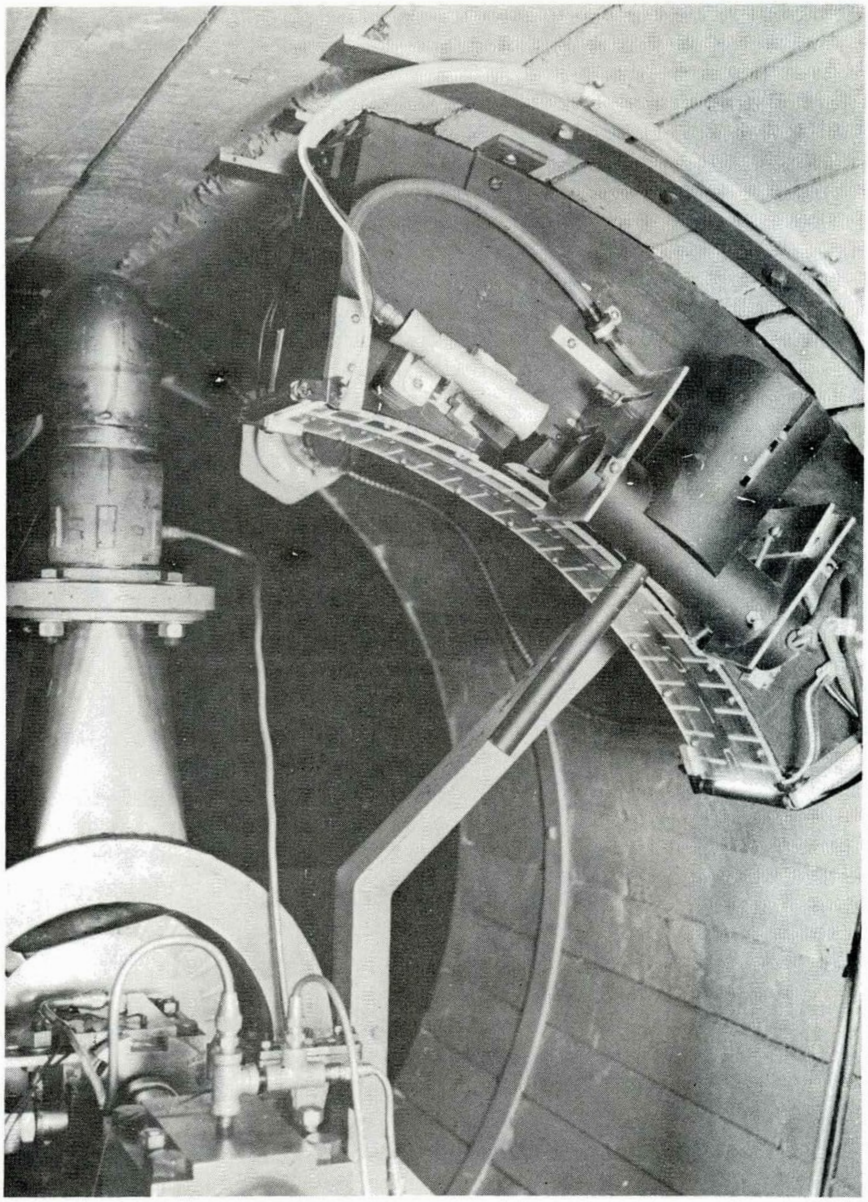


SIMPLIFIED OPTICAL SYSTEM



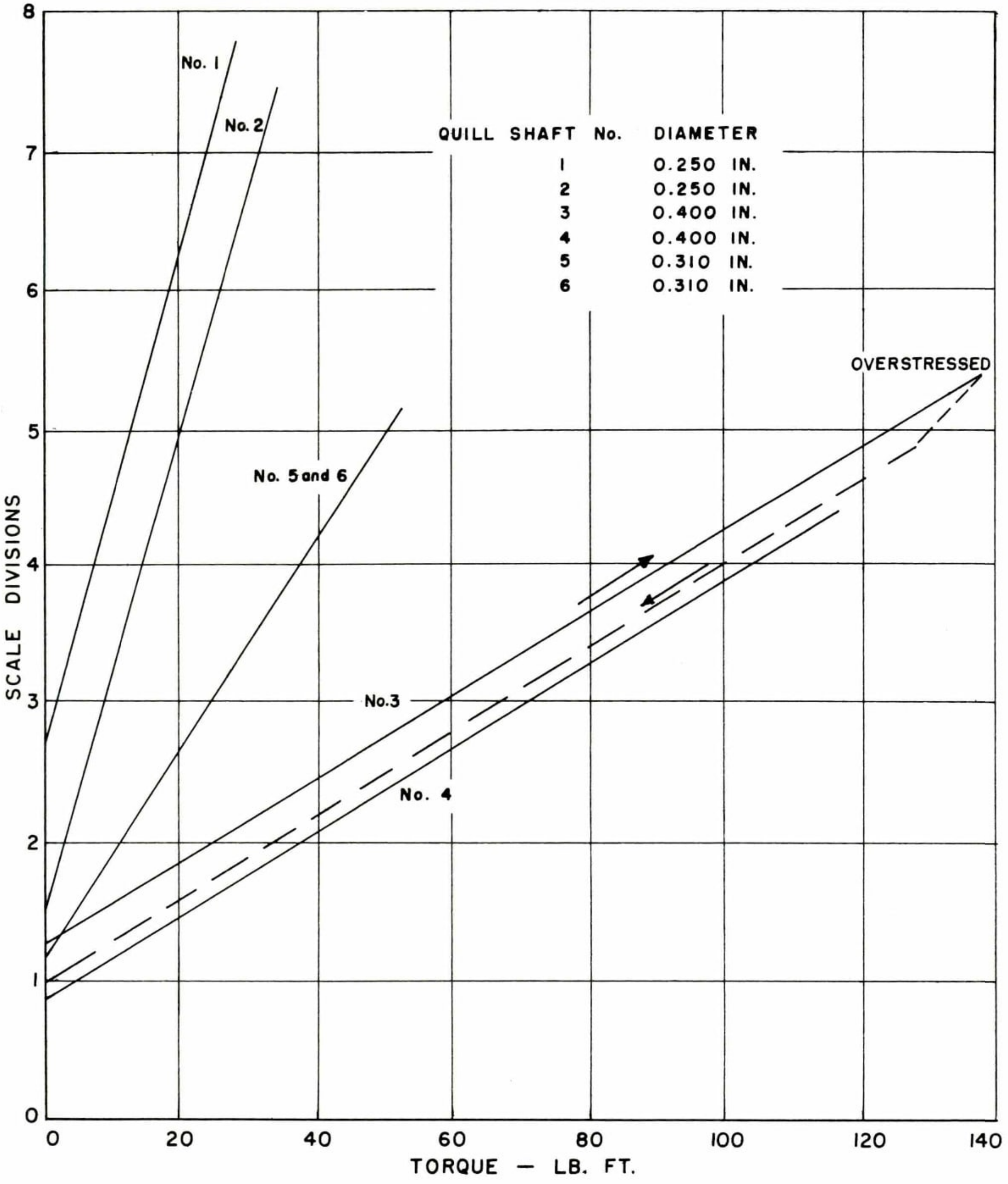
FINAL OPTICAL SYSTEM

TORQUEMETER OPTICS



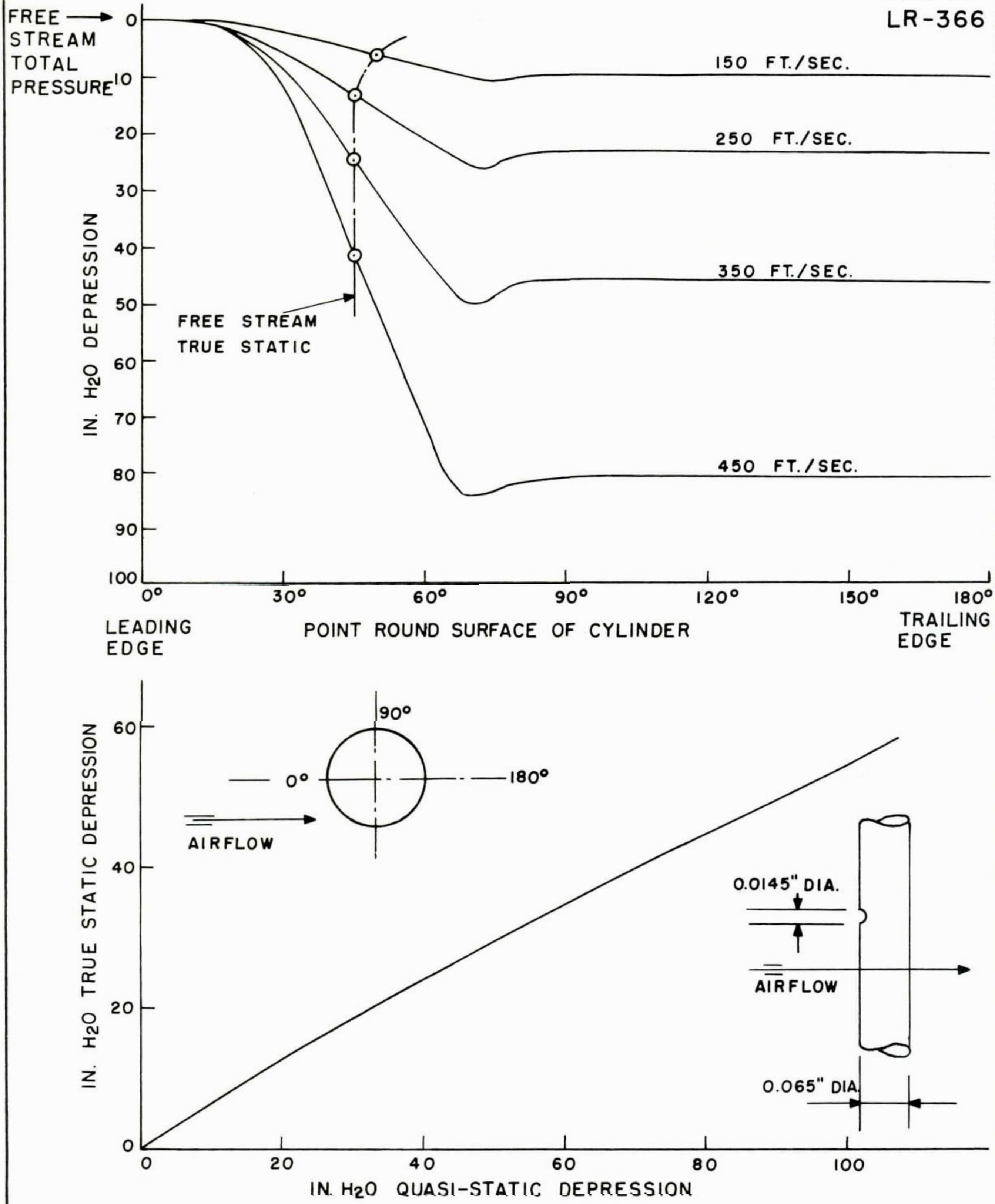
TORQUEMETER, SHOWING LAMPHOUSE, STATIC MIRROR, AND SCALE

FIG. 11
LR-366

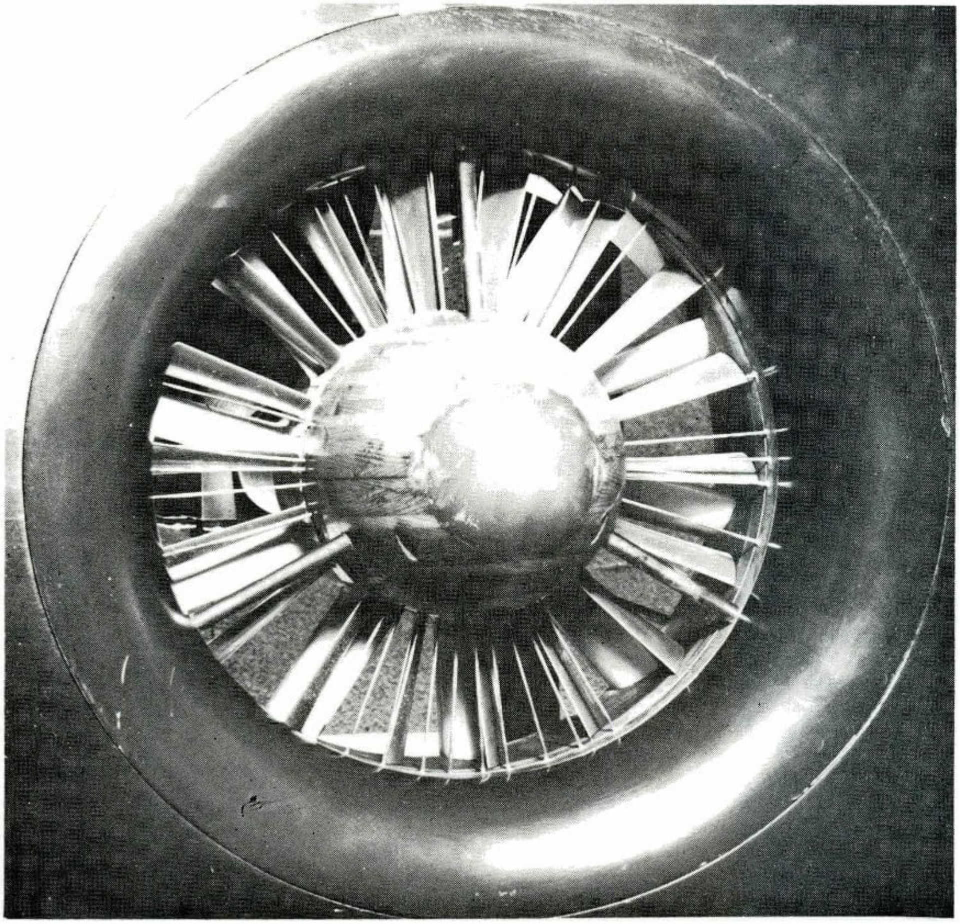


TORQUEMETER QUILL SHAFT CALIBRATION

FIG. 12
LR-366



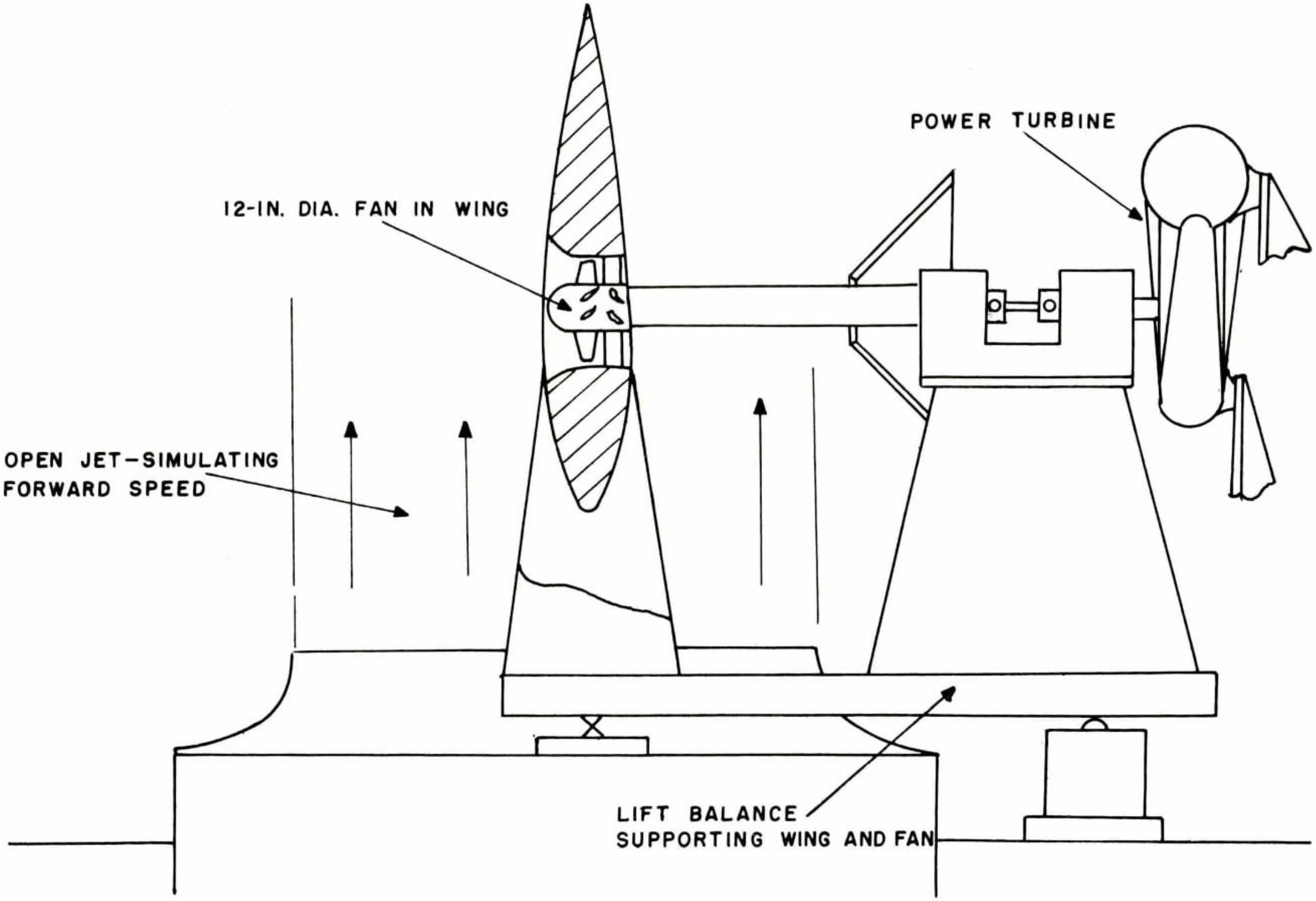
CALIBRATION OF CYLINDER SURFACE PRESSURE
IN TRANSVERSE AIRSTREAM



FAN INLET,
SHOWING 14 TOTAL AND QUASI-STATIC PRESSURE PROBES

FIG. 14
LR-366

FAN EXIT TOTAL PRESSURE RAKE



FORWARD SPEED SIMULATING RIG

FIG. 15
LR-366

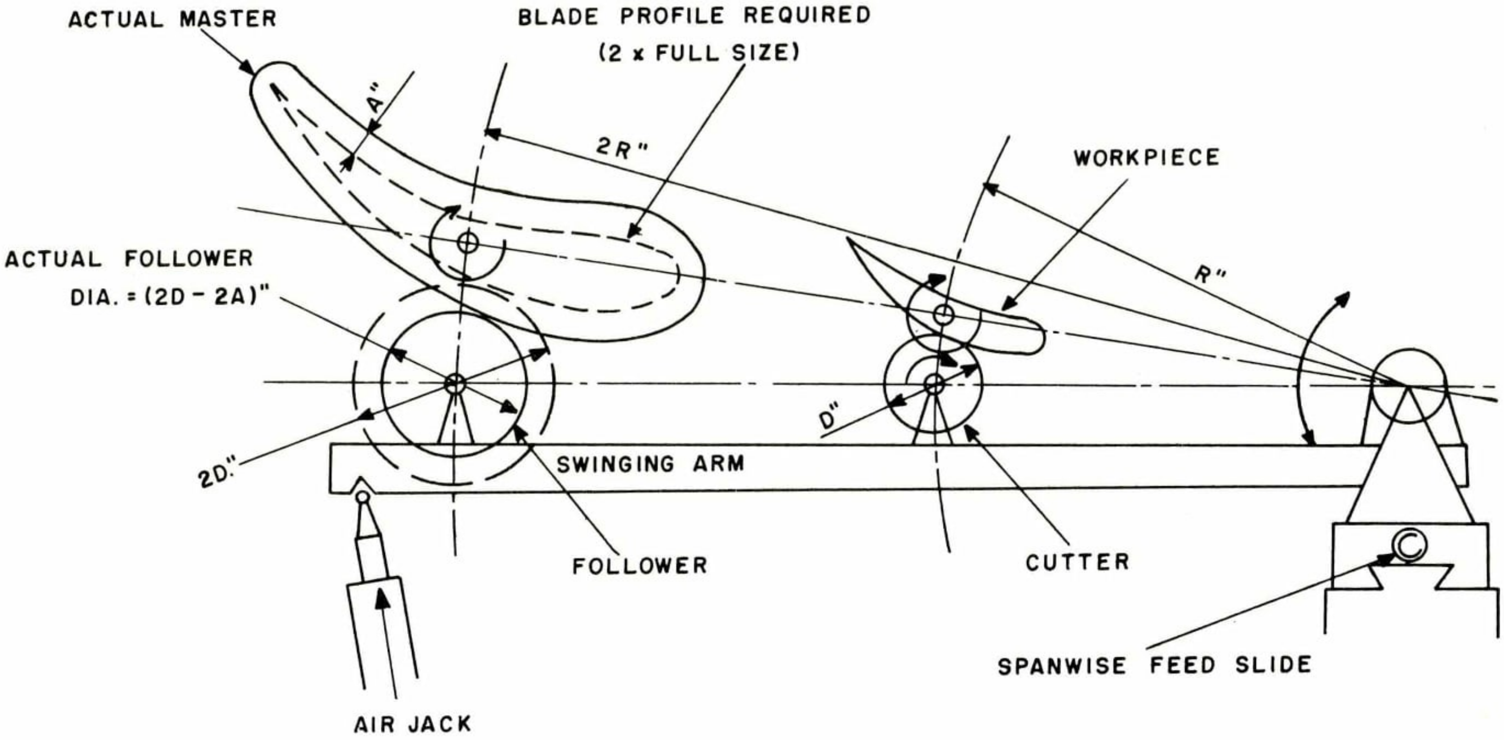


DIAGRAM OF THE PRINCIPLE OF BLADE PROFILING MACHINE

FIG. 16
LR-366

NRC LR-366
National Research Council, Canada. Division of Mechanical Engineering.

THE DEVELOPMENT OF RIG AND INSTRUMENTATION FOR TESTING 12-IN. DIA. MODEL VTOL DUCTED FANS.
H.S. Fowler. January 1962. 16 pp. + 16 figs.

In order to obtain design data for highly loaded ducted fans suitable for installation buried flat in the wing of a VTOL aircraft, it was decided to carry out a programme of experiments on 12-in. O/D model fans. These were to be tested at true Mach number, and disc loadings of the order of 500 lb./ft.^{2} were to be sought, requiring a rotational speed of about 15,000 r.p.m.

A test rig capable of driving these fans was built, and instrumentation to measure their performance developed for use with it. Most of the running carried out was without any forward-speed effect across the fan inlet, but a later version of the rig was capable of simulating forward speeds up to 250 ft./sec.

The rig and instrumentation are described, and the method of manufacturing fan blades is also outlined. The testing carried out on this rig is reported and analyzed in N.R.C. Aeronautical Report LR-367.

UNCLASSIFIED

1. Propellers (Ducted) - Test facilities

I. Fowler, H.S.
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