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Appendix II

STATE-OF-THE-ART OF INDUSTRIAL TECHNOLOGY OF ROTATING DIFFUSER (RD) FANS FOR LARGE SURFACE EFFECT SHIPS

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G. D. Boehler

AEROPHYSICS COMPANY
Washington, D.C. 20008
Tel.: (202) 244-7502

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INTRODUCTION

The Naval Sea Systems Command of the U.S. Navy is currently taking a new look at Surface Effect Ships (SES), for a range of missions and sizes extending from patrol ships (under 100-ton displacement) to large logistic transports (10 to 15,000 tons).

The Navy's interests are addressing foremost the short- to mid-term time-frame and searching questions are being asked about technical risks of SES development programs, especially for large ships. What distinguishes the SES from the conventional ship is the presence of the air bubble on which it rides. To many traditional naval engineers, the development, fabrication and installation of the air moving machinery which creates and maintains this air bubble is an unfamiliar technology, which they view with apprehension, because of the lack of experience in this area in the Navy's past and present fleet.

For example, in the MPS study performed by the Navy a couple of years ago, Aerophysics Company/Neu centrifugal lift fans of the Rotating Diffuser type were proposed and presented as being low-risk, state-of-the-art technology. These fans, with an outside diameter of 8.3 ft, are absorbing 7,000 Horsepower, and delivering 350,000 cubic feet per minute at a pressure rise of 100 inches W.G. (520 pounds per square foot). By comparison, existing lift fan systems for SES (the 100-A, the 100-B, the BH-200, the LCAC, for example) operate at cushion pressures one-quarter that of the MPS fans and at powers that are an order of magnitude smaller, as illustrated in Figure 1. It is interesting to note that all current ACV or SES machines operate near the upper limit of the state-of-the-art of backward-inclined centrifugal fans. Therefore, questions have been asked about the "low-risk" statement concerning RD lift fans, made in the MPS study.

The purpose of this report is to supplement the information provided in the MPS report about the "credibility" of the MPS lift fan system. The opportunity is also taken to show the higher limit of pressure rise currently available, using RD fans, over the MPS duty point. It is shown that fan pressures twice as high as the MPS (15,000 ton) duty point, can be obtained from off-the-shelf fans.

In the first section of the report, the required characteristics of the MPS lift fan are recalled, and how they are met by using an Aerophysics/Neu RD 195-.55-1.3-90° fan. In the second section, a list of over one hundred industrial fan wheels installed by Ets Neu in the past fifteen years in steel plants around the world is presented and summarized in table III. The duty point for each of these fans is shown on figure 6 and compared with the 10,000-ton MDC fan duty point; most importantly, each of the 14 fan systems shown on figure 6 (for which a total of 98 wheels were furnished) <u>belong to the same class of fabrication as the MPS fan</u> (referred to by Neu and Aerophysics as Class IIIs).

Photographs of a few of the fan wheels listed in table III, which happened to be in the Neu-Lille shop for overhaul at the time of the latest November 1983 visit by Navy representatives, are also shown. Also shown is

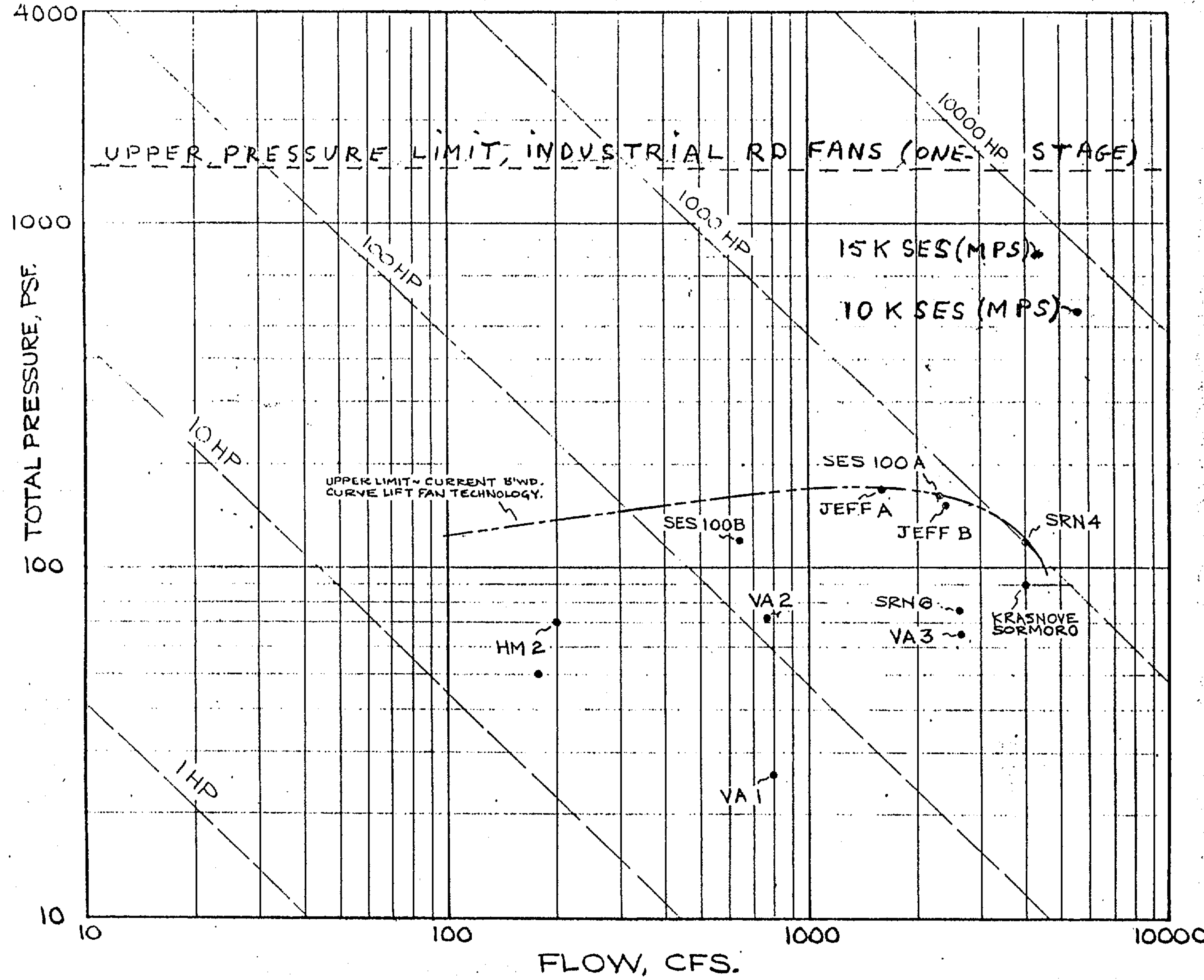


Figure 1: Major ACV and SES lift fan systems, and comparison with required MPS lift fan system.

the full-scale performance of two of the typical fans of table III. In the third section (figure 7), a list of Neu fan wheels is shown, which extends to pressures in excess of those required for the MPS lift fan (15,000 ton). However, this chart (figure 7) must be used with caution, because it does not show fans of the same class of fabrication as the proposed MPS fans. In the fourth section pressure-flow maps of off-the-shelf RD blowers operating at pressures twice those required for the MPS duty are shown (figure 18). This extends the available family of RD blowers usable for RD fans to total pressures in excess of 1,500 pounds per square foot.

It is therefore concluded that the statements made earlier in the MPS report about the availability of industrial RD fan technology to meet large SES fan needs are fully justified.

I. THE PROPOSED MPS LIFT FAN (10,000 AND 15,000 TONS)

The Aerophysics-proposed RD fan system for the MPS ship was presented in Aerophysics Company Report 80-93-1 and later incorporated into a Navy report. One of the interesting problems of the MPS mission, as stated in 1980, was to have a common fan for a 10,000-ton and for a 15,000-ton ship, the increased pressure requirements of the 15,000-ton ship being accommodated by an increase in fan RPM and the increased flow by a greater number of fan modules, if necessary.

The proposed Aerophysics fan was a Double Width Double Inlet (DWDI) series 195-0.55-1.3-90° fan. The nomenclature is as follows:

195 stands for the blade diameter of the fan, in centimeters

0.55 is the ratio of the inlet eye diameter to the blade diameter

1.3 is the ratio of the rotating diffuser (or overall diameter) to the blade diameter

90° is the blade angle at its tip of discharge (β_2). In this case, the blade is radial.

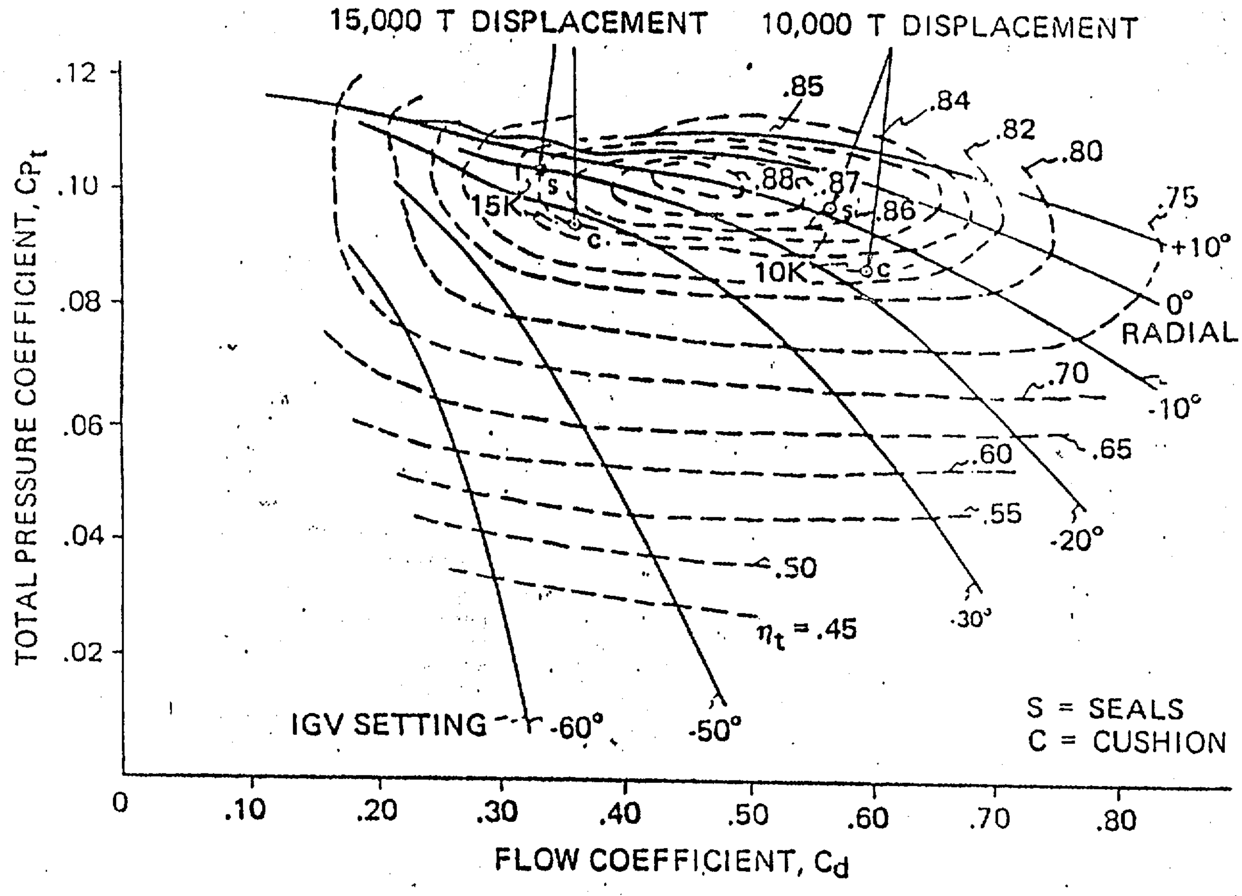
The performance of the proposed RD wheel is shown, in non-dimensional pressure-flow coefficients, as figure 2, where it is shown that the same fan can accommodate, with good efficiency, both the 10,000-ton and the 15,000-ton duties. For a definition of the non-dimensional pressure and flow coefficients Cp and Cd, the reader is referred to Aerophysics Company Report 80-93-1.

The lift system requirements for the MPS are shown on table I for the 10,000-ton ship and table II for the 15,000-ton ship.

Two pictures of Neu industrial fans with duties similar to that of the MPS fan were shown in the Navy report and are reproduced here as figures 3 and 4. Note that the first one operates at a pressure rise similar to that of the MPS, while the second one - a forced draft fan for an electrical-generation power plant - operates at a much lower pressure rise than the MPS fan (47 in. W.C. against 107 in. W.G.).

A side view of the MPS lift fan is shown as figure 5.

GENERAL PERFORMANCE OF FULL SIZE RD WHEEL



SERIES RD 195–.55–1.3–90°
80°F TEMP
50% REL. HUMIDITY

FIGURE 2

MPS LIFT SYSTEM PERFORMANCE REQUIREMENTS
(10,000 LT)

SUB-SYSTEM	SEALS	CUSHION
NO. OF DWDI RD LIFT FANS	4	2
NO. OF INLETS	8	4
HORSE POWER AVAILABLE/INLET	3500	3500
P_S STATIC, PSF	514	467
P_T TOTAL, PSF	555	504
DELIVERED FLOW/INLET, CFS	2917	3120
TOTAL FLOW IN CUSHION, CFS	—	12480
TOTAL FLOW IN BOTH SEALS, CFS	23336	--
TOTAL FLOW/SHIP, CFS	35815	
C_{Pt}, TOTAL PRESSURE COEFFICIENT	.0970	.0881
C_d, FLOW COEFFICIENT	.551	.584
N_t, TOTAL EFFICIENCY	.865	.825
IGV BLADE SETTING, DEGREES	-9	-16
SLOPE OF PERFORMANCE CURVE	STABLE	STABLE
TIP SPEED, FT/SECOND	549	
RPM, ENGINE - FAN	1350 - 1639	
GEAR RATIO REQUIRED	1.214	

TABLE I

MPS LIFT SYSTEM PERFORMANCE REQUIREMENTS
(15,000 LT)

SUB-SYSTEM	SEALS	CUSHION
NO. OF DWDI RD LIFT FANS	4	2
NO. OF INLETS	8	4
HORSE POWER AVAILABLE/INLET	3500	3500
P_S STATIC, PSF	700	700
P_T TOTAL, PSF	808	735
DELIVERED FLOW/INLET, CFS	2191	2190
TOTAL FLOW IN CUSHION, CFS	—	8762
TOTAL FLOW IN BOTH SEALS, CFS	17528	—
TOTAL FLOW/SHIP, CFS	26290	
C_{Pt}, TOTAL PRESSURE COEFFICIENT	.1050	.0955
C_d, FLOW COEFFICIENT	.322	.354
N_t, TOTAL EFFICIENCY	.850	.850
IGV BLADE SETTING, DEGREES	-10	-32
SLOPE OF PERFORMANCE CURVE	STABLE	STABLE
TIP SPEED, FT/SECOND	636	
RPM, ENGINE - FAN	1350 - 1900	
GEAR RATIO REQUIRED	1.407	

TABLE II

MPS TYPE LIFT FAN DURING INSTALLATION

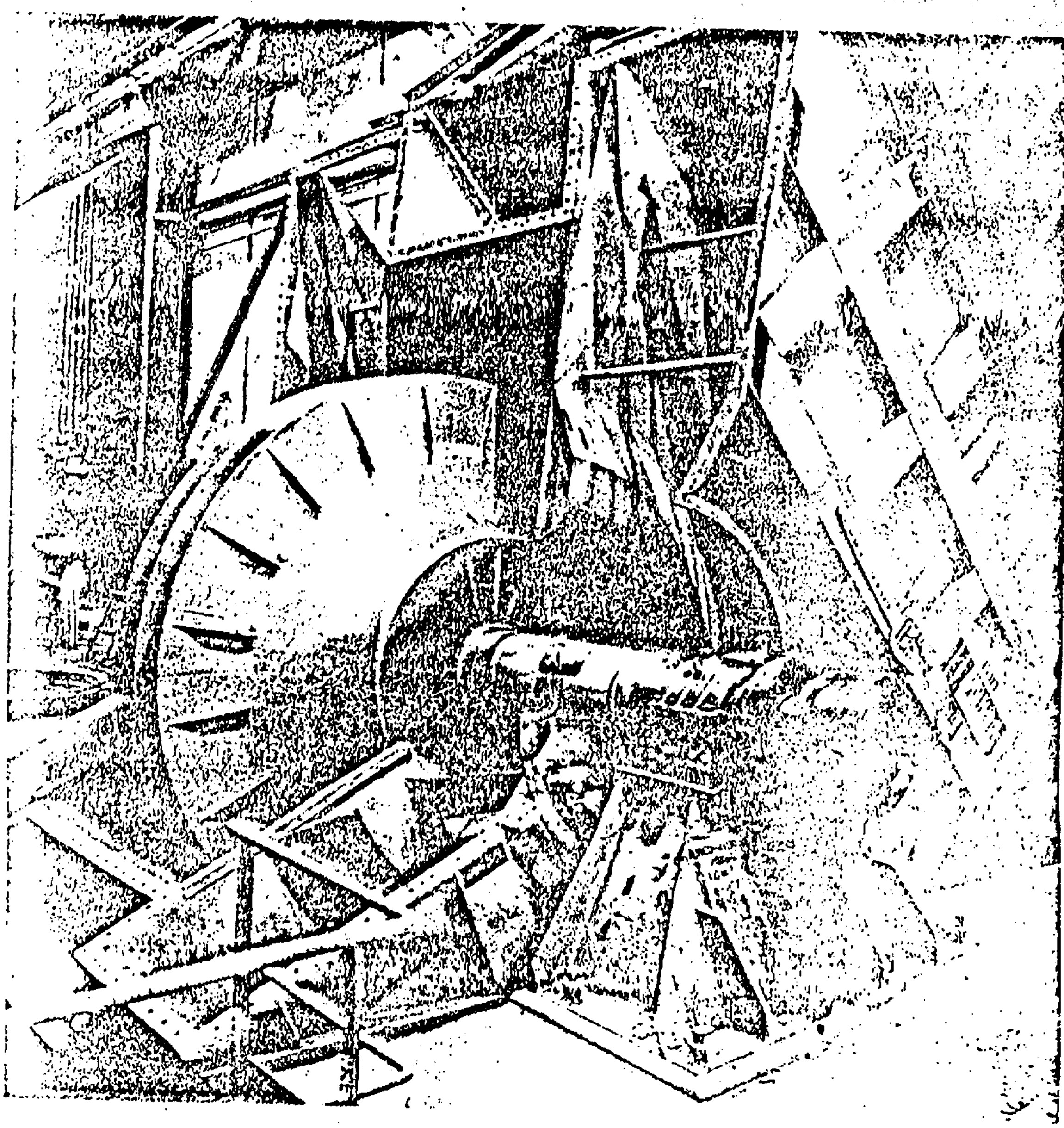


FIGURE: 3

ROTARY DIFFUSER FAN DURING ASSEMBLY

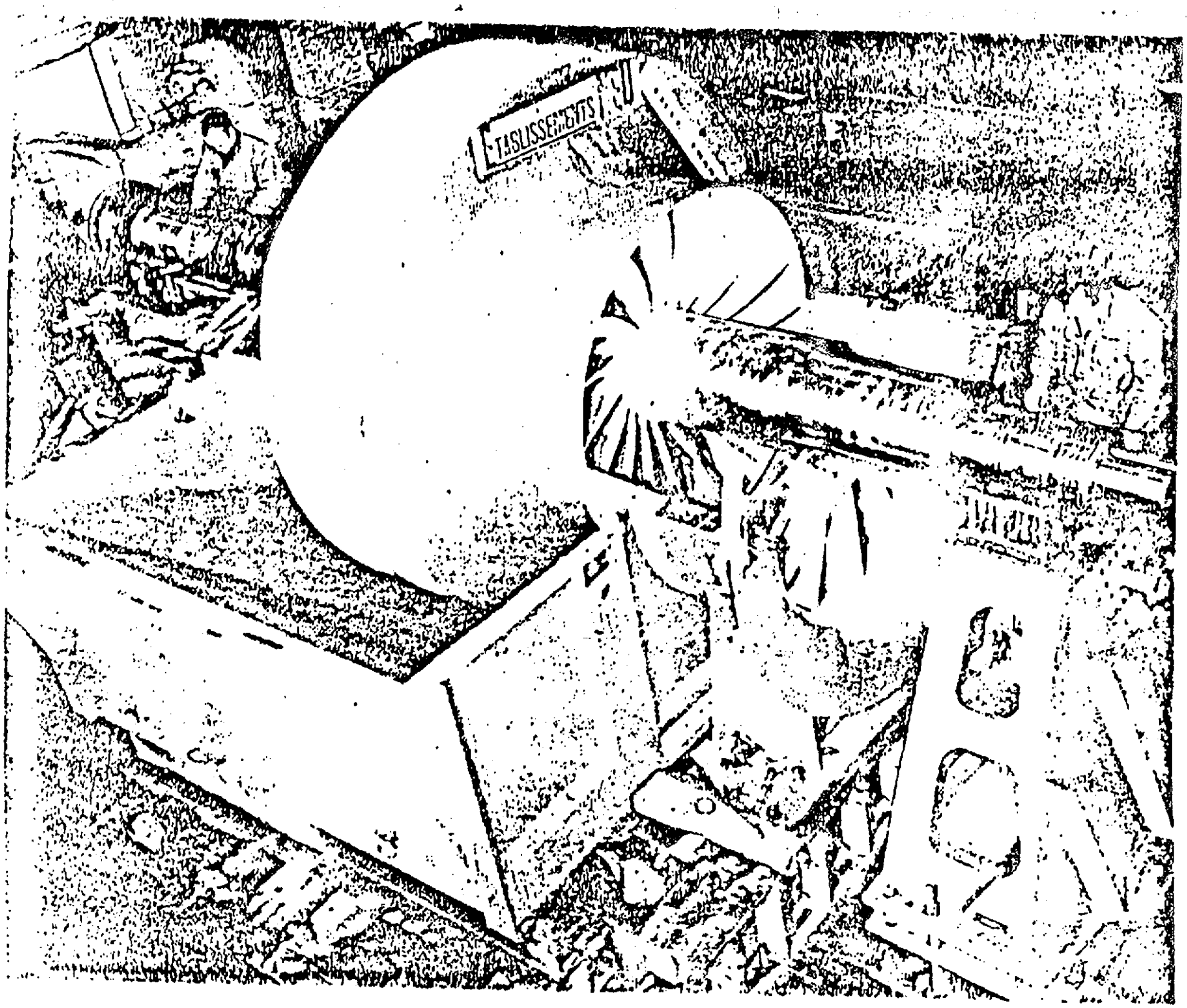


FIGURE 4

MPS LIFT FAN – SIDE VIEW

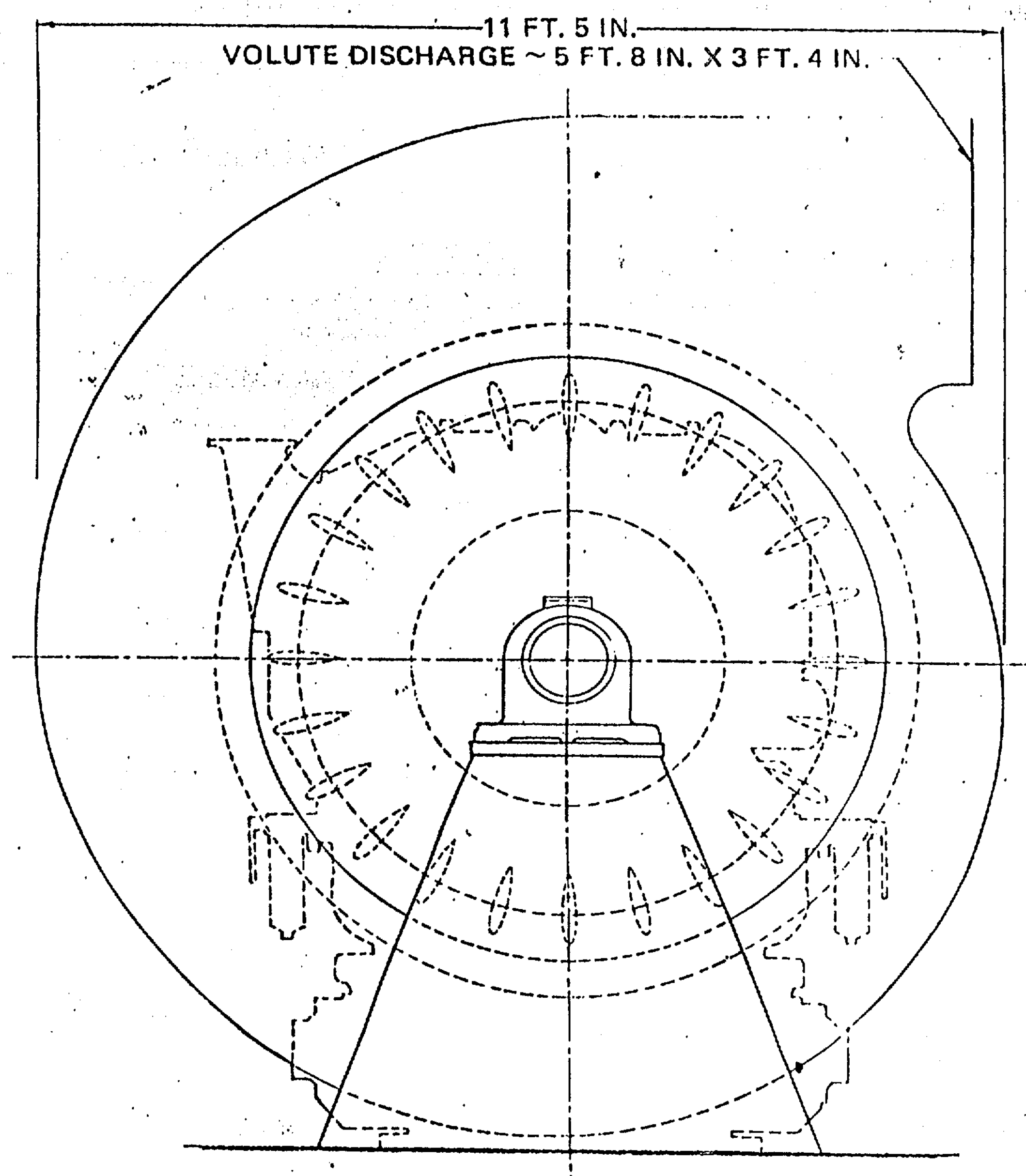


FIGURE 5

II. STATE-OF-THE-ART OF INDUSTRIAL RD FANS IN THE MPS (10,000-TON) DUTY RANGE

1. Customers' List of Recent Industrial RD fan Installations

During a trip to Ets Neu, in Lille, France, in November 1983, by G. Boehler of Aerophysics, and W. White of NAVSEA, a review was made of the list of references of Neu industrial RD fan installation of the last 15 years. A table, shown here as table III, was prepared of fan installations with pressure and flow characteristics similar to those of the MPS, e.g. pressure rises aroun 100 in. W.G. and flows around 300 to 400,000 cfm. Sixteen such installations are listed in table III. They cover sizes between 185 and 307 cm. blade diameters (the MPS fan blade diameter is 195 cm), pressure between 75 and 130 in. W.G. (the MPS pressure rise is 107 in. W.G.) and flows between 100,000 CFM and about 800,000 CFM.

The industrial fans listed in table III were designed for variable operating temperatures, which could be as high as 1000°F. The pressure rise of a fan is proportional to the density of the fluid which it handles. Therefore, if at high temperature the density of the fluid is only half that at standard conditions, the pressure rise at 1000°C is twice that required under standard conditions. Therefore, the performance of various fans can only be compared meaningfully under the same inlet flow conditions. Therefore, the performance of the 16 fans shown on table III was recalculated for "standard" conditions (corresponding to a fluid density of 1.2 kg/m^3), for the point of maximum efficiency, and is based on the performance curves of each fan developed by Ets. Neu over the last 30 years.

Each of the fans of table III is a so-called "heavy duty" fan, e.g. one operating in a difficult environment: high temperatures, with flying ashes going through the fan, large temperature gradients, etc., and under full-time duty conditions: 24 hours a day, usually 360 days of the year. As far as is known, every one of the 16 fans of table III is currently operating, and none has ever failed during operation. For Example, No. 12 (Arbed) and No. 13 (Solmer) have been operating continuously for 10 years, except for yearly shut-down of the plant. These two installations are also the largest RD wheels ever built by Neu (307 cm. dia., 57% larger than the proposed MPS lift fan) and operate at a higher pressure rise than the MPS fan (120 in. W.G. against 107 in. W.G.). The 307-cm wheel is the one that is shown on figure 2 of this report. Figure 6 shows a pressure-flow duty point (at the design point) for 14 of the 16 fans shown in table III. It compares these duty point with those of the MPS 10,000 ton lift fan (and, for further comparison, of the MPS 15,000-ton and of the old Rohr 3KSES). Most importantly, all fans shown on figure 6 are designed to identical structural and fabrication criteria, corresponding to RD fan heavy duty. In the Neu-Aerophysics nomenclature, this corresponds to the class of fabrication III-s and the class of quality Q1. Because of the importance of this point, it is elaborated on further here.

TABLE III: REFERENCE LIST OF TYPICAL NEU HEAVY-DUTY RD FANS

JOB NUMBER A.C.	JOB NUMBER NEU	LOCATION OF INSTALLATION	FAN TYPE	NUMBER OF WHEELS DELIVERED	DATE OF INITIAL FABRICATION	CLASS OF FABRICATION	TYPE OF STEEL	ROTATIONAL SPEEDS RPM	ROTATIONAL SPEEDS Blade Tip Speed m/sec	ROTATIONAL SPEEDS Diffuser Tip Speed, m/sec	PERFORMANCE, STD CONDITIONS Δp, in. W.G.	PERFORMANCE, STD CONDITIONS Q ave., cfm
1	1.E3.74	HUTA KATOWICE	RD 218-.65-1.2	18	1976	IIIs	18M5f	1500	171	203	105.	489,000
2	13.E3.76	ITALSIDER TARENTE	RD 200-.55-1.3	10	1977	IIIs	A42C1	1500	186	203	127.	331,000
3	8.E3.75	METALLURGIE NORMANDY	RD 185-.5-1.3	6	1976	IIs	18M5f	1500	165	186	100.	208,000
4	3.V3.79	USINOR DUNKERQUE	RD 220-.55-1.09	2	1979	IIIs	18M5f	1500	170	186	106.	373,000
5	21.E3.76	HBL-CARLING (COKE PLANT)	RD 185-.38-1.2	3	1977	IIIs	A42C1	1500	154	171	88.	103,000
6	14.E3.77	V.Z.K.G.	RD 220-.38-1.2	2	1962	IIIs	A42C1	1500	174	190	112.	147,000
7	10.V3.79	SACILOR ROMBAS	RD 200-.6-1.2	10	1962	IIIs	A42C1	1500	160	188	93.	351,000
8	5.E3.76	SACILOR JOEUF	RD 200-.65-1.3	8	1969	IIIs	A42C1	1500	155	203	86.	214,000
9	3.E2.74	POSCO KOREA	RD 260-.6-1.3	2	1976	IIIs	A42C1	1200	160	211	93.	574,000
10	8.E2.74	TAIWAN	RD 240-.6-1.3	4	1976	IIIs	A42C1	1200	159	193	92.	485,000
11	9.E2.75	TMM CHARLEROY	RD 307-.5-1.3	4	1977	IIIs	A42C1	1000	173	209	110.	610,000
12	209.E2.71	ARBED BELVAL	RD 307-.55-1.3	8	1973	IIIs	A42C1	1000	171	209	107.	727,000
13	42.E2.71	SOLMER FOS	RD 307-.55-1.3	8	1973	IIIs	A42C1	1000	181	209	120.	770,000
14	27.E3.77	USINOR DUNKERQUE	RD 185-.55-1.2	4	1973	IIIs	A42C1	1450	142	171	74.	213,000
15	18.E3.75	SOLLAC KNUTANGE	RD 280-.5-1.3(S)	6	1965	IIIs	A42C1	1000	152	189	85.	225,000
16	23.E3.77	HAINAUT SAMBRE	RD 280-.53-1.2	6	1975	IIs	A42C1	1000	153	175	86.	502,000

→ except class IV c, which is a cast wheel.

In the design of RD fans, there are 4 "classes" of fabrication: IIs, IIIs, IVs and IVc, this for a wheel of given geometry and size. Class IIs corresponds to "light" duty and Class IIIs to "heavy duty", as defined above (continuous operation for a year, adverse environment, etc.). Classes IVs and IVc are applicable to "compressor" duty, meaning pressure rises between 200 and 300 in. W.G., which are currently way above any range of interest for SES. All RD fans are bent sheet metal welded structures. The class of fabrication therefore depends upon two major elements: the basic material used and the quality control of the manufacturing operation, especially of the welds (a derivative element is the strength of the structure, i.e. the thickness of blades and shrouds). It is of great interest to note in table 3 that the material used in the majority of Neu heavy-duty fans is ordinary steel (A42C1, which corresponds to ASTM A515. gr. 60, in the U.S.). In fact, the highest-performance fans, i.e. No. 12 (Arbed) and 13 (Solmer) are made of ordinary steel. The other steel used is 18 M 5 f, which is a relatively high strength steel, equivalent to the CORTEN C in the U.S.. Both are very easy to weld.

The detailed quality control characteristics of class IIIs fabrication for an RD fan are available from Aerophysics and are summarized here, as follows:

1. Materials

All materials entering into the fabrication of the fan are identified and controlled individually when received. The supplier is required to provide a certificate of chemical analysis and of mechanical characteristics for each lot, as well as an overall "control certificate". Weld materials are subjected to strict specifications, which must also be certified in writing by the supplier. Suppliers must meet a particular specification for forged materials.

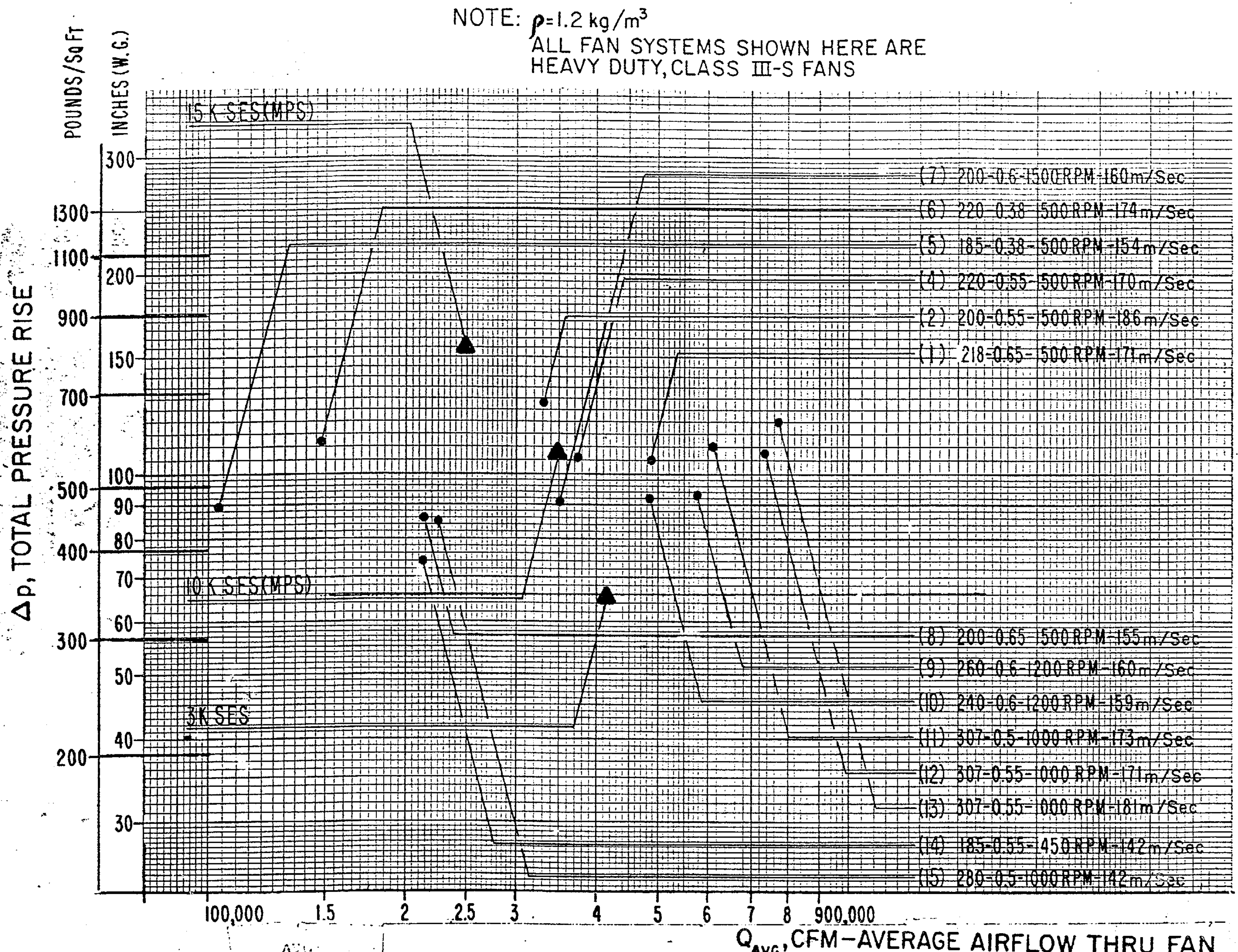


FIGURE 6 — PRESSURE-FLOW DUTY POINTS OF OPERATIONAL NEU Heavy-Duty INDUSTRIAL RD FANS COMPARED WITH SES MPS LIFT FANS

2. Fabrication processes

- any subcontracted item requires from the subcontractor submission of detailed procedures, which must be approved by us

- When a new fan goes into the shop, a meeting between engineering, quality control and shop personnel (welders) must take place and welding procedures approved for that particular job.

- All welders are certified by a State organization. In addition, each welder must be certified individually, in-house, for each class of fabrication. Only a fraction of the welders are certified for Class III fabrication.

- All welders must comply with a detailed specification about the quality of welds (minimum number of passes as a function of metal thickness, etc.).

3. Quality Control

- All welds are:

  - visually inspected

  - subject to sweating, in accordance with a specification, preceded by sand blasting, if there has been previous heat treat. A written report is required

  - X-rays, both before and after assembly. A written report is required

- visual check of surface conditions and of cleanliness of the air passages

- check dimensions against drawings: check direction of rotation. A written report must show actual measured dimensions.

4. Heat treating

The heat treating cycle is as follows:

- Increase heat at 150°C/hr - up to 600°C. Stay at 600°C ± 10 for one hour

- Cooling unitl 300°C in the oven at the rate of 50°/hr, then cooling in ambient air. A report on the heat treat cycle must be furnished.

5. Dynamic balancing

Dynamic balancing is performed in accordance with the Company specification (not reproduced here). Balancing masses must be added in accordance with Company Specification. A special form must be filled up.

Based on the showings of figure 6, it is clear that the technology embodied in our class IIIs fabrication is fully adequate for SES lift fan systems for the 10,000-ton SES ship, as currently contemplated. Again, every single fan shown on figure 6 was built to the same structural and environmental standards as the proposed MPS fan and forty (40) of the fans shown on figure 6 have duties, in both pressure and flow, that equal or exceed the duty of the 10,000-ton MPS fan.

2. Photographs of Typical Fan Wheels

During the trip to Ets Neu, in Lille, France, in november 1983, Mr. W. White of NAVSEA had the opportunity to photograph several RD wheels, which happened to be in the Neu shop for repair or overhaul or as spares. Some of these photographs are shown here, with the other visitors, Mrs. White and G. Boehler, to show the "scale" of the fans.

As stated earlier, the most interesting RD fan in terms of the MPS duty, is the RD 307-.5-1.3, "Arbed-Belval" shown as No. 12 on table III. Three photographs of this fan wheel are shown, as figures 7, 8 and 9. Another earlier version of the same fan (Rombas) is shown on figure 10. The rusty-colored fan of figure 10 has about 50,000 hours of operation in a hot, dusty environment. Shown on figure 11 is a slightly smaller fan (11 ft outer diameter, instead of 13 ft, for the Belval fan), which is single width, instead of double width. This fan is of interest because it is built entirely of stainless steel. It is not shown on table III, which includes fans made of ordinary steel.

The fan shown on figures 12 and 13 is interesting, because it represents a sery advanced technology. It is not an RD fan, but a "pellet" fan, designed as an induced-draft blower for chains of pelletization (the manufacture of pellets of iron ore, in such places as the Mesabi range in Minnesota). Its diameter is 17 feet and it weighs 15 tons. It is designed to operate continuously at high temperatures and under high temperature gradients.

Finally, the fan wheel shown on figure 14 is No. 8, on table III: Sacilor Joeuf. It is of interest, because it is of identical geometry with the fan chosen as the Rohr 3K SES back-up lift fan.

3. Performance of two typical fan wheels:

The full-scale performance of the Belval fan (No. 12 on table 3 and figures 7, 8 and 9) is shown on figure 15, which is a pressure-flow map for various Inlet Guide vane angles (0° is fully open, 90° fully closed), together with constant-efficiency curves.

The performance of the SWSI stainless steel fan of figure 11 (Saulnes-Uckange) is shown on figure 16.

Figure 7: Close-up Photograph of Inlet of RD Fan Wheel 307-.55-1.3
(Fan No. 12 on Table III)

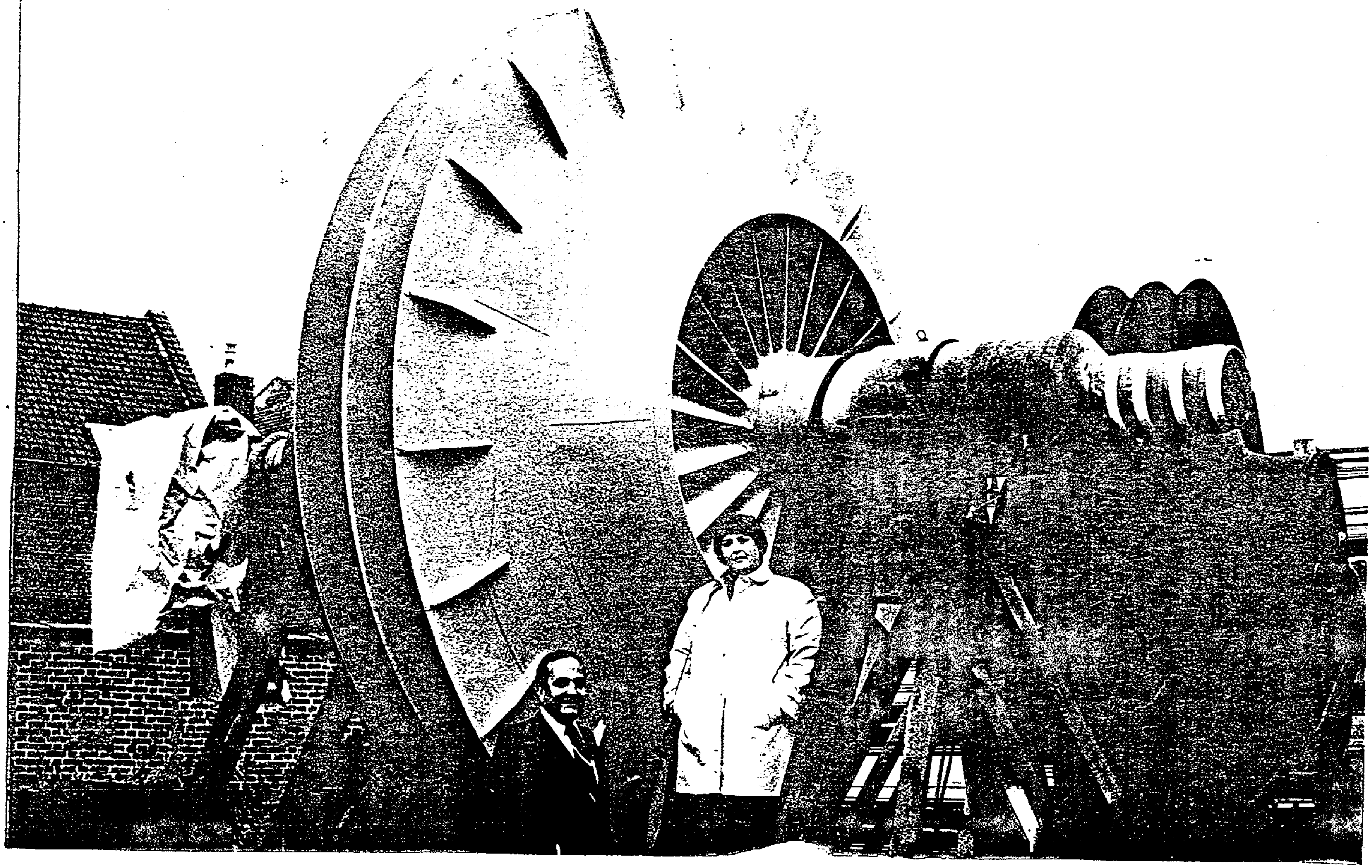


Figure 8: Overall Photograph of RD Fan Wheel 307-.55-1.3 (No. 12 on Table III)

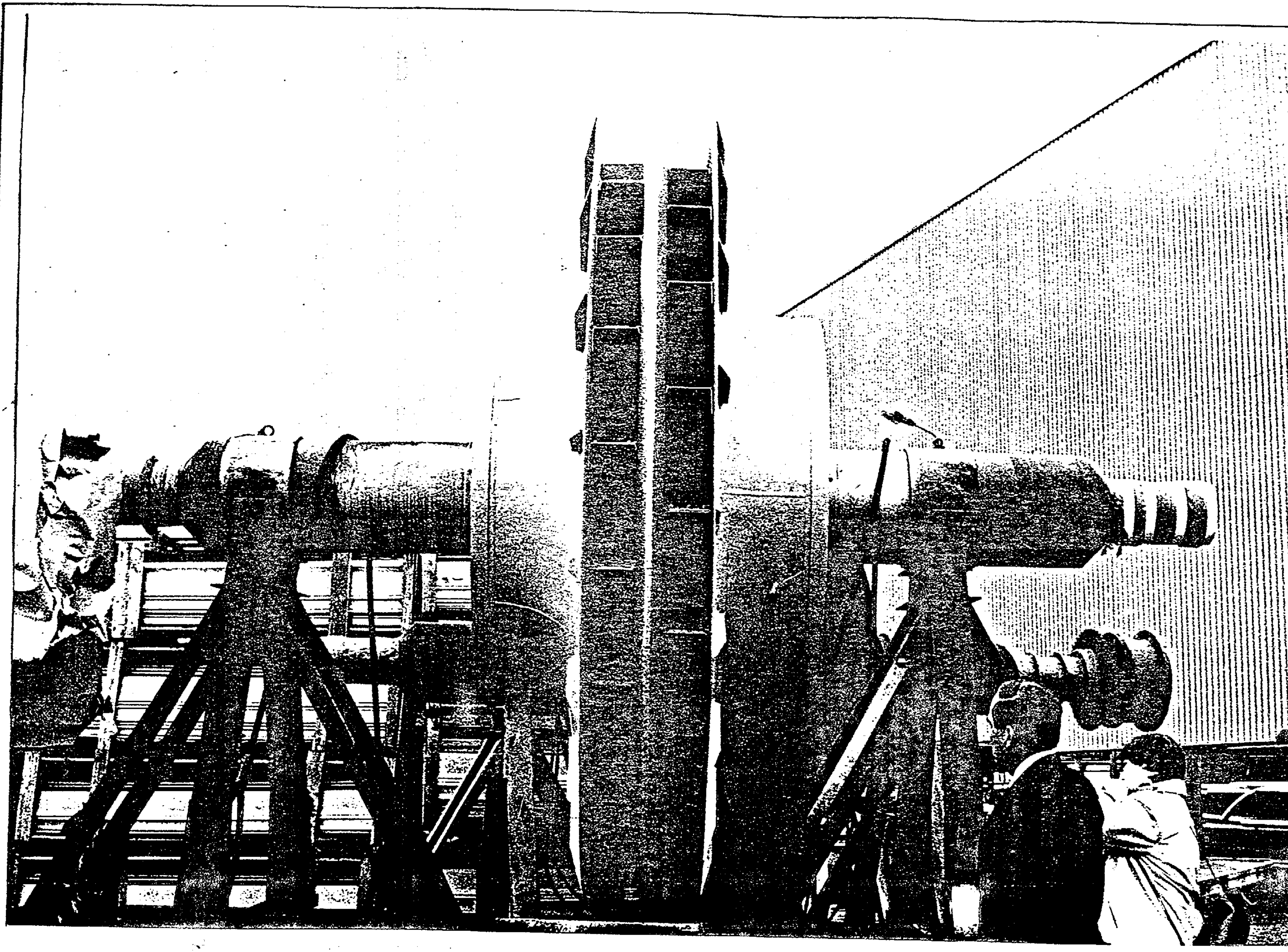


Figure 9: Side Photograph of RD Fan Wheel 307-.55-1.3 (No. 12 on Table III).

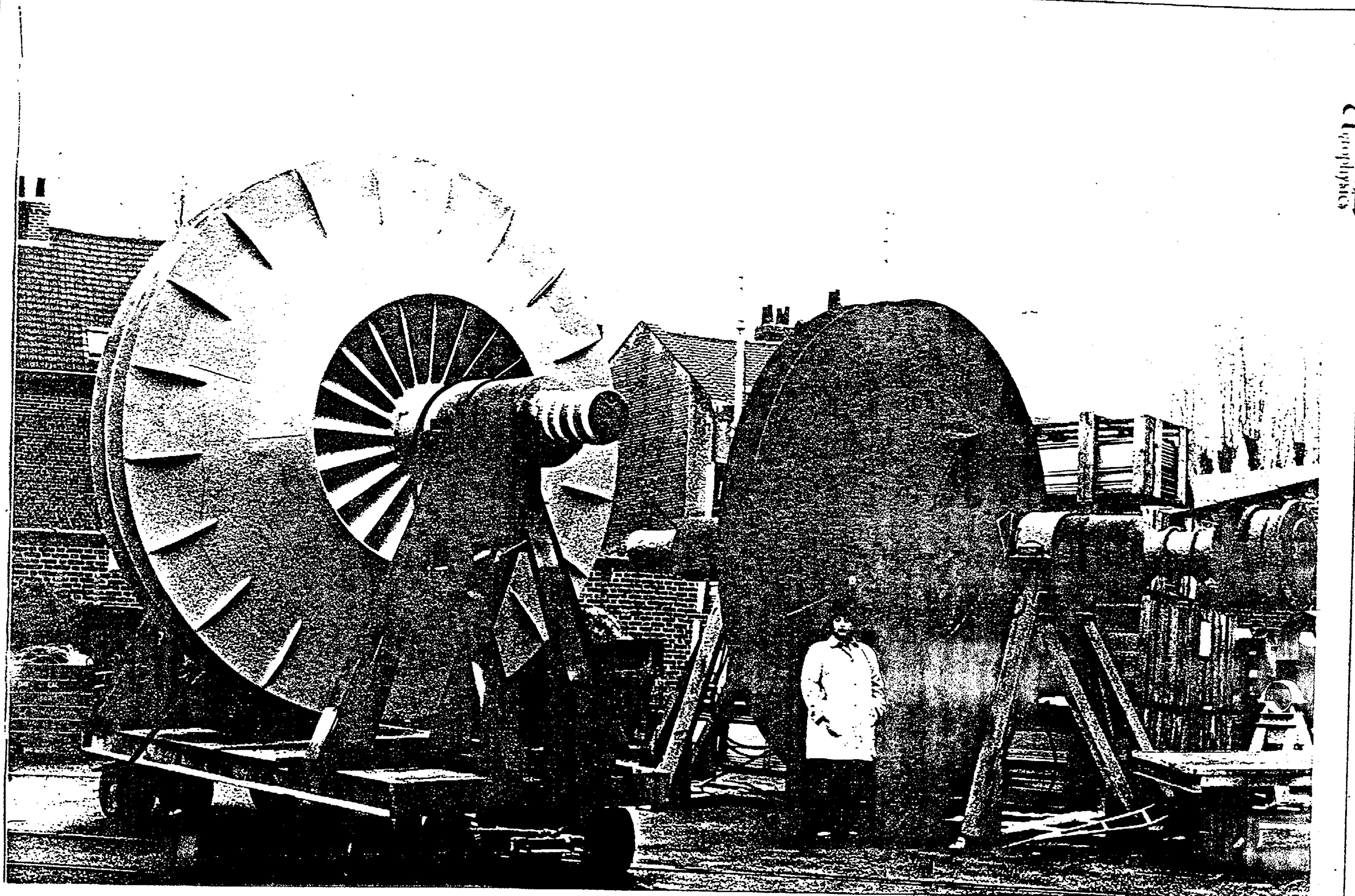


Figure 10: Photograph of Two RD Fan Wheels, Model 307-.55-1.3, Original on the Right (1970), and Improved Version on the Left (1972).

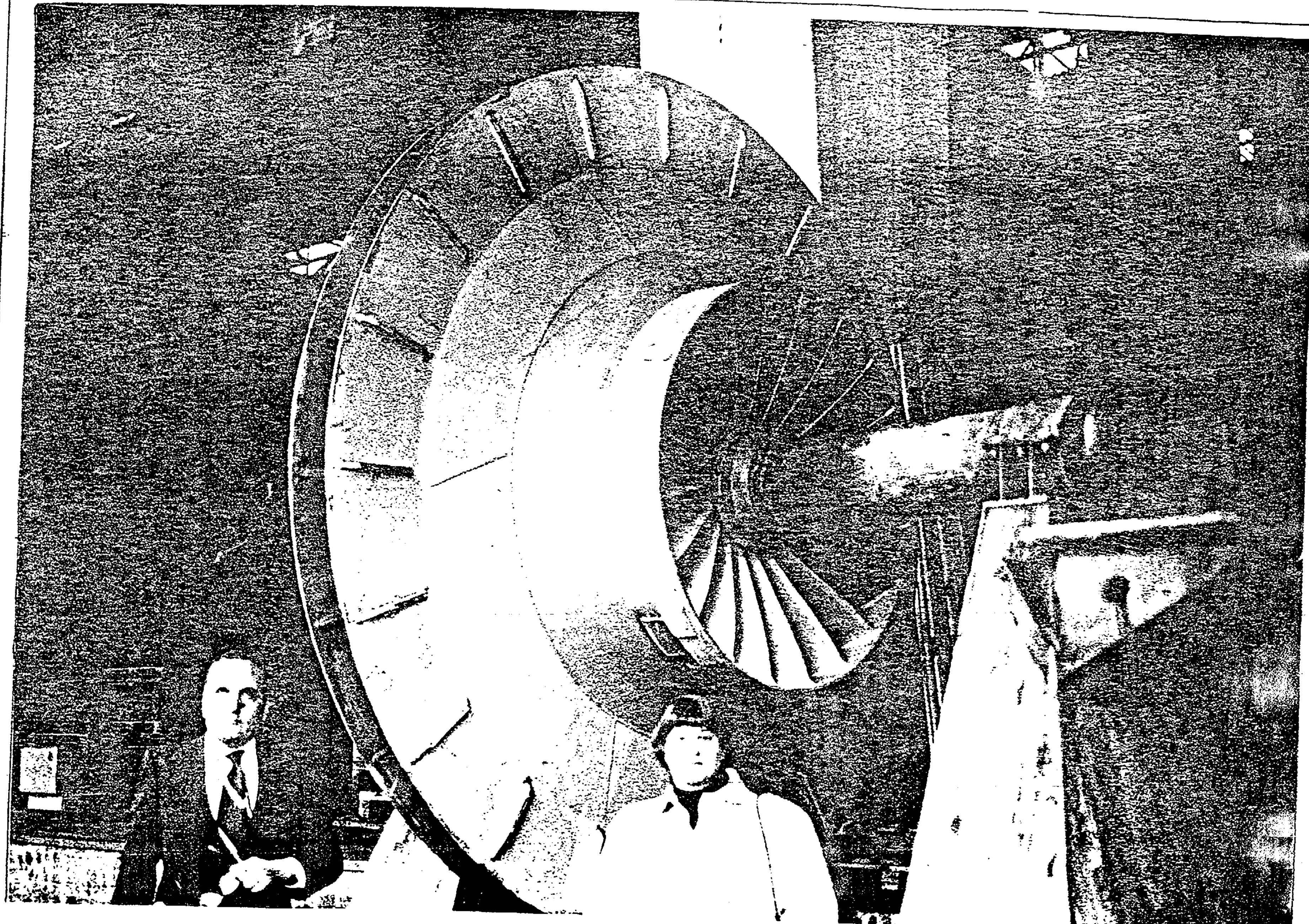


Figure 11: Photograph of Stainless Steel Fan Wheel, 280-.5-1.3(S) (~~No. 18 on Table III~~) (unchanged)

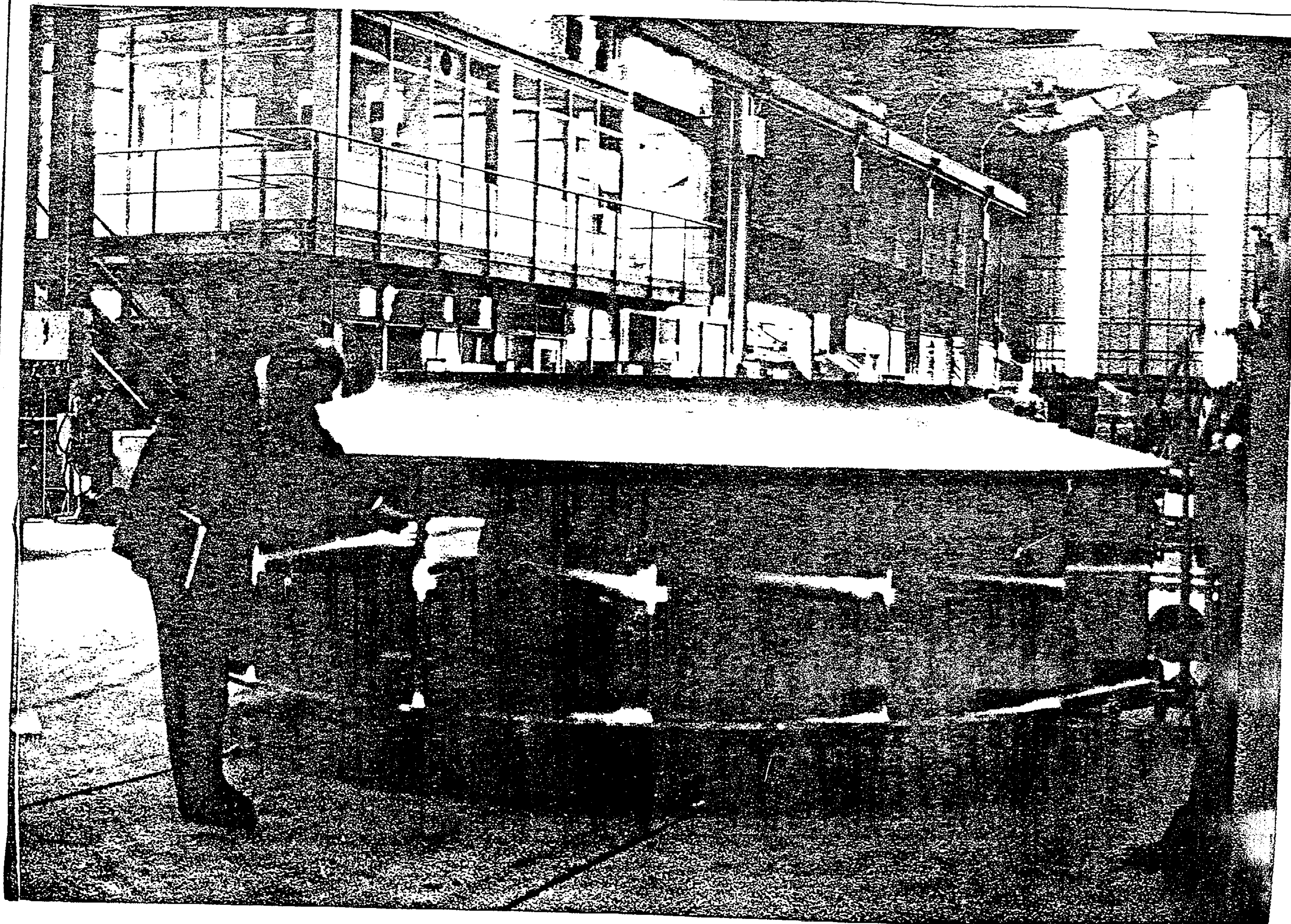


Figure 12: Photograph of UNIPEL Wheel, 14.4 ft Diameter (Duty Point Shown on Figure 17).

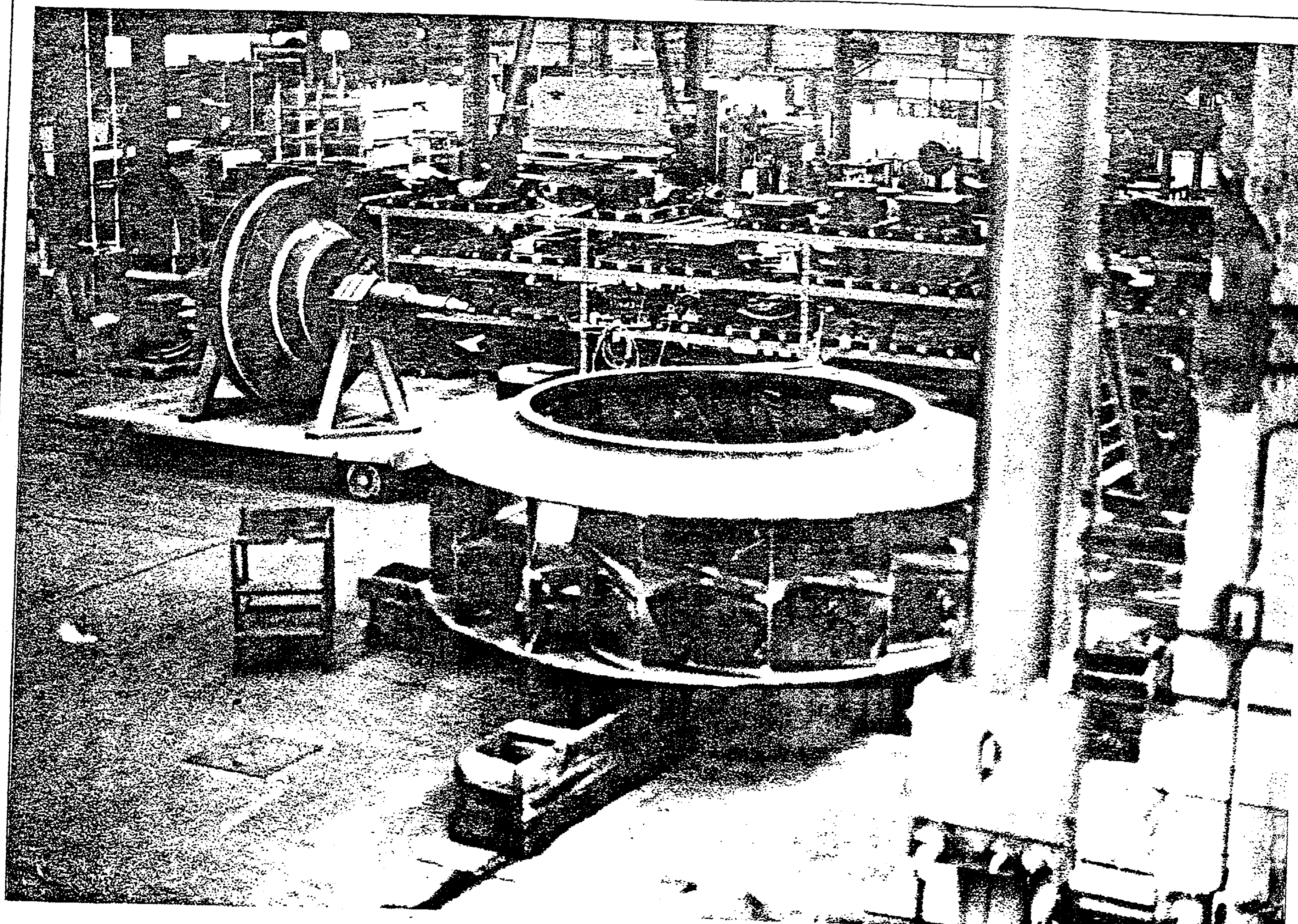


Figure 13: Overall Photograph of 17-ft Diameter UNIPEL Wheel

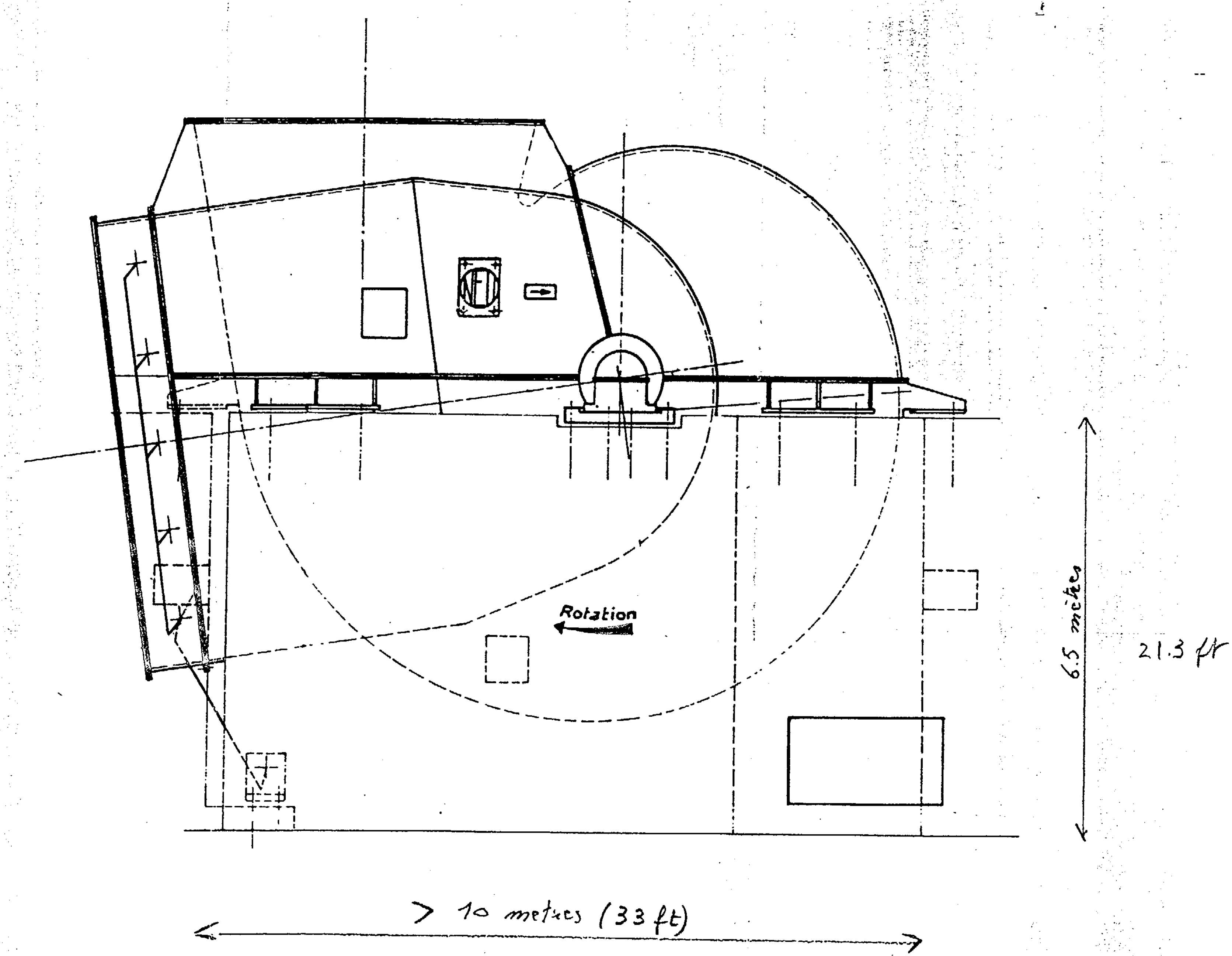
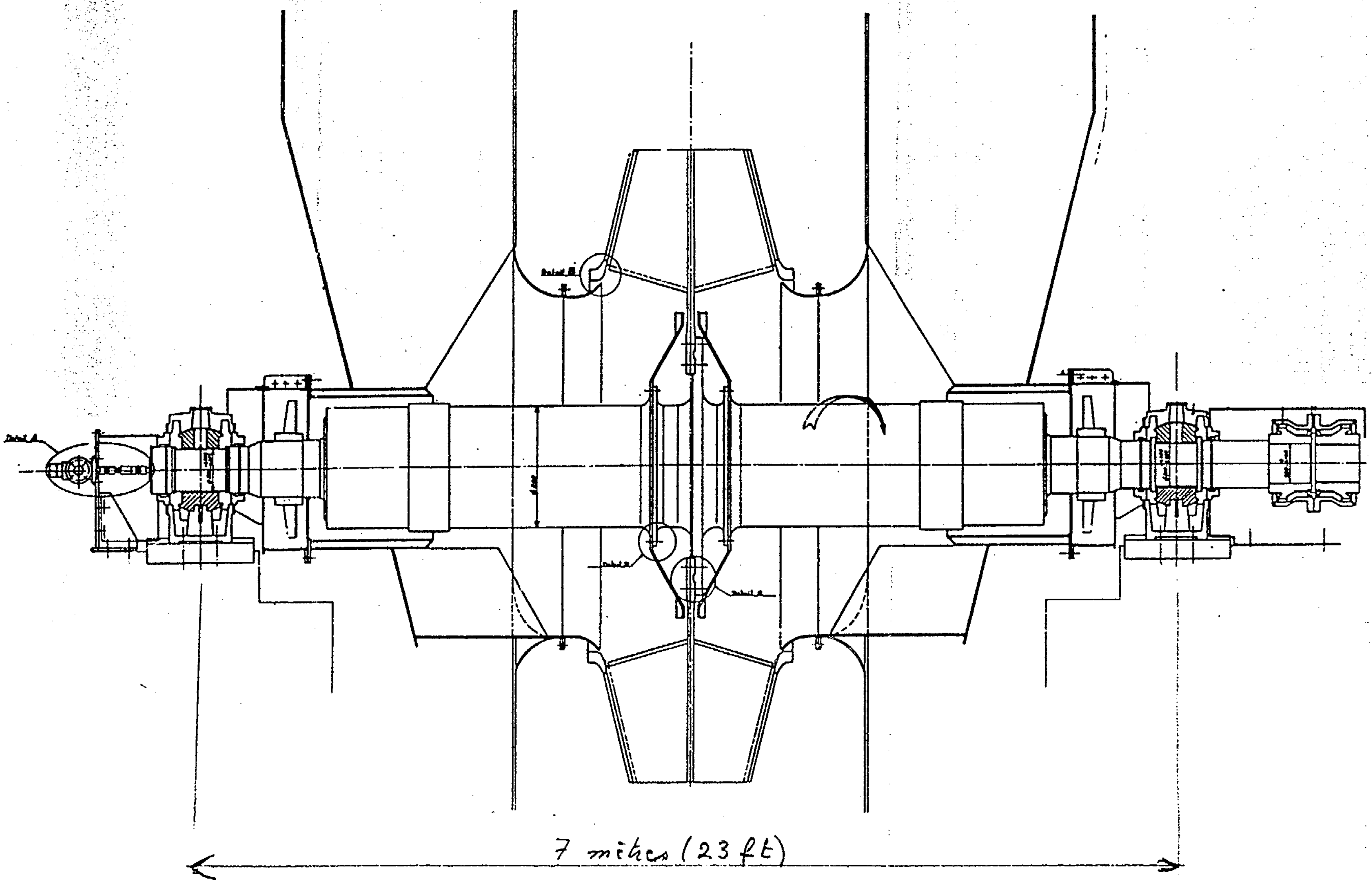


FIGURE 13 b: HOUSING FOR 14.4FT DIA. "UNIPEL" WHEEL

wheel D = 4.4m
= 14.4 ft

23 c



Bearing Dia ≈ 11 inches
Dia. ≈ 33 inches

FIGURE 13 c: FAN-WHEEL ASSEMBLY FOR "UNIPEL" WHEEL

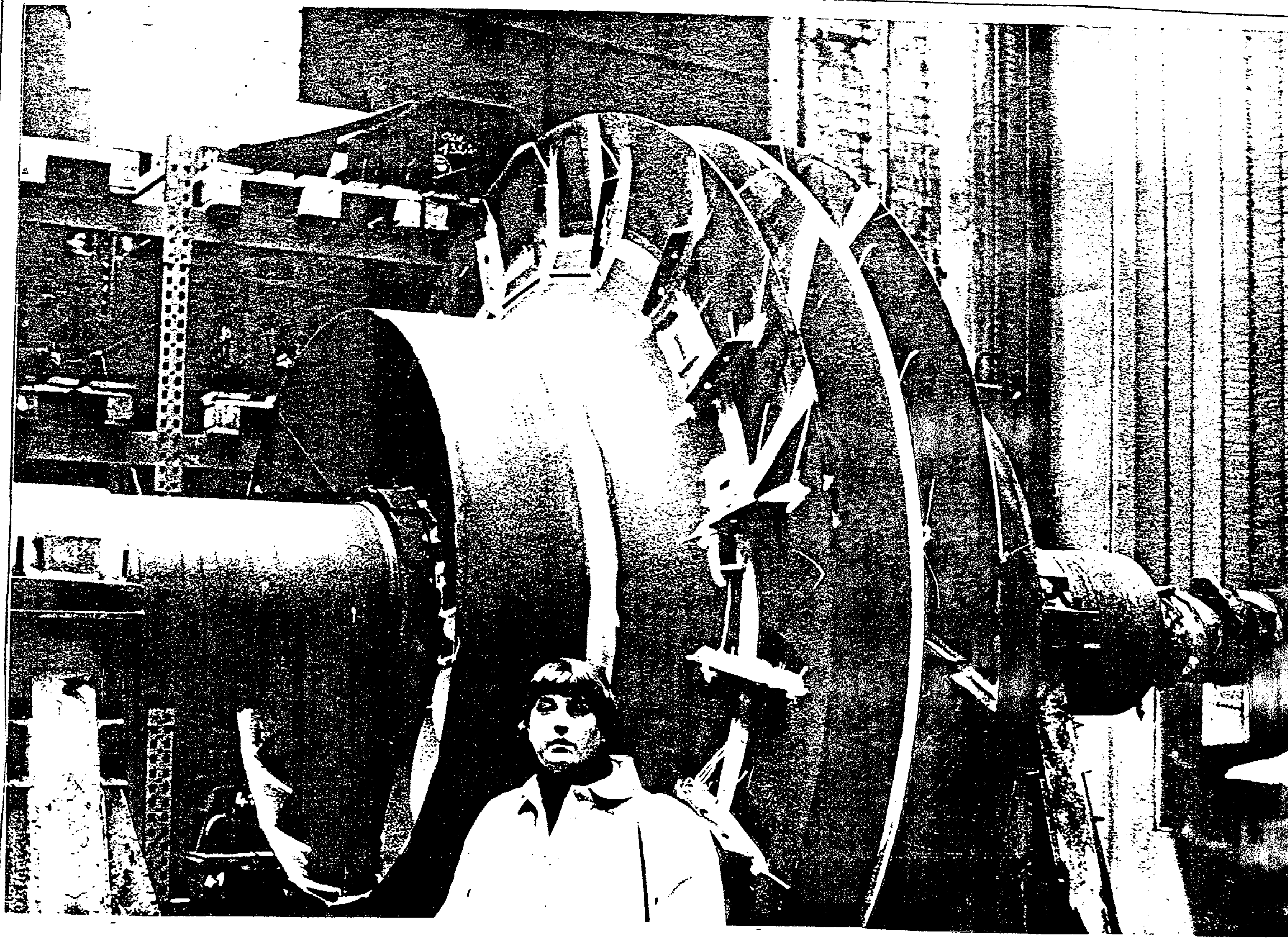


Figure 14: Photograph of RD Fan Wheel 200-.65-1.3 (No. 8 on Table III).

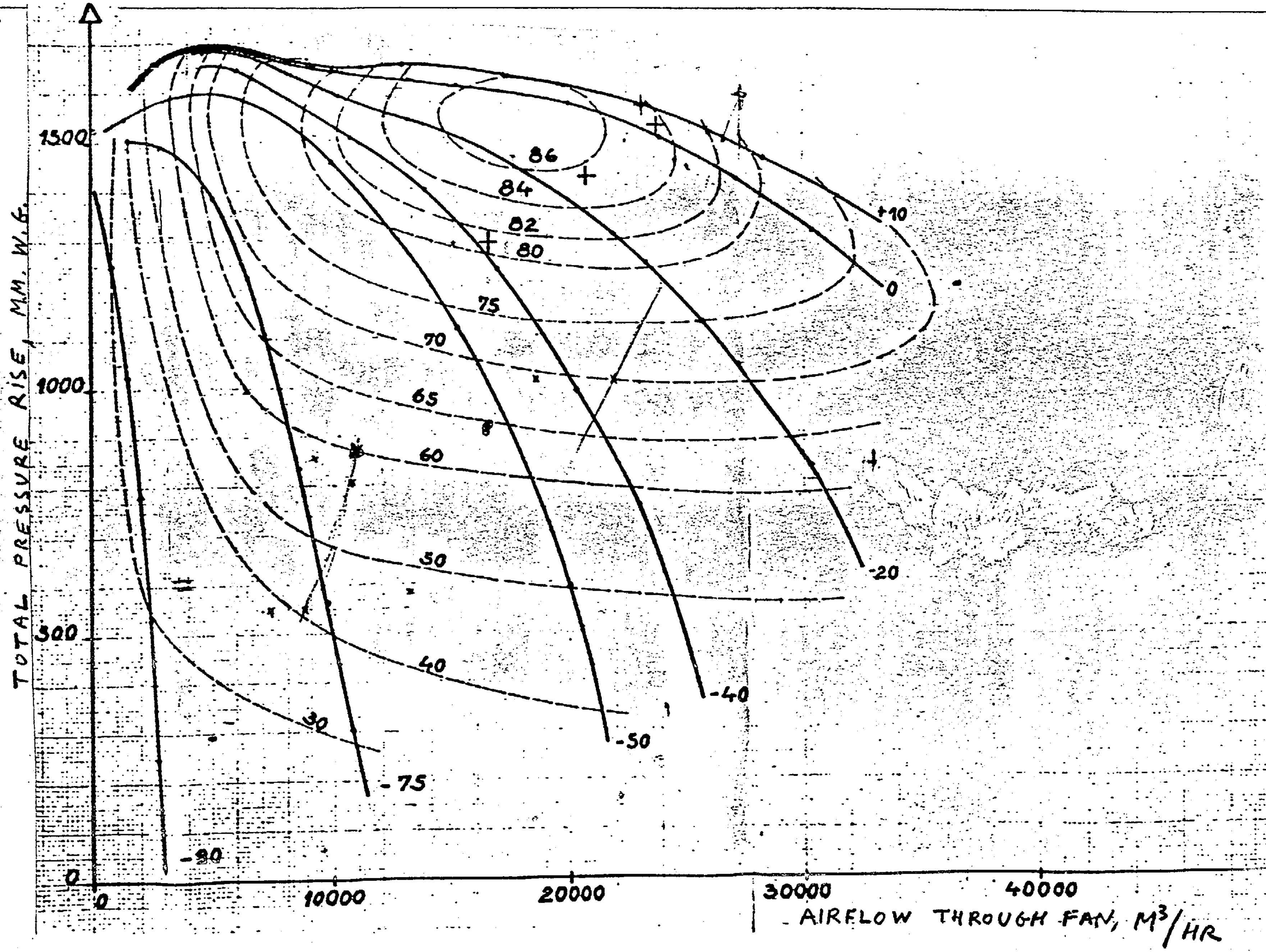


Figure 15: Full-Scale Performance of RD Fan 307-.55-1.3 (No. 12 on Table III, and Figures 7 to 9).

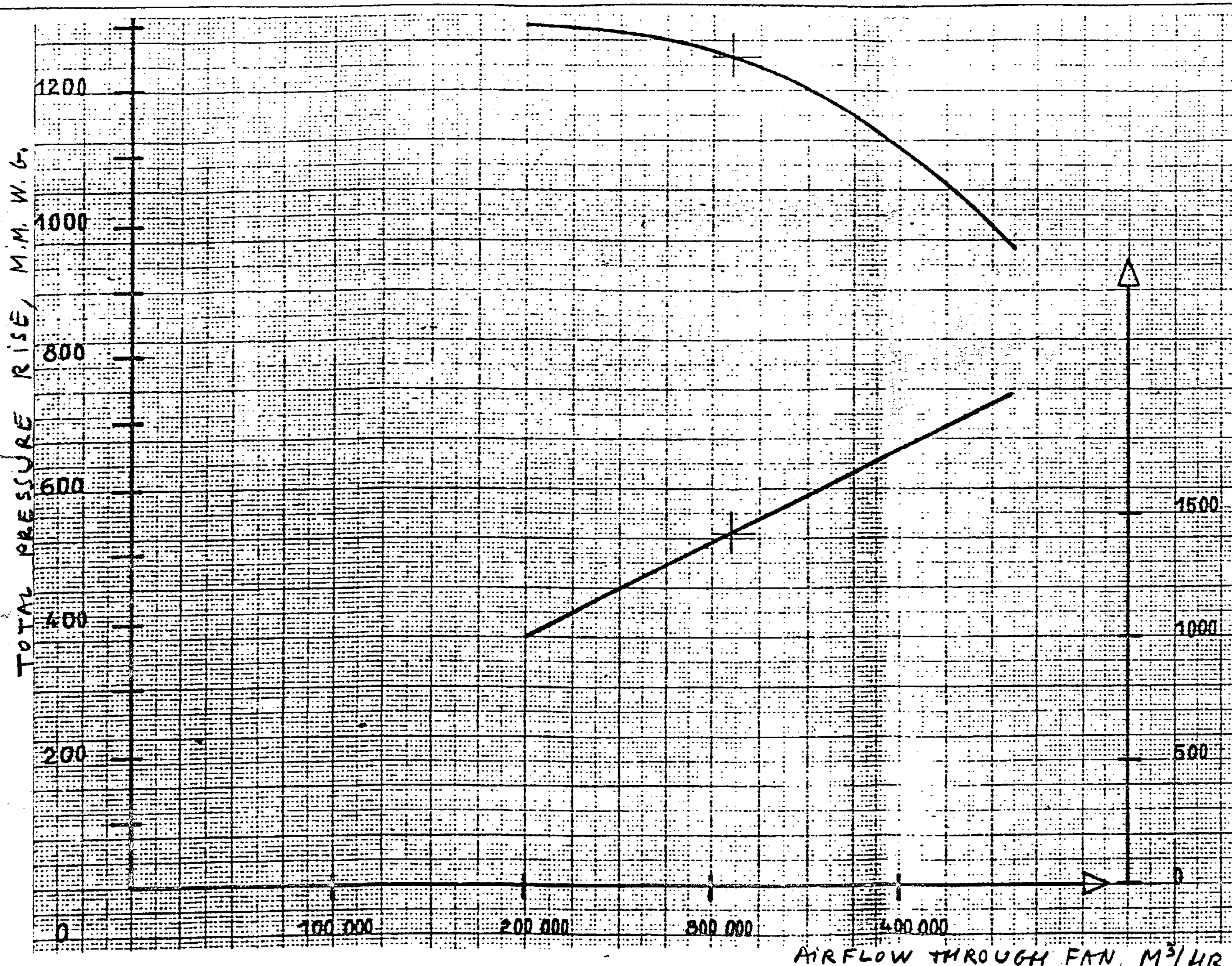


Figure 16: Full-Scale Performance of RD Fan 280-.46-1.2(S) (figure 11)

III. BROAD STATE-OF-THE-ART OF INDUSTRIAL RD FANS, INCLUDING LARGE FANS OPERATING AT HIGHER PRESSURES THAN THE MPS (15,000 TON) LIFT FAN range

As far as the design of the 15,000-ton SES fan is concerned (a fan that could meet the 10,000-ton requirement, but also a pressure rise of 150 IN. W.G., instead of 107 in. W.G. at a somewhat reduced flow) ~~requirement)~~, there are no fans in the steel industry that currently operate in that pressure ~~rise~~. The reason is not that ~~it~~ they cannot be built, but that the steel industry has no need for ~~a~~ heavy-duty fans requiring that much pressure rise. However, the chemical industry has needed higher pressures for a long time, usually with smaller airflows than those in the steel industry. Therefore, figure 17 was prepared. It shows a range of operational Neu fans, and includes ~~other~~ types other than heavy-duty steel fans, to show what has been built to date altogether. The following points relevant to figure ~~6~~ 17 can be made:

- There exists a number of RD fan installations, which have operated for a number of years, that <u>have higher pressure ratios than the 15,000-ton SES lift fan</u>:

  - Orenbourg, 23,000 cfm
  - Achères, 41,000 cfm
  - APC Rouen, 115,000 cfm
  - Prahovo, 150,000 cfm

Note that the Prahovo unit is a Single-Width-Single-Inlet (SWSI) fan, producing 150,000 cfm. All that is needed is to build the same unit as a Double Width-Double-Inlet (DWDI) fan, and the cfm will be 300,000 cfm, which is more than the required duty for the MPS 15,000-ton lift fan.

It may also be noted that technology of RD fans allows fabrication of wheels up to 4-meter diameter (the largest ones built to-day being Model 307). They were not built, because industry has had no need for it. What industry preferes to do is to put two fans in parallel, for a given duty, and <u>shut down</u> one fan when the plant is operating at reduced load. In addition, transportation and installation problems become more severe for fan sizes much above 3 meters in diameter.

The 1-meter RD fan wheel, which is a half-scale model of the full-scale MPS fan is shown on figure 18.

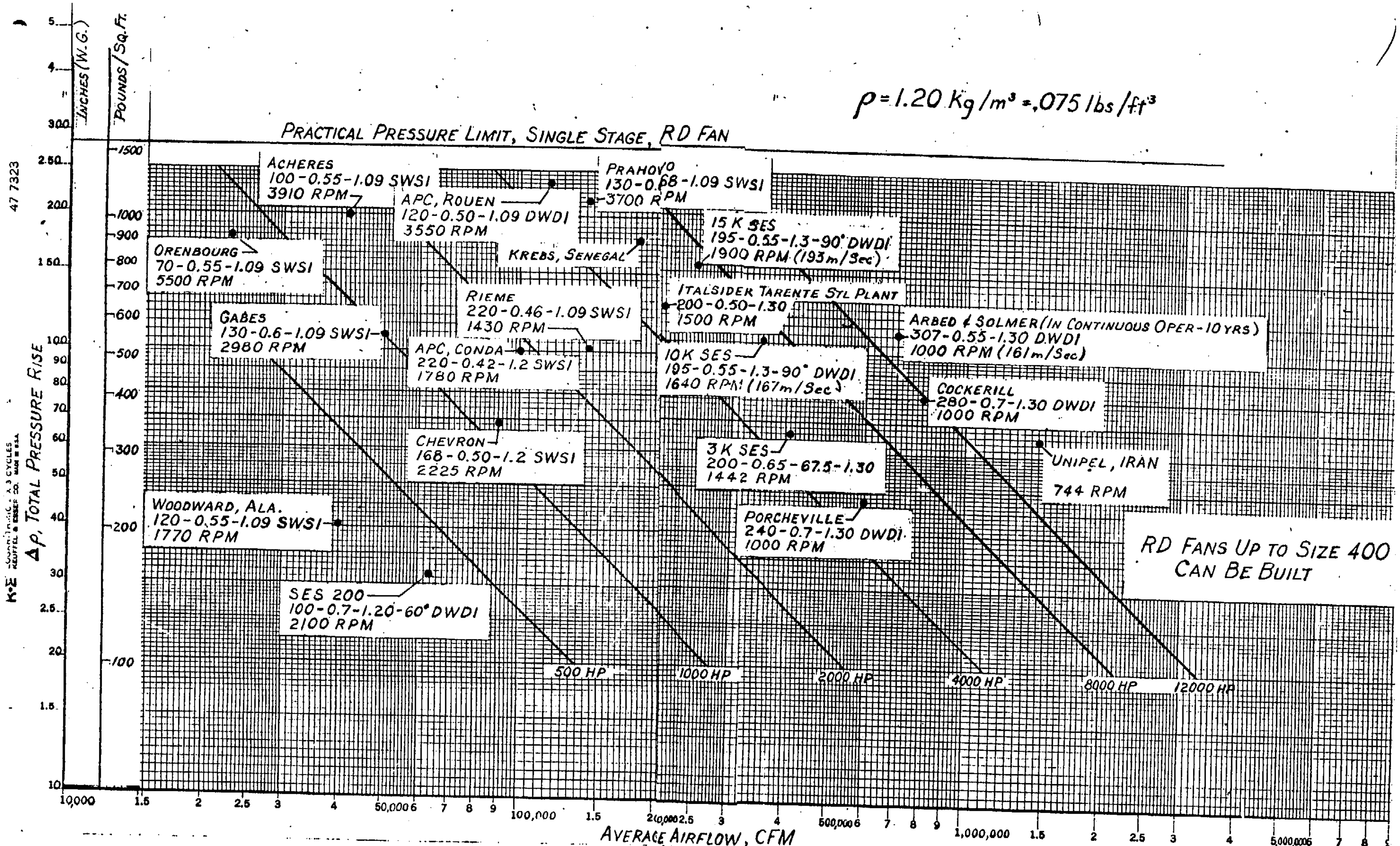


FIG 17— PRESSURE-FLOW DUTY POINTS OF TYPICAL INDUSTRIAL FANS (MOSTLY OF THE "RD" TYPE)

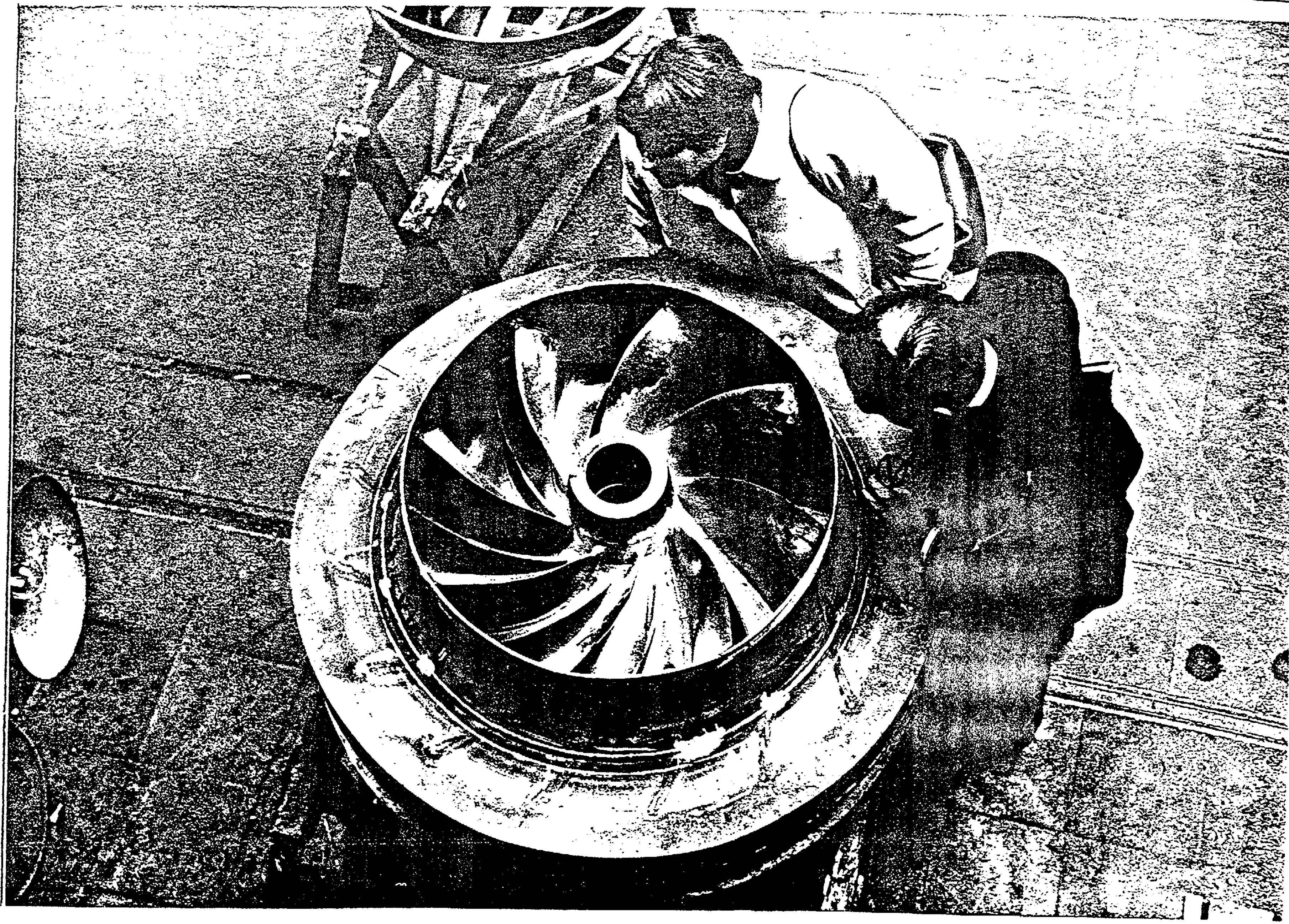


Figure 18: Photograph of RD Fan Wheel 100-.7-1.2 (Model Fan for MPS Lift Fan System) During Fabrication

IV VERY-HIGH-PRESSURE BLOWERS FOR FUTURE SES LIFT FAN APPLICATIONS

For planning purposes, the U.S. Navy is interested in cushion (and therefore fan) pressures much higher than those proposed for the MPS (for example, for catamaran SES configurations). A brief set of selection curves is shown on figure 19 to show the available range of Neu RD "blowers".

1.3

It is useful to mention here that, in standard rotating machinery terminology, pressure-rising equipment at low pressure ratios (between 1 and 1.2, *for example) is called "fans"; for intermediate pressure ratios (between 1.2 and 2) it is called "blowers". Above a pressure ratio of 2, it is called "compressors". Therefore, strictly speaking, the fans discussed in this report in connection with the MPS should be called blowers. However, the above definitions are rather loose, and it is felt that to introduce the name of "blower" for current SES lift fan applications could be confusing.

1.3

However, one is talking in this section of pressure ratios above 1.5. Therefore, it would be stretching the convention a little to call the equipment "fans". Also, to avoid the use of large numbers, it is conventional to express pressures in pounds per square inch, instead of pounds per square foot (1 pound per square inch equals 144 pounds per square foot).

About eight years ago, the decision was made by Neuair, Inc., a joint subsidiary of Aerophysics Company and of Ets. Neu, to sponsor the development of a family of modular blowers. Ten sizes were selected, with blade diameters between 55 cm (labelled "No. 55") and 120 cm. All wheels were of the RD type and were aerodynamically identical, with a proportion of 0.55 and a diffuser ratio of 1.09.

A summary chart of the pressure-flow characteristics of the 10-blower family is shown on figure 19. It can be seen that the family covers airflows between 10,000 and 100,000 cfm and pressures between 6 psig (about 900 pounds per square foot) and 11 psig (about 1600 psf). A manual is available from Aerophysics, showing the performance of each blower.

As an example, suppose that a blower is to be chosen to supply a total pressure rise of 1300 psf (about 9 psig) with a corresponding flow of 45,000 cfm. This is shown as point A on figure 19. Therefore, an RD blower No. 92 is chosen. In turn, the detailed performance of blower No. 92 is shown on figure 20. The general configuration of this blower is shown on figure 21. It can be seen that the No. 92 fan sized for the above duty rotates at 5440 rpm and absorbs approximately 2,250 Horsepower.

* ACCORDING TO "NORME" (STANDARD) E51 001.

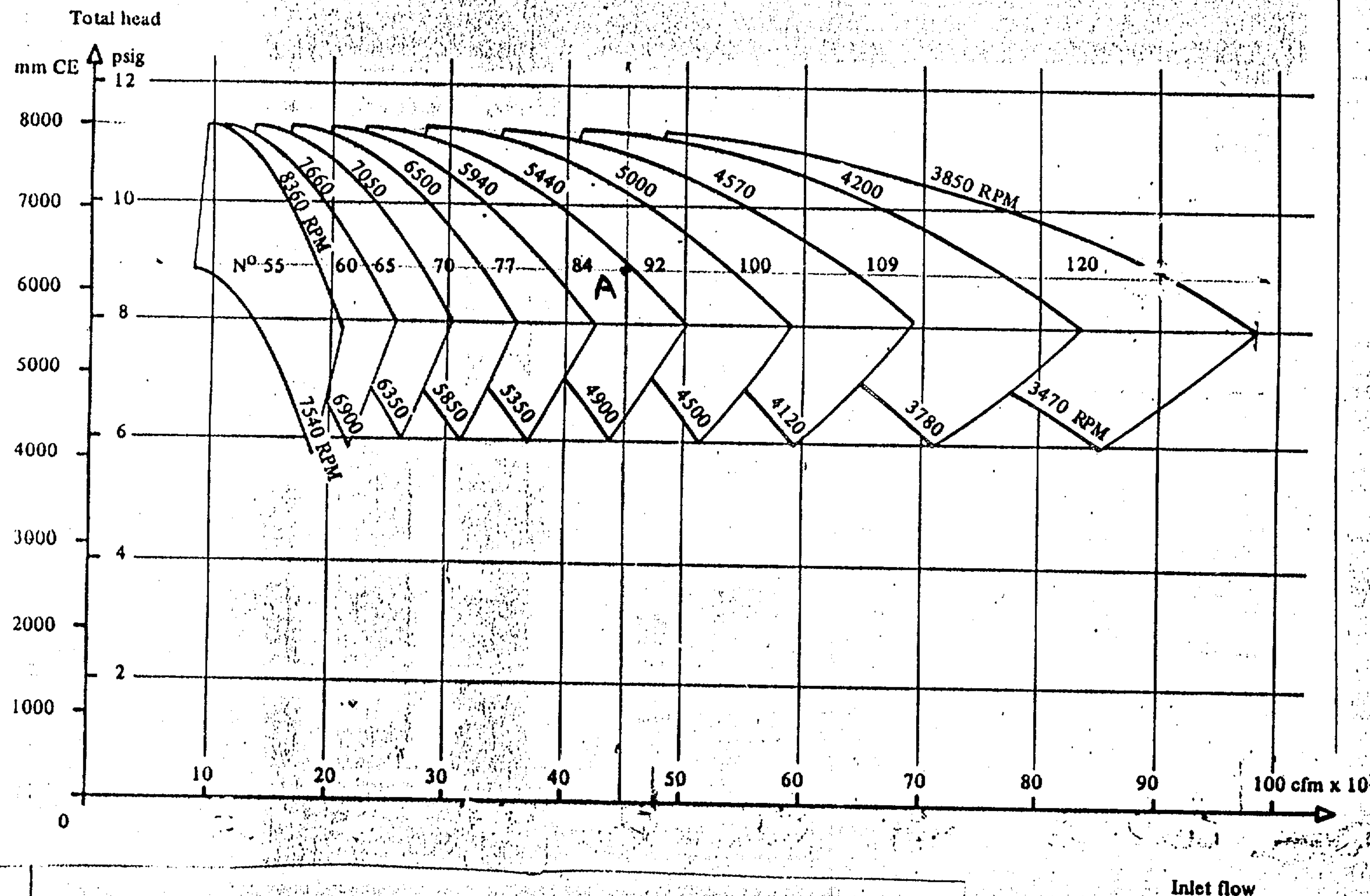
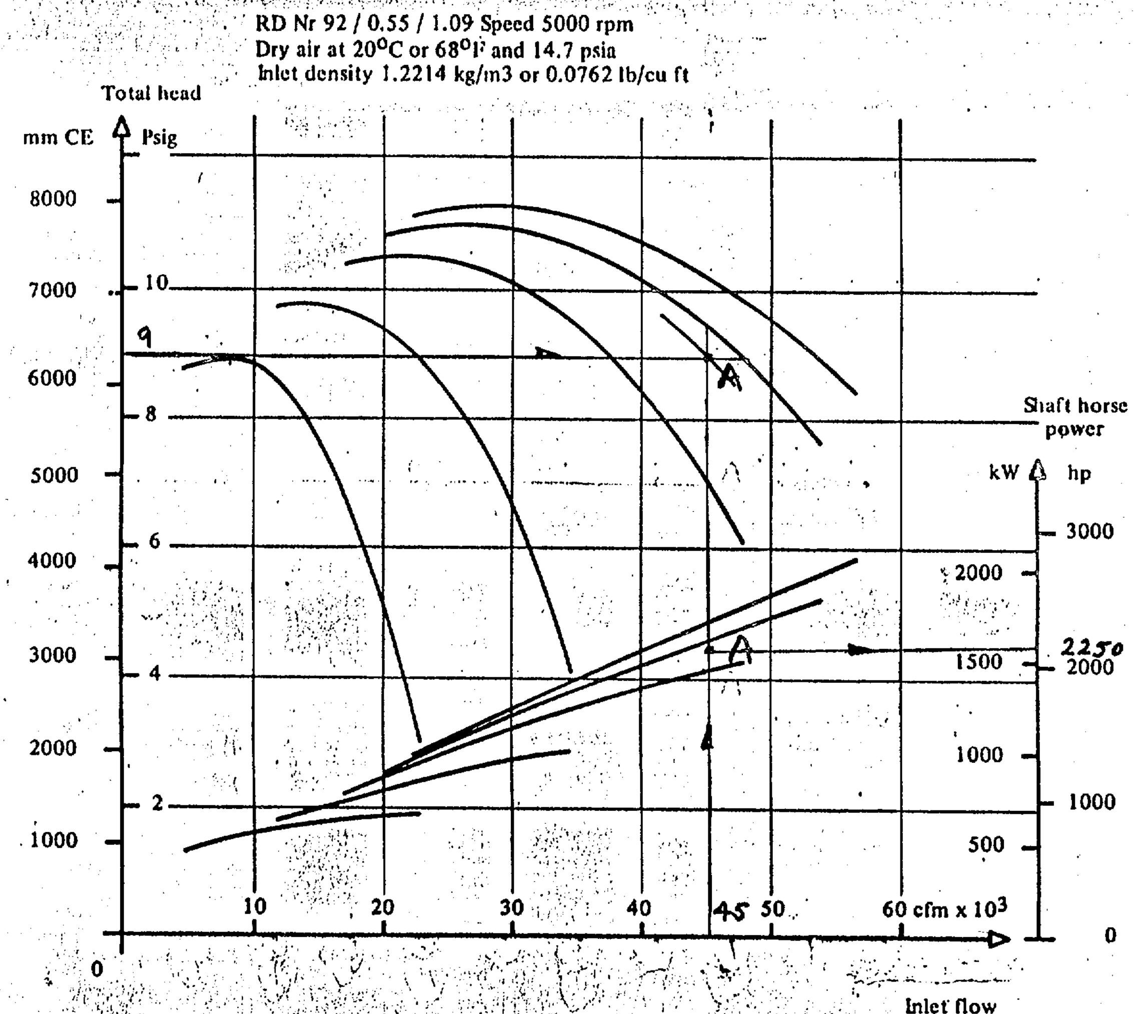


Figure 19: Selection Curves for High-Pressure RD Blowers for Future SES Lift Fan Applications



The R. D. N° 92 / 0.55 / 1.09 is one of the ten blower sizes making up the "Neuair L" family of standard single-type blowers.

The above curves give the maximum performance obtainable from this blower. Other operating points can be obtained by changing the angle of the inlet guide vanes or by reducing the speed.

Figure 20: Performance of RD No. 92-.55-1.09 Neuair Blower

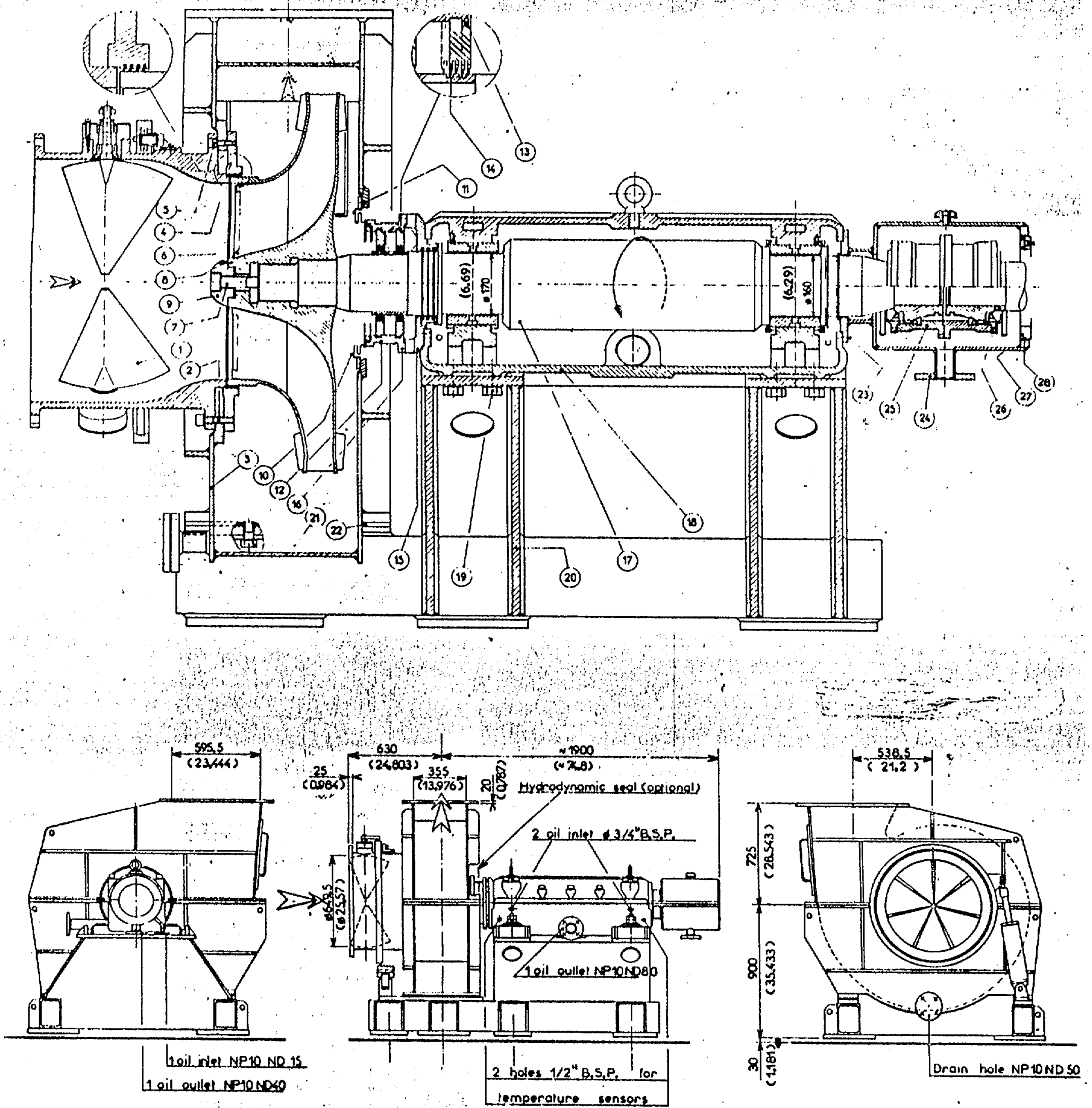


Figure 21: General Arrangement Drawing of Neuair Blower RD 92-.55-1.09

CONCLUSIONS

In the official Navy MPS report, the following statement is made:

" 4.4.6 Lift System Risk Assessment

Lift fans - No risk. Rotating Diffuser fans have been built for duty points that meet those required for the MPS. Successful fan operation has demonstrated their reliability "

It is believed that the information contained in this report fully documents the above claim. It is therefore sound to make development plans for large SES, assuming that the technology base for lift fans exists and is acceptable.