AEROSPACE RECOMMENDED PRACTICE

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TURBINE NOZZLE AREA MEASUREMENT BY WATER FLOW METHOD

1. PURPOSE

To provide a recommended practice to establish the system concept, interface adapter flange standard and procedure for determining turbine nozzle effective area by the water flow method.

2. SCOPE

2.1 This recommended practice covers the essential features of the water flow test stand concept, adaptation flange details, nozzle mounting fixtures and adapters, reference orifice plates, and procedure for determining nozzle effective area by the water flow method.

2.2 The water flow system measures the time (Te) required for a given turbine nozzle to pass a known volume of water through its nozzle area. The measured time is compared to the time (Ts) required for the same volume of water to pass through a calibrated orifice of known area (As). The calculation of the effective area is determined by converting the flow time data into effective nozzle area (Ae) after applying test stand correlation factor (K).

Example: $Ae = K \frac{As\ Ts}{Te}$

3. LIMITATIONS

3.1 The water flow method is essentially intended for measuring turbine nozzle areas up to approximately 200 sq in. (1290 cm^2). Experience indicates that it may not be practicable for measuring larger areas. Larger nozzle areas require larger water flows, and consequently larger storage tanks. In large tanks it is difficult to still the water. Swirls resulting from filling the tank may take hours to settle out - even with elaborate baffling. If stilling is not complete, repeatability of readings is impossible. Furthermore, large tanks can take a substantial amount of time to fill. Delays due to filling and stilling time can be the determining factor in the overall usefulness of the water flow systems. Because of these, and related problems, other techniques are being used to measure large nozzle areas, such as mechanical gaging.

3.2 Presently the largest nozzles which are known to be accurately measured by the water flow method are 94 sq in. (606 cm^2). The storage capacity of the tanks used to measure these nozzles is 1700 gallons (6435 l).

4. GENERAL REQUIREMENTS

4.1 Applicable Specifications and Standards: The following specifications and standards of the issue in effect on date of invitation for bids form a part of this recommended practice to the extent specified herein.

4.1.1 AMS 2469: Process and Performance requirements for hard coating treatment of aluminum alloys.

4.2 Materials and Workmanship:

4.2.1 Material: Material used in the fabrication of a water flow stand should be of the best commercial quality suitable for the purpose. All surfaces that are in contact with the water should be corrosion resistant. The adapters, because of their size, may be aluminum, but should be hard anodized per AMS 2469 or equivalent to prevent corrosion and general handling damage. Any burrs or evidence of corrosion should be removed as soon as noticed to enhance the concept of providing a smooth and continuous surface for water to flow over and prevent turbulence.

4.2.2 Cleanliness: Turbine nozzles should be cleaned before water flow testing. Water cleanliness should be maintained by periodic draining of all the water and cleaning residue from the tanks. Recommend that water be changed and tank wiped down every 2 to 4 weeks. Longer periods will permit scum to form and cause level sensing devices (float switches) to become sluggish and erratic. When new water is added, chemical additives may be added to inhibit algae growth and to increase the operating periods between cleaning. Sodium nitrite may also be added to reduce staining and corrosion.

5. SYSTEM REQUIREMENTS

5.1 Water Flow Stand Concept (See Fig. 1 for Schematic):

5.1.1 The stand shall be sized so that the minimum running time is at least ten seconds for any given turbine nozzle.

5.1.2 Height to diameter ratio approaches point of diminishing returns. Volume of water should be capable of flowing through the nozzle for at least 10 seconds so that accuracy of time readings below the $\pm$ 0.1 second level would not lead to measurement problems.

5.1.3 The repeatability of the system shall be $\pm$ 0.15% for any nozzle tested and should be determined by a minimum of three tests per nozzle. The correlation between stands shall not exceed $\pm$0.30%.

5.1.4 Provision should be made for suitable adapters and fixtures to permit testing a wide size range of nozzles on the same tank. See paragraph 5.2 for Standard Tank Flange Design.

5.1.5 The cleanliness of the water should be maintained by continuous filtering and by periodic flushing and draining of the entire system. See paragraph 4.2.2 for additional cleanliness requirements.

5.1.6 Baffles should be provided in the lower portion of the tank to prevent the formation of a vortex.

5.1.7 Provision for a "dwell" period should be made after water is pumped into the tank to eliminate "frothing" and still the water. The initial water level above the top level switch should repeatedly be the same and high enough to permit full opening of the bottom doors before the timer starts the count.

5.1.8 Provisions to control water temperature between 68° F and 80° F (20° C and 27° C) in order to insure re-
ø quirements specified in 5.1.3.

5.2 Standard Tank Adapter Flange Design:

5.2.1 The conical section of the head tank should be equipped with two standard mounting flanges. The upper mounting flange (See Fig. 3) should permit adaptation of nozzles up to 200 sq in. (1290 cm^2) in area with an outside diameter up to 35 in. (889 mm). A transition conical section should mate with the upper mounting flange and reduce down to the lower mounting flange (See Fig. 2).

The lower mounting flange should permit adaptation of nozzles up to 120 sq in. (774 cm^2) in area with an outside diameter up to 20 in. (508 mm).

5.2.2 Figures 2 and 3 provide dimensional details of the standard mounting flange configuration.

5.3 Nozzle Adapter and Fixture Design Considerations:

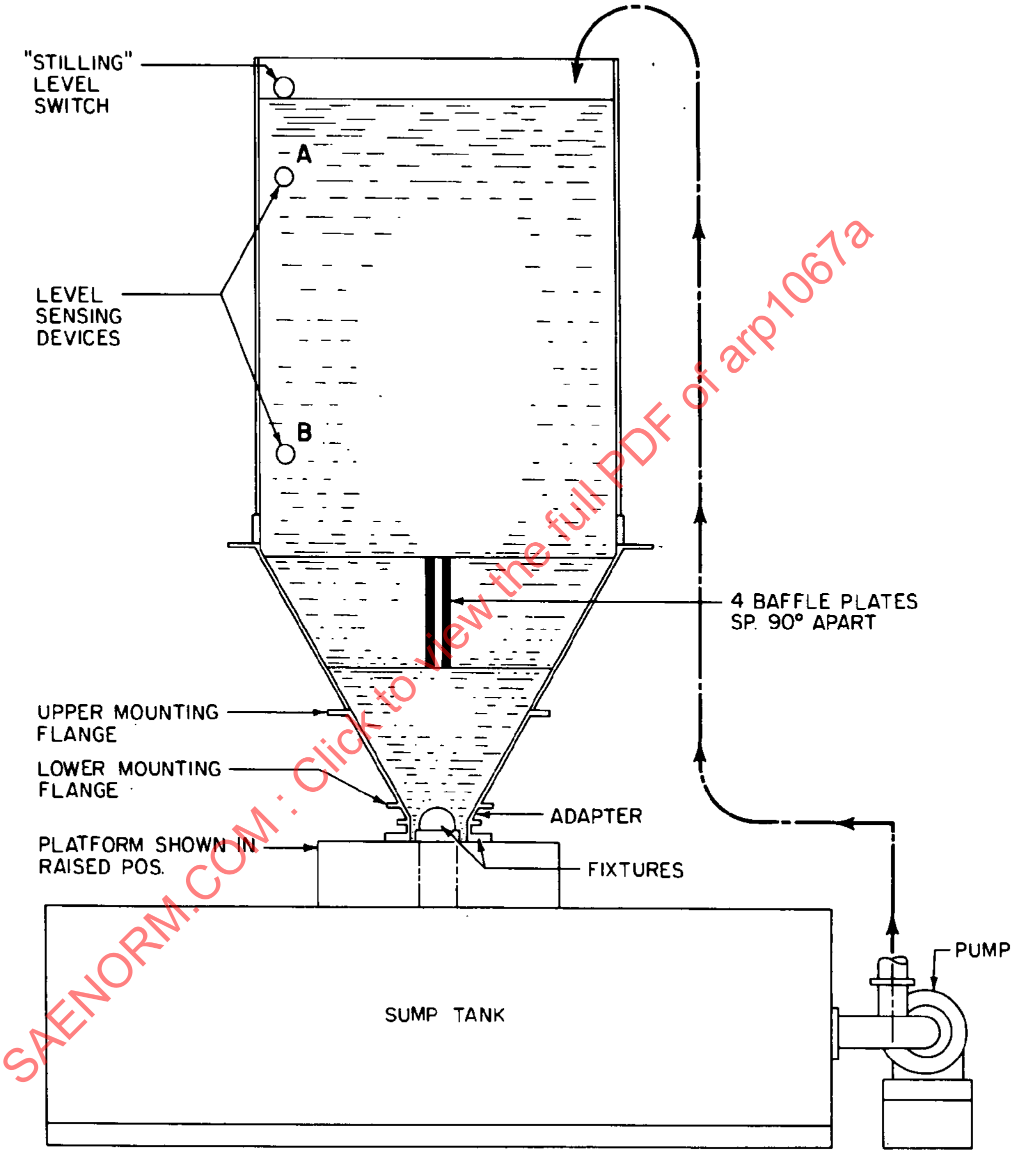


FIGURE 1 - WATER FLOW STAND CONCEPT

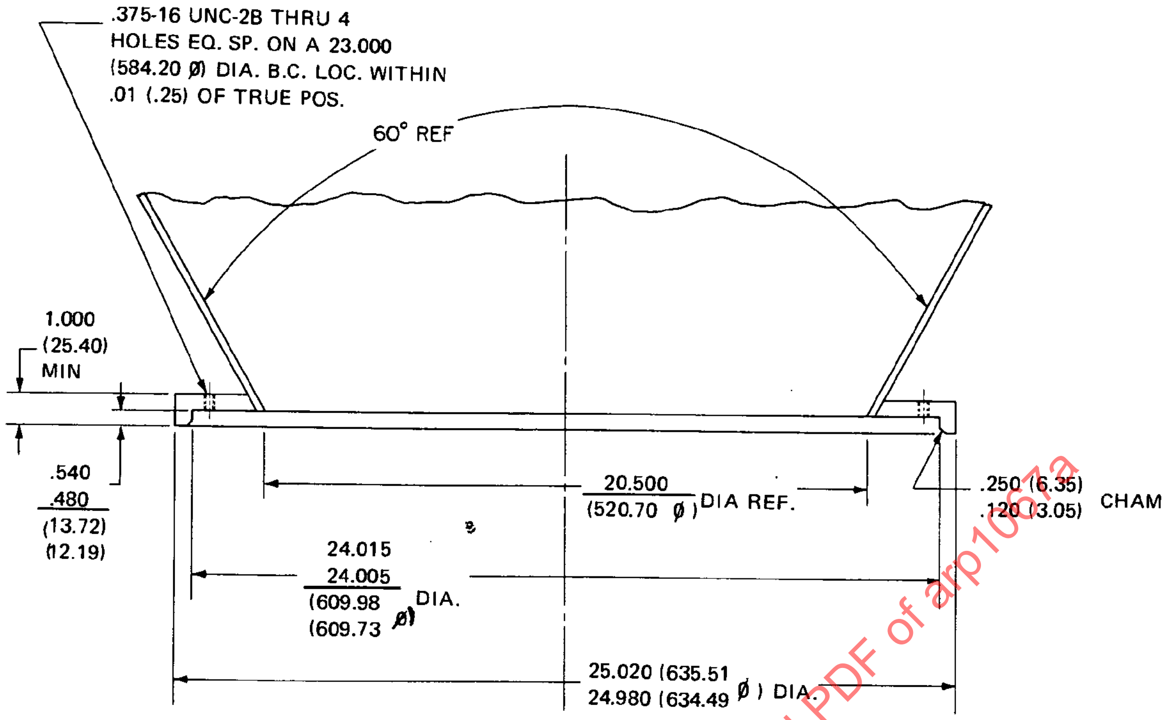


FIGURE 2 - LOWER MOUNTING FLANGE

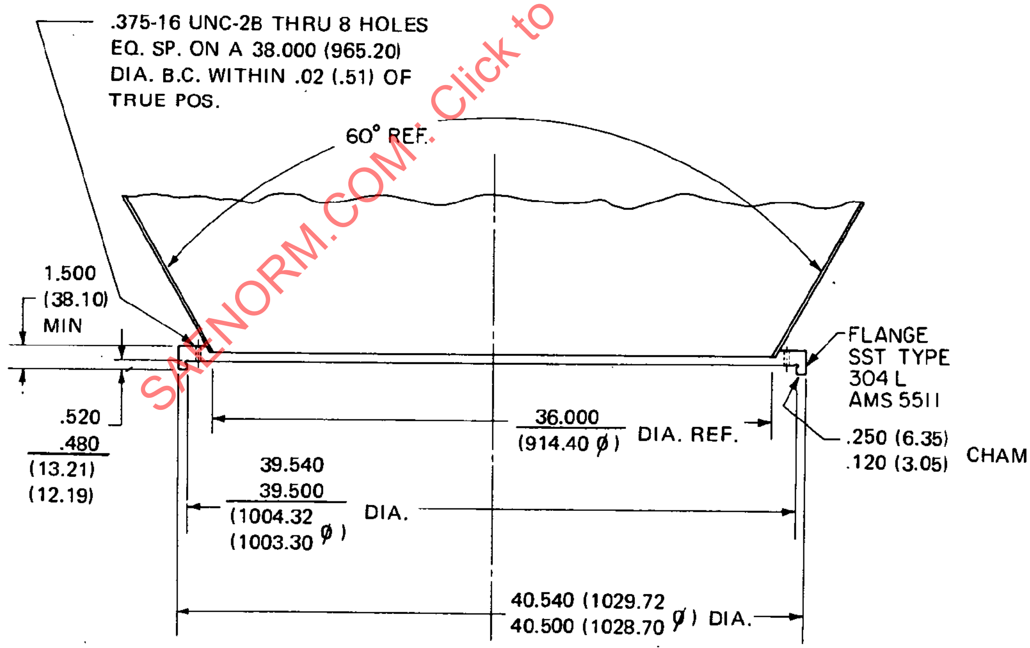


FIGURE 3 - UPPER MOUNTING FLANGE

NOTE: Dimensions shown in inches (millimetres).

5.3.1 The adapters and fixtures from the tank mounting flanges to the turbine nozzle should be designed so that the inlet surfaces are smooth and continuous. Fig. 4 depicts typical mounting arrangement for turbine nozzle and adapters.

5.3.1.1 If the included angle of the funnel shape is too large, the flowing water may create a vortex condition at the nozzle which will lengthen the time (Te) it takes for the head of water to flow thru the nozzle. This would result in an incorrect nozzle area calculation.

5.3.2 Fixture to hold the turbine nozzle may not permit its I.D. to protrude into the path of inlet or exit water thru the nozzle partition. This could cause a vortex condition at inlet and back pressure at the exit. Both conditions would lengthen (Te) and again calculates into an erroneous area.

5.3.3 Center of nozzle should be plugged by a dome (usually at inlet flow side) whose height to diameter ratio is taken care of by a spherical radius. This is further evidence that inlet water should flow over a smooth and continuous surface at all times.

5.3.4 The clamp plate that secures the dome to the nozzle should not protrude into the path of water. Turbulence and erroneous readings of (Te) would result.

5.3.5 For certain nozzles it may be necessary to control the lower adapter surface contour in order to obtain repeatable flow results. Contour variations below the lower lip of the outer band can cause flow time variations. The exit diameter of the lower fixture must be controlled so as not to prevent a free fall of water that has passed the trailing edges of the partitions in the nozzle.

5.3.6 The vertical distance from the nozzle trailing edge plane to the flow stand lower mounting flange surface should be called out as distance "Y". It is based on nozzle position in this fixture and once established should remain constant for a given turbine nozzle. Where the distance "Y" appears on a product drawing, it is a value established for a particular design stand used for the initial testing of the nozzle for determining flow characteristics (effective area). As stands vary in geometry, so must the "Y" value for any particular nozzle and must be determined by correlation studies with a known system.

5.3.7 In general, turbine nozzle sector areas should not be flow checked individually except where the flow capacity exceeds the capacity of the flow stand. Split nozzles should be flow checked assembled.

5.3.8 Provisions should be made for plugging all extraneous holes such as AIR impingement starter manifold, sawcuts, horizontal splits, torque pins and hollow nozzle partitions. The provisions need not consist of plugging each hole individually as long as the outer and inner flanges or bands are appropriately sealed. Plastic coated tape is adequate in most cases.

5.3.9 Design of each fixture or adapter should be such as to prevent water leakage at adapter and flange joints.

5.4 <u>Standard Orifice Plate Design</u>:

5.4.1 The critical dimensions and flow time of the standard orifice plates are defined in Fig. 6. The orifice plate should be assembled in the flow stand with surface "C" facing up. Vertical drop "X" shown on Fig. 5 once established should remain constant for a given orifice or test stand.

5.4.2 Orifice plate design should be such that it will fit into the same adapters used to test the turbine nozzle. See Fig. 5 for typical mounting arrangement.

Ø 5.5 <u>Level Sensing Devices</u>:

5.5.1 Ø Level sensing device A (Fig. 1) to be positioned to indicate flow time for largest orifice (part no. 02) specified as nominal flow time in Fig. 6.

An orifice correction factor (k_t) (par. 7.2.1) to be established for other orifice flow times to preclude resetting level sensing device.

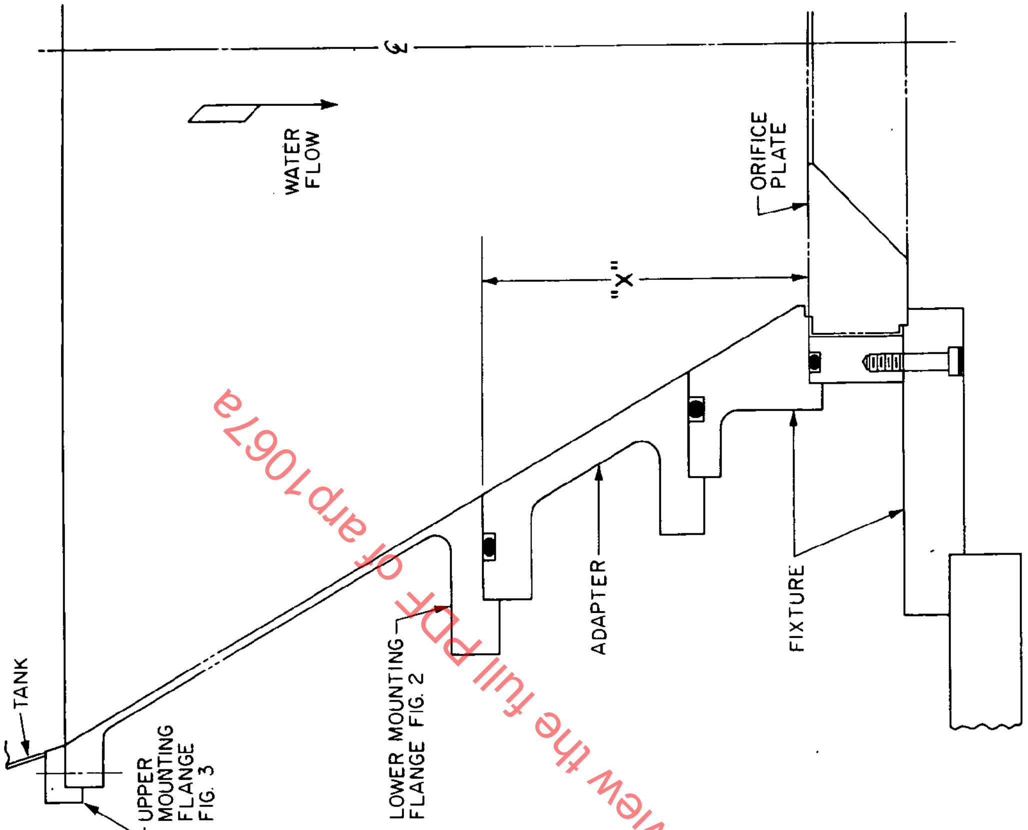


FIGURE 5 - ORIFICE PLATE MOUNTING ARRANGEMENT

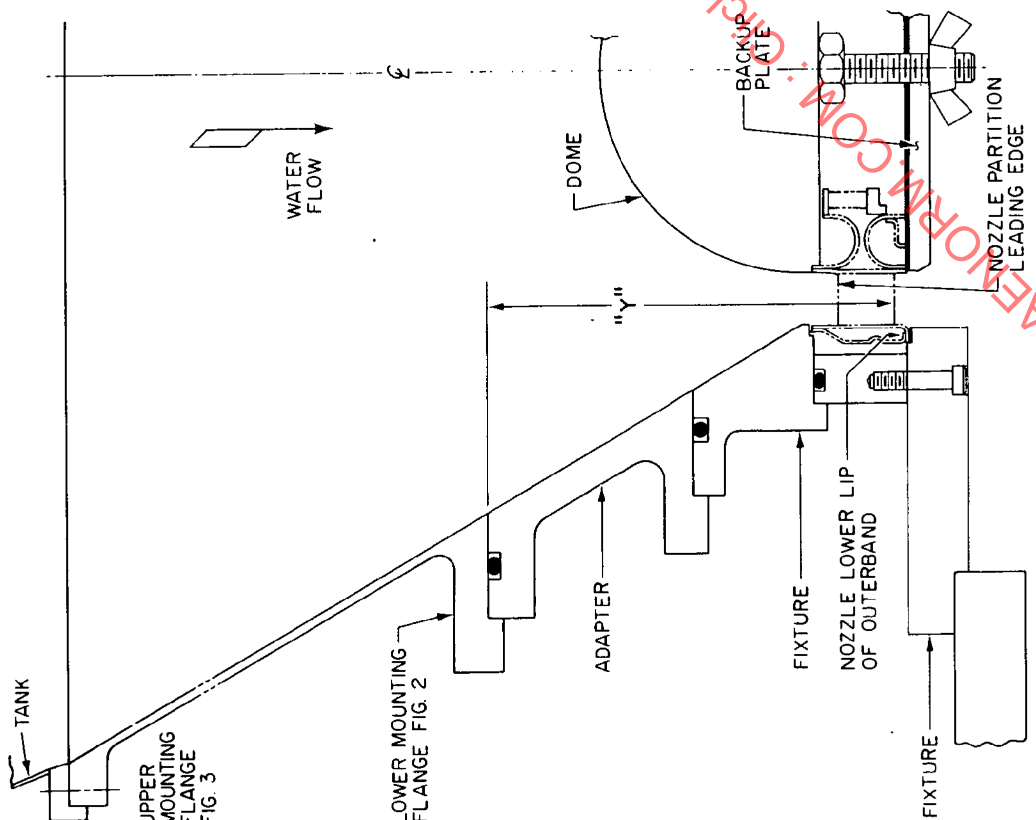
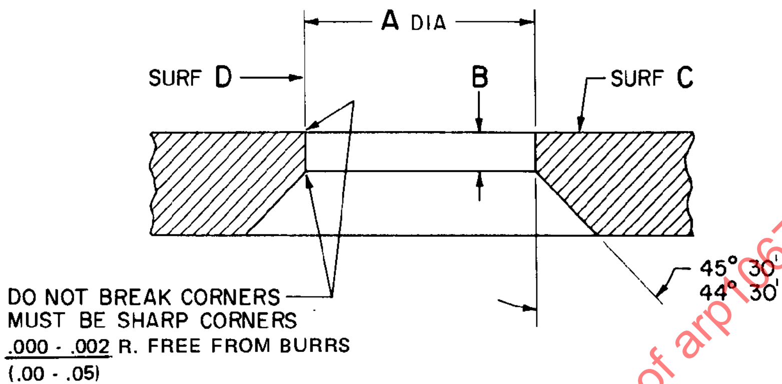


FIGURE 4 - TURBINE NOZZLE MOUNTING ARRANGEMENT



NOTES: 1. FINISH 16 ON SURF C & D
2. HARDNESS OF SURF C & D TO BE AT LEAST RC 45
3. OUT OF FLATNESS OF SURF C NOT TO EXCEED .003 (.08)

PART NO.	A ± .002 (.05)		B ± .005 (.13)		NOZZLE AREA RANGE		NOMINAL FLOW TIME T_s ± .15%
	Inches	Millimeters	Inches	Millimeters	Inches 2	Centimetres 2	
01	4.400	111.76	.096	2.44	0-50	0 - 322.5	119.0 sec
02	12.073	306.65	.160	4.06	50-100	322.5 - 645	15.7 sec
03	14.600	370.84	.200	5.08	100-150	645 - 967.5	—
04	15.500	393.70	.250	6.35	150-200	967.5 - 1290	—

FIGURE 6 - ORIFICE PLATE DESIGN CONFIGURATION

6. FLOW STAND OPERATING CYCLE

6.1 Seal off the nozzle openings and attach the dome and back-up plate. Position the nozzle assembly into the holding fixtures with partition leading edge facing "up". Place the adapter on top of the fixture.

6.2 The assembly is aligned under the tank mounting flange and raised into position.

6.3 The trap doors close.

6.4 The pump returns the sump water to the head tank.

6.5 The pump is shut off when a pre-determined level near the top is reached. (Approximately 12 in. (305 mm) above the top level sensing device A.)

6.6 After a dwell time, the trap door is opened and the outflow of water starts through the turbine nozzle (or orifice).

6.7 The water level drops past level sensing device A which starts the timer.

6.8 The timer is stopped after the water level drops past the second level sensing device B.

6.9 The cycle may be repeated before the assembly of adapter and fixture is lowered and the nozzle removed.

6.10 Calculations of effective nozzle area should be performed to 0.001 sq in. (.0064 cm^2) significance based on flow times recorded.

6.11 Turbine Area Measurement: The effective area of a turbine nozzle is defined as:

$$Ae = K \frac{As\ Ts}{Te}$$

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where:

Ae - effective area (inches squared or centimetres squared) of nozzle on test
K - test stand correlation factor
As - effective orifice area noted on drawing
Ts - flow time measured in the relevant flow stand through the standard orifice
Te - flow time measured in the relevant flow stand through the actual part being inspected.

6.12 Example of Flow Check Calculation:

$$Ae = K \frac{As\ Ts}{Te}$$

As = 9.512 sq in. (61.371 cm^2) corrected orifice area
Ts = 118.17 sec. (determined per paragraph 7.2)
Note: Average Ts obtained from a periodic check per paragraph 7.3 = 118.20 sec. 118.20 sec. is within 118.17 $\pm$ 0.15%,
ø use 118.17 in calculation.

Te readings: 46.592, 46.692, 46.461 sec. obtained in nozzle runs.

Average Te = 46.582 sec.

K = 1.0 (determined per paragraph 8.1.3)

$$Ae = 1.0 \frac{9.512 \times 118.17}{46.582} = 24.130 \text{ square inches.} \qquad \left(= 1.0 \frac{61.371 \times 118.17}{46.582} = 155.68\ cm^2 \right)$$

Drawings limit Ae = 23.37 - 24.09 sq in. (150.78 - 155.43 cm^2).

Part does not meet drawing limits - troubleshoot the stand or rework nozzle as required.

7. SYSTEM PROCEDURE

7.1 The effective area "As" is based on a knowledge of the desired flow time limits "Te", the effective area "Ae" and the flow time "Ts" achieved with the standard orifice plate. This constant would be the same regardless of where a part is flow checked. Fig. 7 depicts typical steps in determining "As" as a corrected orifice area.

7.1.1 The most important assumption necessary to water flow checking is that the ratio of incompressible to compressible flow coefficients be a constant for a fixed geometry. The system provides a measure of the incompressible nozzle effective area, while the compressible nozzle effective area is determined in the engine during operating conditions where the nozzle exit mach number may vary from 0.8 to 1.05.

7.2 Ø The value of "Ts" would be initially established by a minimum of 10 actual tests of the orifice plate. The average of these tests defines the nominal value of "Ts" which will be used to calculate effective nozzle area. The average value of "Ts" is to be adjusted to the flow time specified as nominal in Fig. 6 table by the application of an orifice correction factor (k_t). It would be adjusted only as specified in paragraph 7.3.

7.2.1 The k_t factor for correcting "Ts" is determined as follows:

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$$k_t = \frac{\text{Nominal Flow Time } T_s \text{ (Table 6)}}{\text{Average Time } T_s \text{ (Par. 7.2)}}$$

7.3 The value of "Ts" should be checked periodically. An average of 3 successive flow times may be used. The allowable variation is ± 0.15% about the nominal determined in 7.2. When "Ts" exceeds these limits, and a trend is indicated, a new nominal may be established with prior approval of purchaser. A new nominal may also be established if adjustments to the level sensing device fail to return the Ts to its original value.

7.4 The Te value obtained from the test nozzle may be a single run or it may consist of the average of up to five runs. A single run is permissible if the maximum variation of a group of five readings is less than 0.10% of the full reading.

7.5 After turbine nozzle effective area has been established, add the effective orifice area (As), orifice plate size and "Y" dimension to turbine nozzle drawing for control of system. "Y" dimensions not only vary for each nozzle design, but they also vary with each flow stand design.

7.6 When water flow parameters have been established for a particular nozzle, it constitutes a system consisting of:

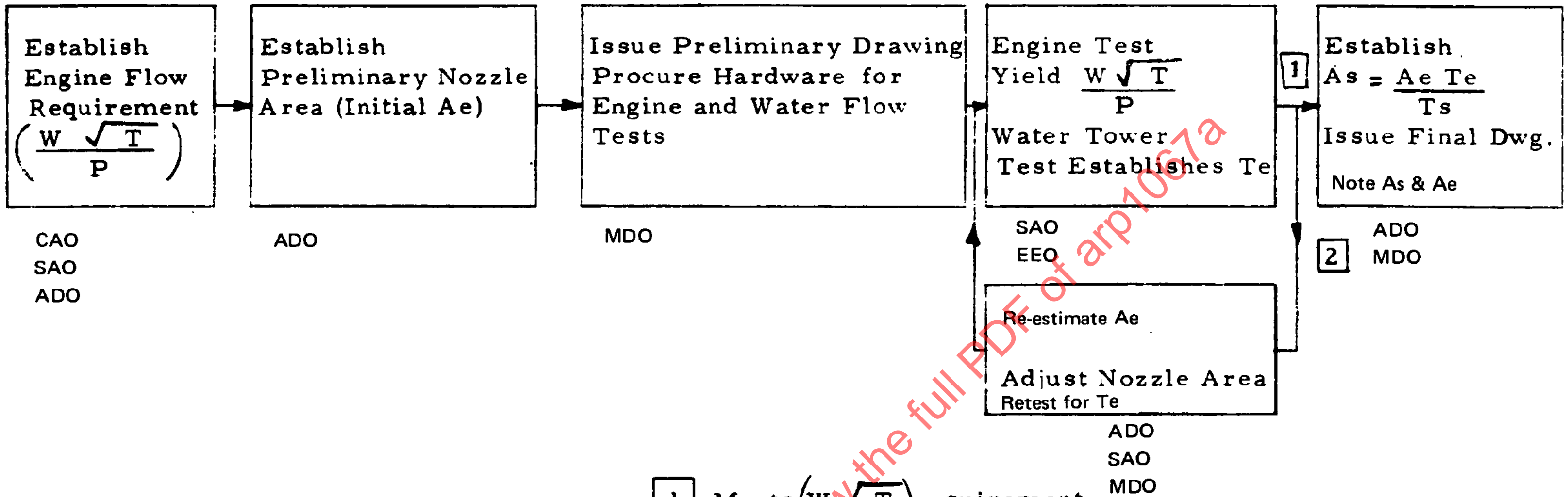
(a) stand geometry
(b) orifice (including "X" dimension)
(c) fixtures (including dome and "Y" dimension)
(d) gasketry and design features to minimize secondary leakage

Changes in the parameters will result in changes in flow time Te. For repeatability in any one stand, or correlation between stands, conditions must remain the same or compatible.

7.6.1 For any stand, the orifice plate reading is the best measure of the repeatability of the stand itself.

7.6.2 For any nozzle with its fixturing and gasketry, etc, a master nozzle with known area can be used to check out the entire system on a periodical basis.

7.6.3 Ø A master nozzle is one that has nominal area as determined or selected by Prime Contractors Quality Control Engineering. A master nozzle of the size and type being checked must be available at each test stand.



$\boxed{1}$ Meets $\left(\frac{W\sqrt{T}}{P}\right)$ requirement

$\boxed{2}$ Does not meet $\left(\frac{W\sqrt{T}}{P}\right)$ requirement

Adjust Ae

Typical flow chart to define manner in which a nozzle is flow area-sized.

FIGURE 7 - FLOW CHART

TYPICAL ORGANIZATION RESPONSIBILITY CODE:

ADO - Aerodynamic Design Operation
MDO - Mechanical Design Operation
SAO - Systems Analysis Operation
CAO - Cycles Analysis Operation
EEO - Evaluation Engineering Operation