AEROSPACE RECOMMENDED PRACTICE

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ARP 588A

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STATIC BALANCING EQUIPMENT FOR JET ENGINE COMPONENTS COMPRESSOR AND TURBINE - ROTATING TYPE FOR MEASURING UNBALANCE IN ONE TRANSVERSE PLANE

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1. PURPOSE

1.1 This Aerospace Recommended Practice (ARP) delineates the technical specifications for rotating type of static balancing equipment for measuring the amount and angle of unbalance correction required in any transverse plane to balance jet engine components. (For Glossary of Terms and Nomenclature, see Appendix A. 1)

1.2 This document also delineates performance tests to be used to ensure compliance with this document.

1.3 This document was prepared to give a general description of equipment which will be capable of balancing all jet engine compressor and turbine rotor components either now in service or to be put into service in the foreseeable future. This will enable both engine and balancing equipment manufacturers to standardize, avoiding the need for separate tooling to adapt a particular component to a variety of machines in one capacity range. It can also be used as a general specification for purchasers in procuring suitable balancing machines for this type of work.

1.4 To make this ARP sufficiently flexible so that it can be adapted to other applications requiring various size components to be balanced by the accessory and missile industries where a wide range of balancing tolerances are specified, it has been written in terms of A units rather than fixed physical values such as ounces, ounce-inches or microinches.

2. SCOPE

This ARP specifies those requirements of balancing equipment which make it suitable for the subject class of work.

It specifies:

a. Sensitivity
b. Accuracy of indication of amount and angle of unbalance.
c. Ability to measure static unbalance unaffected by couple unbalance.
d. Machine capacity relating to weight and physical dimensions of the rotors which can be balanced.
e. Balancing speed of rotation.
f. Standard balancing machine drive adapter flange dimensions.
g. Power requirements.

3. REQUIREMENTS

3.1 Static and Couple Unbalance Separation:

3.1.1 The balancing machine shall read out the amount and angular location of the static unbalance unaffected by couple unbalance, for any selected correction plane in the proving rotor.

3.1.2 The balancing machine shall indicate less than 2A units unbalance in the static correction plane of the proving rotor when 40A units of unbalance (static test weights) are added in the couple test planes of the proving rotor. (Test of 4.4)

3.2 Amount Indication:

3.2.1 All analogue types of amount of unbalance readout devices shall have at least 1/8 in. displacement for measurement of one A unit of unbalance over a range of 20A. (Test of 4.3.6)

3.2.2 For any amount of unbalance less than 5A, the unbalance measuring device shall deviate by less than 0.25A from the actual amount of unbalance in the proving rotor. (Test 1 of 4.3.5)

3.2.3 For all unbalances above 5A, readout amount shall not deviate more than 5% from the applied unbalance. (Test of 4.5.1)

3.2.4 The unbalance measuring range shall extend to at least 50A. (Test of 4.5.1)

3.2.5 If the indicated unbalance is less than one A, successive application of the indicated corrections shall not result in a new indicated unbalance greater than one A. (Test of 4.3.3)

3.2.6 Indicated static unbalance linearity shall be within 5% of the applied static unbalance for the applied unbalances of 40A, 20A and 10A. For an applied static unbalance of 2.5A, the indicated static unbalance shall be between 2.25A and 2.75A. (Test of 4.8)

3.2.7 A proving rotor corrected for unbalance until the amount of unbalance indicator shows a minimum reading shall not have an unbalance greater than 0.5A. (Test 2 of 4.3.5)

3.3 Correction Indication:

3.3.1 The machine shall read out the angle of unbalance where addition or removal of material is necessary to balance the rotor. (Test of 4.6.2)

3.3.2 The machine shall indicate the angle of unbalance in any plane of the proving rotor to such accuracy that for actual unbalance conditions up to 5A units only a single correction is required. When the indicated amount of correction is applied at the indicated angle of unbalance in any correction plane, the machine shall indicate that such single correction has been effective by indicating a residual unbalance amount of less than one A. (Test 1 of 4.3.5)

3.3.3 For applied unbalance conditions in the proving rotor of any value from 5A to 40A, the machine indications shall be of such accuracy that when the indicated correction is made the resulting unbalance shall not exceed 10% of the original applied unbalance. (Tests of 4.5.1 and 4.6.2)

3.4 Practical Correction Units: The balancing machine shall provide unbalance amount readout in terms of the correction units actually used, number of weights, number of washers, etc., within the requirements of 3.2 and 3.3, subject to the interpretation by the testing procedure of 4.2.2 (Tests of 4.3.2, 4.5.1 and tests for 3.2 and 3.3). Because of the many different types of readout devices, it is considered impractical to write a specific testing procedure to satisfy 3.4 for all machines. However, it is necessary that the balancing equipment manufacturer demonstrate to the purchaser that his equipment will readout in the terms of correction units actually used, such as number of weights, number of washers, etc. At the same time, the readout shall retain the requirements of 3.2.1 and the sensitivity required in other portions of this document.

3.5 Drive for Workpiece:

3.5.1 The maximum unbalance disturbance of the drive system shall not exceed 0.5A units. Correction means shall be provided in order to make subsequent unbalance adjustments which may be necessitated by wear or abuse. The drive system includes all components necessary to drive the proving rotor. (Test of 4.7.3)

3.5.2 All drive flanges shall conform to drawing specified in 3.8.6.

3.5.3 The direction of rotation shall be counterclockwise when viewed from the drive adapter flange toward the workpiece.

3.6 Speed of Rotation During Balancing: The machine shall be capable of operating at a speed of 900 rpm or more.

3.7 Driving Motor and Control: Refer to details of contractual negotiations, Appendix A.2.

3.7.1 The minimum motor horsepower shall be as shown in 3.8.10 and Note C.

3.7.2 The machine shall be capable of making repeated starts to full speed and stops with the maximum weight proving rotor for one hr in accordance with the test of 4.7.1, during which time a minimum of 30 recorded cycles must be completed.

3.8 General Dimensional and Capacity Requirements: The general requirements for each class of machine are listed in 3.8.1 through 3.8.10.

Characteristic		25 lb Machine	100 lb Machine	250 lb Machine	500 lb Machine
3.8.1	Capacity designation	25 lb Machine	100 lb Machine	250 lb Machine	500 lb Machine
3.8.2	Minimum load - lb (See Note A)	1	2	10	20
3.8.3	Maximum load - lb (See Notes A & B)	25	100	250	500
3.8.4	Maximum height of load c.g. above machine spindle - inch	5	5	10	10
3.8.5	Maximum diameter of rotor - inch	24	43	60	57
3.8.6	Drive adapter flange	Fig. 1 Table A	Fig. 1 Table A	Fig. 1 Table B	Fig. 1 Table B
3.8.7	Proving Rotor	Fig. 2	Fig. 2	Fig. 3	Fig. 3
3.8.8	One A unit (See A.1.9) - microinch	50	50	50	50
3.8.9	Minimum balancing speed - rpm	900	900	900	900
3.8.10	Minimum horsepower at minimum balancing speed (See Note C)	3/4	5	7.5	10*

Note A - Load consists of combined weights of workpiece and any adapters necessary to attach workpiece to machine's adapter flange, as specified in 3.8.6.

Note B - Overloading of balancing machines beyond limits specified for the particular class of machine is not recommended unless such action is approved by the particular balancing machine manufacturer.

Note C - Horsepower at higher speeds, N, if used shall be $\left[\frac{N}{900}\right]^2$ x (tabulated value of 3.8.10).

4. TEST REQUIREMENTS

4.1 Proving Rotors:

4.1.1 Each class of balancing machine shall be tested with its appropriate SAE proving rotor as specified in 3.8.7.

4.1.2 All SAE proving rotors shall be composed of the following units complete to SAE drawings and specifications:

a. Proving rotor
b. Test weights as defined in 4.1.5 and Fig. 4
c. Proving rotor shipping container

4.1.3 All SAE test weights shall conform to the unbalance test unit system of A.1.9 and A.1.10.

4.1.4 Test weight classes, other than those specified in this recommended practice shall be provided when special test points are required which are not specified herein. These test weights shall conform in design, specifications, dimensional tolerances, and weight tolerances to the specified SAE test weights.

* Wound rotor motor or DC motor required.

4.1.5 The following quantities and classes of test weights should be provided for the proving rotors for each class of machine.

Quantity	Class
2	10A
2	12.5A
1	20A
1	30A
2	40A
1	50A

4.2 Performance Tests:

4.2.1 The tests described in the following paragraphs represent a minimum test procedure. The requirements of 3 have been written to define the characteristics of the machine. This test procedure will not prove all requirements over the full range of all variables. The procedure proposed will not measure nor define the exact reasons for failure of any particular balancing machine such as lack of ruggedness or machine not being properly anchored to the floor.

4.2.2 In applying these tests, the user shall provide an examiner trained in the use of balancing equipment. The manufacturer shall instruct the user's representative in the use of the equipment. The user shall either operate the equipment or satisfy himself that he could obtain the same result as the manufacturer's operator. The manufacturer shall ensure that his written operating instructions are followed by the user.

4.2.3 The manufacturer and user shall be satisfied with the weighing and location of correction weights and that the proving rotor and the test weights conform to the SAE specifications (Figs. 2, 3, and 4). The user shall be permitted to witness or check any of this work.

4.2.4 An accurate and precise weight scale shall be available for the test. This scale shall be accurate and precise to at least two decimal places beyond the smallest A test weight. For example, if the A test weight weighs 0.00842 oz, the scale should be accurate to 0.00008 ounce.

4.2.5 For all calibrations, the following calibration weights shall be used: for tests from 0 to 5A, 10A; for tests from 5A to 20A, 30A; for tests from 20A to 40A, 50A.

4.2.6 Tests and Rechecks: In the following tests, a machine which would normally conform to a test could, by chance, fail to conform in a single test run. Therefore, in most tests, when the machine fails to conform in a single test run, two rechecks shall be made, in which case the machine shall conform in both recheck tests in order to qualify as acceptable under the specified test.

4.2.6.1 Each test specifies the conditions for conformance (acceptability) or nonconformance (nonacceptability) to the specific test.

4.2.6.2 It shall be understood that in all cases of rechecks, the same conditions for both rechecks as for the original test shall determine conformance or nonconformance.

4.2.7 Transparent overlay, Fig. 6, is designed for use with Keuffel and Esser Company's #359-31 co-ordinate graph paper, Fig. 5.

4.3 Testing Procedure for Readout Sensitivity (3.2.1), Accurate Amount Indication (3.2.2), Stable End Point (3.2.5), Residual Unbalance (3.2.7), and Accurate Angle Indication (3.3):

4.3.1 Set up the machine with the appropriate proving rotor (See 3.8.7) according to the written procedure specified by the manufacturer. The machine shall be set up to indicate the location at which weight should be removed to balance the proving rotor.

4.3.2 Adjust the amount calibration of the machine to give readout directly in units of A (or 0.01, 0.1, 10, 100, etc. times A), as convenient. Use a 30A test weight for calibration in plane 2.

4.3.3 Using the normal balancing procedure, read the unbalance, as indicated. If the unbalance is less than 5A, shut down and apply an arbitrary unknown weight to the proving rotor to give a resultant unbalance greater than 5A, but less than 20A. Apply a correction weight of the indicated amount at the indicated location. Record the angular location and the amount reading on test log sheet. Record four more successive sets of readings, always applying the indicated correction. Do not apply further corrections after these five recorded corrections.

Tests - After initial correction, if any of the last four recorded amount readings are greater than 1A, the machine does not conform, since it cannot consistently balance to a value of one A unit. (See 3.2.5)

NOTE: The unbalance now remaining in the proving rotor is considered to be the residual unbalance. Further tests will indicate its amount (but not measure it) and if it is too large will cause rejection.

Recheck - In the case of nonconformance, the manufacturer is permitted to check, modify, and adjust the machine prior to a recheck. The proving rotor should again be unbalanced beyond 5A. Repeat the above test twice in succession.

4.3.4 Fit a 2.5A test weight at any one of the following locations: 15, 165, 195, or 345 degrees. (Call this location angle E.) This weight remains on the rotor at this location for the following series of tests (See Test Log Sheet for 4.3.5).

4.3.5 Fit another 2.5A test weight at the locations indicated in column G of the test log sheet. Read and record the amount and location of the resultant unbalance as indicated by the balancing machine for each of these locations. Repeat these tests twice more. Plot the results with the symbols shown on the polar graph, Fig. 5. Rule in heavily the line from the origin in the direction of E.

Test 1 - Place the transparent overlay, Fig. 6, over the graph and adjust it, keeping the 0° to 180° axis parallel to the direction of E until all the plotted points are enclosed in their respective regions as indicated by the symbols. If any points fall outside their regions, check to insure that they have been correctly plotted. If no more than one point falls outside its region, the equipment conforms. If two points fall outside, the machine does not conform because of lack of repeatability, amount indication errors, angular indication errors, or cut off at low unbalance.

Test 2 - If the origin of the overlay falls within radius 0.5A units when adjusted as for Test 1, the machine conforms for residual unbalance (See 3.2.7).

Recheck 1 and 2 - In case of nonconformance, the manufacturer is permitted to check, modify, and adjust the machine prior to a recheck. Repeat 4.3.3, 4.3.4, and 4.3.5 twice in succession. If both Tests 1 and 2 result in conformance both times, the machine conforms to this requirement (See 4.2.6.2).

4.3.6 Measure the displacement of analogue readout device in inches. Divide the measured displacement in inches by the indicated unbalance in A units.

Test: If the sensitivity is less than 0.125 in. per A unit, the machine does not conform because of inadequate sensitivity (See 3.2.1).

Recheck: In case of nonconformance, the manufacturer is permitted to check, modify, and adjust the machine prior to a recheck. Repeat tests of 4.3.3 and 4.3.6 for the first two readings for test log sheet, as specified in 4.3.5 (See 4.2.6.2).

4.4 Testing Procedure for Static and Couple Unbalance Separation (3.1):

4.4.1 With the proving rotor set up and balanced as for the previous tests, continue by removing all 2.5A test weights.

4.4.2 Fit a 40A static test weight to both planes 1 and 3 of proving rotor at locations shown in test log sheet and read the indicated static unbalance and location. Plot the last two static readings of 4.3.3 with a ⊙ on a polar graph, Fig. 5. Plot the readings of 4.4.2 with a + on the same graph.

Test - Set overlay with its center midway between the two ⊙ points. If all the + points fall within the static-couple separation circle, the machine conforms. Static unbalance indication is independent of couple unbalance.

Recheck - In case of nonconformance, the manufacturer is permitted to check, modify, and adjust the machine prior to recheck but preceding tests must be redone also.

4.5 Testing Procedure for Range of Unbalance:

4.5.1 With a 40A test weight fitted at a known angle in plane 2 of the proving rotor, read the unbalance. It is permissible to change the readout units from those used so far for this test. For example, if 1 unit on the readout scale represented one A to insure that 4.3.5 be passed, it is now permissible to employ a range-multiplying device so that 1 unit on the readout scale now represents 5A or some other convenient value without affecting the calibration, as set out in 4.3.2.

Test - If the indicated unbalance is between 38A and 42A, the machine conforms. If the indicated unbalance is beyond this range, repeat the work of 4.5.1 to this point once more. If this does not give an indication within 38A to 42A, the machine does not conform. No further recheck is permitted.

4.6 Testing Procedure for Indication of Location for Removal or Addition of Material (3.3.1):

4.6.1 Set the machine, as necessary, to readout the location at which weight should be added to balance the proving rotor.

4.6.2 With the 40A test weight fitted as specified in 4.5.1, read the location at which weight should be added to balance the proving rotor.

Test - If the indicated location is diametrically opposite the test weight within ±8 deg, the machine conforms. If the indicated location is beyond this range, repeat the procedure of 4.6 to this point once more. If this does not give an indication within the ±8 deg, the machine does not conform. No further recheck is permitted.

4.7 Testing Procedure for Drive System Reliability and Unbalance Disturbance:

4.7.1 With the 40A test weight still fitted, cycle the equipment repeatedly from start to full speed and then to a stop condition. Time at full speed should be only sufficient to readout the amount and location of unbalance. Time at the stop condition should be only sufficient to record the amount and location of unbalance in test log sheet. These cycles should continue for a period of one hour during which time at least 30 cycles must be completed. This test must be performed without the use of auxiliary cooling devices which are not a part of the basic equipment.

Test 1 - Reliability - If the machine fails to function mechanically during any part of the test, it does not conform and no further checks are permitted.

4.7.2 Within 5 min. of completion of 4.7.1, the proving rotor must be removed from the machine and test 4.7.3 completed.

4.7.3 With the equipment running at full speed and without changing the previously established machine calibration, record the amount of unbalance indication.

Test 2 - Drive System Unbalance Disturbance - If the value of this unbalance reading exceeds 0.5A, the machine does not conform. No further rechecks are permitted.

4.7.4 The manufacturer should demonstrate satisfactorily to the user that the system provided for subsequent correction of static unbalance in the workpiece drive system is adequate.

4.8 Testing Procedure for Indicated Unbalance Linearity (3.2.6):

4.8.1 Reinstall the proving rotor and remove all test weights to return rotor to balanced condition as obtained in 4.3.3. It is permissible to change the readout units from those used so far as described in 4.5.1.

4.8.2 To obtain a random order of application of unbalances and their positions on the proving rotor, proceed as follows. Mark four slips of paper with 2.5A, 10A, 20A, and 40A. Place these in a hat or suitable box. Mix the slips and draw a slip. For the first run, place a test weight of the amount shown on this slip in plane 2 of the test rotor. Continue drawing remaining slips until all four runs have been made. Repeat this procedure three times.

4.8.3 To obtain the angular position for the applied unbalance runs in 4.8.2, mark four slips of paper with 0, 90, 180, and 270 deg and mix them in a hat or container. Draw one of these, note the angle, replace it and use the angle for the location of the unbalance to be applied.

4.8.4 Record the 12 runs on the test log sheet and plot each point on graph for this test.

Test - If not more than one plotted point is outside the limit lines of the graph, the machine conforms to these specifications for static indicated unbalance linearity. If more than one plotted point is outside the limits, recalibrate the machine and proving rotor and repeat the entire test. If more than one point is outside the graph limits on the rerun, the machine does not conform to this specification.

4.9 Drive System, General:

4.9.1 Check direction of rotation to insure that it is clockwise when looking down on the drive adapter flange.

4.9.2 Measure the operating speed of the proving rotor to insure that it is 900 rpm or more.

4.10 Other Dimensional Inspection:

4.10.1 Ordinary dimensional inspection should be done to insure that the machine complies with 3.8.5 and 3.8.6. Other requirements of 3.8 are a guide to the equipment designer, are met if the detailed performance tests are passed, or are demonstrated by the performance tests. To keep the testing procedures short enough to be practical, some requirements are accepted on faith or as corollaries of the successful completion of the test procedures specified.

4.10.2 The proving rotor and the drive spindle of the balancing equipment should be made so as to allow no radial play in the attachment of the latter to the spindle. The drive spindle by itself shall not have a radial runout in excess of 0.0005 in. (T.I.R.).

4.10.2.1 The procedure to be followed in checking this alignment is:

The spindle concentricity test shall be made without the use of the proving rotor.

Fasten a low friction, type 1 (0.0001 in.) dial indicator to the balancing machine frame. Lock the vibratory system. Adjust the dial indicator so that the indicator tip contacts the outside diameter of the piloting portion of the spindle.

Test - Rotate the spindle slowly by hand and read the indicator for five full turns. The T.I.R. shall not exceed 0.0005 inch.

APPENDIX 1 - GLOSSARY OF TERMS AND NOMENCLATURE

Definitions are given for those technical terms which have a particular meaning for this document. Some of these terms have been written with capitals throughout the document, particularly where they have definite meanings in this context. The more general use of the same word will not be capitalized. An attempt has been made throughout to use the same words to express the same idea. They are given in the approximate order in which they first occur. For additional information see ARP 587A, Appendix 2.

A.1.1 Balancing Machine: A machine that provides a measure of the unbalance in a rotor which can be used for adjusting the mass distribution of that rotor mounted on it so that once per revolution vibratory motion of the journals or force on the bearings can be reduced if necessary.

A.1.1.1 Balancing Equipment: A combination of the balance machine, proving rotor, tooling, and accessories necessary to accomplish a balancing operation.

A.1.2 Symbols:

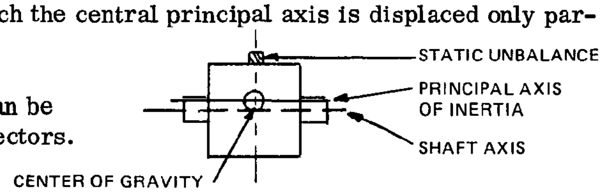
U - Unbalance (oz-in.)
A Units - Required sensitivity of the equipment (microinches); see A.1.9.
V - Weight of one Unbalance Static Test Unit (oz); see A.1.10.
W - Weight of the proving rotor (lb).
r - Radius to the center of gravity (c.g.) of V or w from journal axis (in.).
d - Separation of the Couple Unbalance planes (in.).
w - Weight of unbalance at the correction radius of a rotor or part (oz).

A.1.2.2 Microinch:

One microinch = 10^{-6} in.

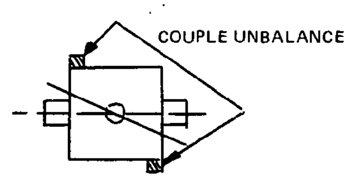
A.1.3 Static Unbalance: That condition of unbalance for which the central principal axis is displaced only parallel to the shaft axis.

Note: The quantitative measure of static unbalance can be given by the resultant of the two dynamic unbalance vectors.



A.1.4 Couple Unbalance: That condition of unbalance for which the central principal axis intersects the shaft axis at the center of gravity.

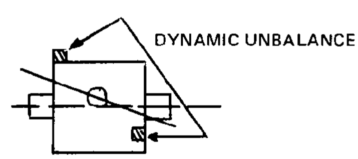
Note 1: The quantitative measure of couple unbalance can be given by the vector sum of the moments of the two dynamic unbalance vectors about a certain reference point in the plane containing the center of gravity and the shaft axis.



Note 2: If static unbalance in a rotor is corrected in any plane other than that containing the reference point, the couple unbalance will be changed.

A.1.5 Dynamic Unbalance: That condition in which the central principal axis is not coincident with the shaft axis.

Note 1: The quantitative measure of dynamic unbalance can be given by two complementary unbalance vectors in two specified planes (perpendicular to the shaft axis) which completely represent the total unbalance of the rotor.



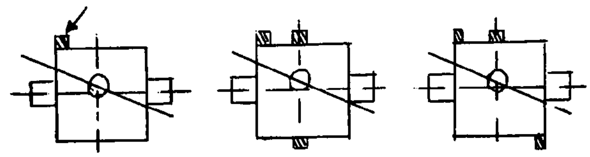
(Unbalance weights not diametrically opposed)

Note 2: Dynamic unbalance is a combination of static unbalance and couple unbalance resolved into two (and in some cases more than two) transverse planes. Only the two-plane case is covered in this document. Analytical conversion by vector analysis can be made from dynamic unbalance to static plus couple unbalance and vice versa. The correction of dynamic unbalance will achieve complete unbalance correction.

A.1.6 Quasi-static Unbalance: That condition of unbalance for which the central principal axis intersects the shaft axis at a point other than the center of gravity.

Note: Quasi-static unbalance is a special case of dynamic unbalance where the angle of the static unbalance coincides with the angle of one of the couple unbalances.

QUASI STATIC UNBALANCE



All three figures represent the same Quasi-static unbalance.

A.1.7 Angle of Unbalance: Given a polar coordinate system fixed in a plane perpendicular to the shaft axis, the angle of unbalance is that angle at which an unbalance mass is located with reference to the given coordinate system.

A.1.8 Readout: As a verb, means to provide an answer or result by whatever means the particular equipment might use, such as a meter indication, position of a control, scale reading, punched card, or counter number.

A.1.9 One A unit: Specified required sensitivity of the balancing machine under test, stated in microinch displacement of the principle axis of inertia from the shaft axis (if the rotor rotated in free space without restraint).

a) in the plane of the c.g. for static unbalance
b) in each bearing plane for couple unbalance

Note 1: For static unbalance an A unit is identical to the minimum achievable specific unbalance; i.e. the displacement of rotor c.g. from the shaft axis.

Note 2: The specified required sensitivity of one A unit must be tested as described herein. To meet the various tests the machine must actually be capable of indicating 0.25 A or better.

Note 3: A by itself is used in this document to denote the weight of a test weight in ounces at radius r of the amount of unbalance which will produce displacement of the principle axis of inertia from the shaft axis equivalent to the value of one A unit described above.

A.1.10 Unbalance Test Unit V_S: An amount of weight which, when added at a radius to a given perfectly balanced rotor, displaces the c.g. of the rotor one microinch from its shaft axis if the rotor rotated in free space without restraint.

Note 1: An Unbalance Test Unit V_S differs from the Unbalance Test Unit V_C as defined in ARP 587A in that V_S constitutes static unbalance whereas V_C constitutes couple unbalance. When a static unbalance test unit V_S is applied in any plane other than the plane of the c.g. it causes a quasi-static unbalance condition. Nevertheless, the displacement of c.g. is the same as if the weight were placed in the plane of the c.g.

An Unbalance Test Unit V_S may be determined by the following formula:

$$V_S = \frac{16W \times 10^{-6}}{r}$$

Wherein V_S = Unbalance Test Unit in ounces for 1 microinch c.g. displacement of rotor

W = Weight of rotor in lb

r = Radius of test weight in inches

Examples:

If for a particular rotor V_S = 0.0003368 oz and A = 50, then 1A = 0.0003368 oz x 50 = 0.01684 oz, to be applied at the same radius for which V_S was calculated. A 40A test weight for the same rotor (for checking range of unbalance indication, for example) would weigh 40 x 0.01684 = 0.6736 ounce (or 40A x V_S = 2000 V_S)

A.1.11 Analogue: Means a readout which is measured on a continuous scale and whose readability depends on the length of the scale.

A.1.12 Numerical Readout: See 4.3.2. The arithmetic number indicated by the readout unit without any physical size or unit. Actual physical unbalance is obtained by multiplying the numerical readout by the appropriate value depending on the set-up of the machine to which a physical unit is assigned.

A.1.13 One pound = 453.6 grams (454 grams round numbers) = 16 ounces

A.1.14 One ounce = 28.35 grams

A.1.15 Plane 1, Plane 2, and Plane 3 are balancing plane designations for proving rotors only.

APPENDIX 2 - DETAILS FOR CONTRACTUAL NEGOTIATION

The following details are considered to be important. The values given may be adjusted for any particular requirements. Test procedures to insure compliance with these requirements are beyond the scope of this document.

A.2.1 The balancing machine should operate in a satisfactory manner over an ambient temperature range of XX-XXX F, and under 100% relative humidity.

A.2.2 All units of the electrical equipment should comply with applicable electrical specifications such as N.E.M.A. and other local codes.

A.2.3 The electrical systems should operate satisfactorily under line voltage variations of ±XX%, line frequency variations of ±XX%, and waveform harmonic distortion of up to XX%.

A.2.4 All electrical systems should be arranged for operation from a supply of XXX volts, X phase, XX cycles/second.

A.2.5 Any need for radio interference suppression should be specified.

A.2.6 Balancing equipment performance may be sensitive to environmental vibratory conditions. No general requirements can be specified due to the wide range of environmental frequencies and amplitudes and due to the varied response of different balancing systems to these excitations.

The responsibility for special mounts which may be necessary to adapt any particular machine to a particular environment should be defined.

A.2.7 All tests should be run at the manufacturer's plant before shipment or at the user's plant after installation. Facilities for making all tests to be provided by the manufacturer or the user. Proving rotors to be provided by the manufacturer or the user.

A.2.8 Installation and service.

A.2.9 Operating and maintenance personnel training.

A.2.10 Operating Manual, Maintenance Manual, Circuit Diagrams, Spare Parts Ordering Information.

APPENDIX 3 - BIBLIOGRAPHY

The following references give some earlier balancing equipment specifications and background information on topics allied to this document.

A.3.1 Report No. 371-V-24; Department of the Navy, Bureau of Ships, Code 371.

A.3.2 MIL-STD-167; Mechanical Vibrations of Shipboard Equipment, Department of the Navy, Bureau of Ships.

A.3.3 MIL-B-25511 (USAF); Military Specification, Balancing Machine, Dynamic-Static, Two Plane.

A.3.4 A.S.T.E. Handbook.

A.3.5 "Performance Tests for Balancing Machines", Werner I. Senger, Machinery's Reference Section, March - April, 1958.

A.3.6 ARP No. 587A, Balancing Equipment for Jet Engine Components — Compressors and Turbine — Rotating Type For Measuring Unbalance in One or More Than One Transverse Planes.

A.3.7 American National Standards Institute S2-65, DS 1925 Balancing Terminology.

A.3.8 MIL-B-25510 (USAF); Military Specification, Balancing Machines - Static-Single Plane.

TEST LOG SHEET FOR 4.3.3

STABLE END POINT

PLANE 2	
Angular Location Degrees	Amounts A Units

TEST LOG SHEETS FOR 4.3.5

RESIDUAL UNBALANCE AND ACCURATE ANGLE AND AMOUNT INDICATION

E =   Plane 2

Symbol	Angle H Degrees	Location G Degrees	Indicated Unbalance					
			1st Run		2nd Run		3rd Run	
		G = H + E (or H + E - 360)	Location Degrees	Amount A Units	Location Degrees	Amount A Units	Location Degrees	Amount A Units
⊙	15			*				
⊡	60							
△	90							
⊙	120							
⊡	150							
△	165							
⊙	**	N. A.						
⬡	195							
⊡	210							
△	240							
⊡	270							
⊙	300							
△	330							

*   See 4.3.6 for sensitivity test when this reading is indicated.

**   For this set of readings remove both 2.5 A Units Test Weights of 4.3.4 and 4.3.5. Be sure to install the same weight at the same angle as 4.3.4 for the next set of readings.

TEST LOG SHEET FOR 4.4.2

STATIC AND COUPLE UNBALANCE SEPARATION

Location of 40 A Weight Degrees		SYMBOL +	
		Indicated Unbalance	
		Location Degrees	Amount A Units
Couple Plane 1	Couple Plane 3	Static Plane 2	
60	240		
150	330		
240	60		
330	150		

TEST LOG SHEET FOR 4.7.1 and *4.7.3
DRIVE SYSTEM RELIABILITY AND UNBALANCE DISTURBANCE

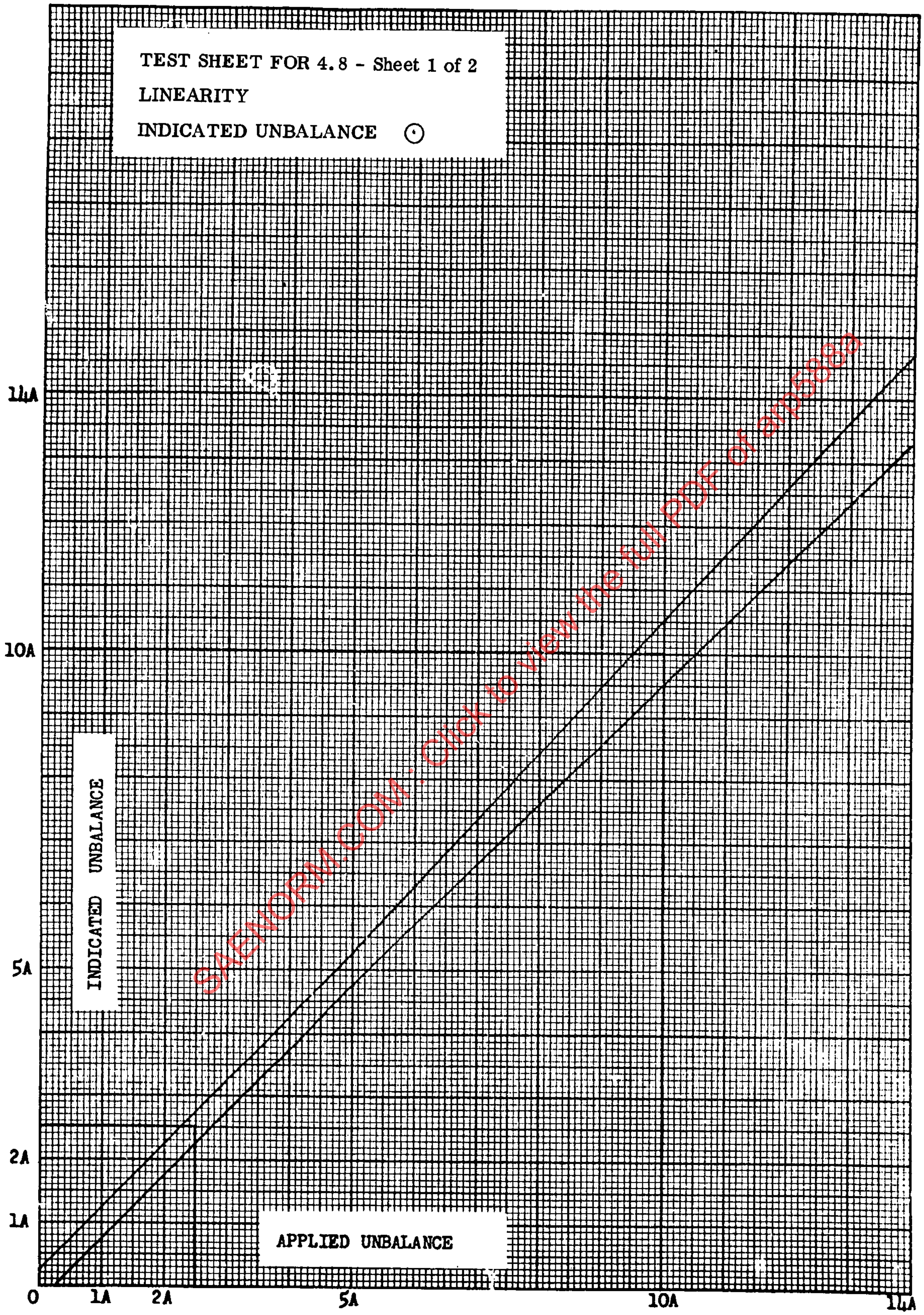
Run #	Amount A Units	Location Degrees	Run #	Amount A Units	Location Degrees
1			26		
2			27		
3			28		
4			29		
5			30		
6			31		
7			32		
8			33		
9			34		
10			35		
11			36		
12			37		
13			38		
14			39		
15			40		
16			41		
17			42		
18			43		
19			44		
20			45		
21			46		
22			47		
23			48		
24			49		
25			50		
			*		

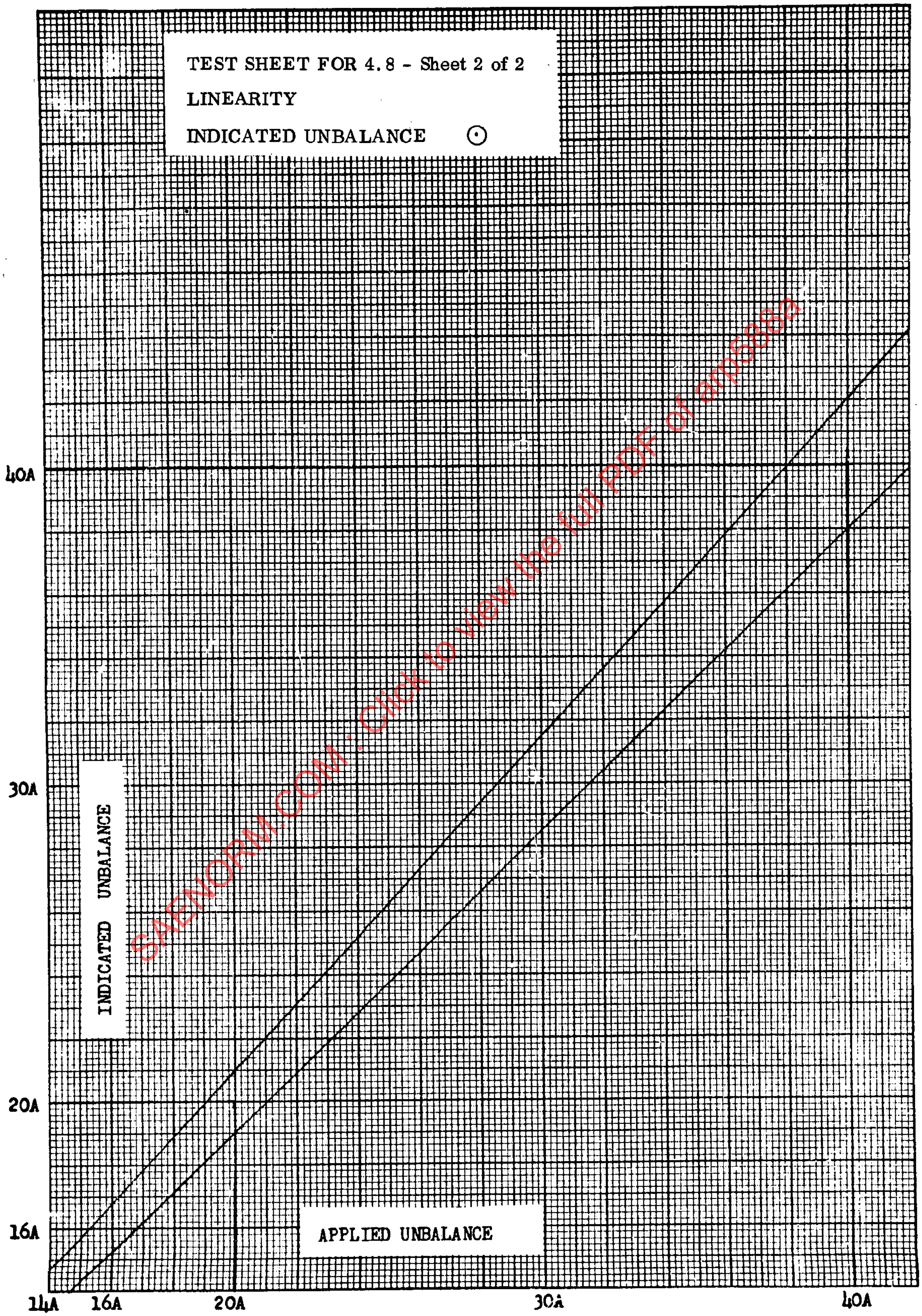
*Record Drive System Unbalance Disturbance after removing proving rotor per 4.7.2.

TEST LOG SHEET FOR 4.8

LINEARITY

Run #	Amount A Units	Location Degrees
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		


TEST SHEET FOR 4.8 - Sheet 1 of 2
LINEARITY
INDICATED UNBALANCE ⊙
INDICATED UNBALANCE
APPLIED UNBALANCE
14A
10A
5A
2A
1A
0
1A
2A
5A
10A
14A


TEST SHEET FOR 4.8 - Sheet 2 of 2
LINEARITY
INDICATED UNBALANCE ⊙
INDICATED UNBALANCE
APPLIED UNBALANCE
40A
30A
20A
16A
14A
16A
20A
30A
40A