U.S. Department of Defense — Naval Sea Systems Command (NAVSEA)

Military Balancing Standards

MIL-STD-167-1A | MIL-STD-810 | MIL-HDBK-17 — Rotating Equipment Balance & Vibration

1. Overview & Governing Authority

The U.S. Department of Defense (DoD) governs the balancing and vibration requirements of rotating mechanical equipment aboard military platforms through a hierarchy of standards managed principally by the Naval Sea Systems Command (NAVSEA). The primary balancing standard is MIL-STD-167-1A, which applies to all rotating machinery installed aboard Navy ships. It is complemented by MIL-STD-810 for general environmental testing of military equipment, and by MIL-HDBK-17 and platform-specific technical manuals for aerospace and ground systems.

Military balancing standards are more stringent than many industrial standards because shipboard and airborne equipment must remain operational under sustained shock, vibration, and dynamic loading conditions that far exceed typical commercial environments.

> **NOTE** MIL-STD-167-1A is approved by NAVSEA and is available for use by all Departments and Agencies of the Department of Defense. Distribution is unlimited (Distribution Statement A). The standard was first published on 1 May 1974 and most recently revised on 2 November 2005.

2. MIL-STD-167-1A — Primary Naval Balancing Standard

2a. Classification of Vibration Testing

MIL-STD-167-1A divides vibration requirements into two types, applied independently:

Type	Name	Scope	Key Requirement
Type I	Environmental Vibration	All shipboard equipment — tests resistance to externally imposed ship vibrations (propeller blade-rate, hull response)	Equipment must survive 4–33 Hz vibration at 0.010±0.002 in single amplitude; 2-hour endurance test at 33 Hz
Type II	Internally Excited Vibration	Rotating machinery only — tests that equipment does not itself generate excessive vibration from unbalanced components	All rotating machinery must be balanced to G1.0 or G2.5; vibration displacement must not exceed Figure 2 limits

CAUTION MIL-STD-167-1A does NOT apply to: high-speed or surface-effect ships (wave-slap vibration exceeds standard limits); single-phase machines; reciprocating machinery (see MIL-STD-167-2A); machines mounted in situ (see ISO 10816-3); water-jet or podded propulsion vessels.

2b. Balance Quality Grade Requirements for Rigid Rotors

The core balance acceptance criterion for rigid rotors under MIL-STD-167-1A Type II is expressed using the ISO balance quality grade G, as defined in ISO 1940-1 / ISO 21940-11. The military grade requirements are more stringent than typical industrial standards:

MIL-STD-167-1A § 5.2.2.2 | Balance Grade Definition

$$G = e_{per} \times \Omega \qquad [\mathrm{mm/s}]$$

G = Balance quality grade (mm/s) — must not exceed the limits below
eper = Permissible specific unbalance / eccentricity of rotor CG (mm)
Ω = Maximum service angular velocity (rad/s) = 2πN / 60

Operating Speed	Max Allowable Balance Grade	Equivalent ISO G-Grade	Application
Below 1,000 RPM	G ≤ 2.5 mm/s	ISO G2.5	Low-speed pumps, fans, deck machinery
1,000 RPM and above	G ≤ 1.0 mm/s	ISO G1.0	Motors, pumps, turbines, generators, compressors
All speeds — low noise	G ≤ 1.0 mm/s	ISO G1.0	Specified when low acoustic signature is required (sonar, quiet spaces)

NOTE G1.0 is significantly more stringent than the ISO default of G2.5 for electric motors and G6.3 for general industrial equipment. The military requirement reflects the acoustic signature sensitivity of naval vessels, where rotor-generated vibration can radiate as underwater noise detectable by adversaries.

2c. Permissible Residual Unbalance Formula

Applying the grade definition, the total permissible residual unbalance for a rigid rotor is calculated as follows:

MIL-STD-167-1A | Total Permissible Residual Unbalance

$$U_{per} = (G \times 9549 \times m) / N \qquad [\mathrm{g \cdot mm}]$$

Uper = Total permissible residual unbalance (g·mm)

G = Balance quality grade (mm/s) — 1.0 for ≥1,000 RPM; 2.5 for <1,000 RPM
m = Rotor mass (kg)
N = Maximum service speed (RPM)
9549 = Conversion constant = 60 × 1000 / (2π)

2d. Two-Plane Unbalance Allocation

In allocating the total permissible unbalance between two correction planes, MIL-STD-167-1A imposes a unique military-specific constraint not found in ISO 21940-11:

MIL-STD-167-1A § 5.2.2.2 | Two-Plane Allocation Rule

$$U_L / U_R \leq 2 : 1 \quad \text{(allocation ratio must not exceed 2:1)}$$

U_L = Unbalance allocated to correction plane L (g·mm)
U_R = Unbalance allocated to correction plane R (g·mm)
≤ 2:1 = The larger plane allocation must not be more than double the smaller

Two-Plane Allocation | Proportional Distribution

$$U_L = U_{per} \times (d_R / b) \qquad U_R = U_{per} \times (d_L / b)$$

d_L = Distance from centre of gravity to left correction plane (mm)
d_R = Distance from centre of gravity to right correction plane (mm)
b = Total distance between correction planes (mm) = d_L + d_R

CAUTION If the proportional allocation gives a ratio > 2:1 (i.e. d_L > 2 × d_R or vice versa), the allocation MUST be adjusted so that the larger plane receives no more than 2/3 of U_per and the smaller plane no less than 1/3. This 2:1 cap is a mandatory MIL-STD-167-1A requirement; it does not exist in ISO 21940-11.

2e. Balancing Methods by Rotor Type

MIL-STD-167-1A Table IV specifies the required balancing method based on the rotor geometry, defined by the L/D ratio (rotor length divided by rotor diameter, both measured exclusive of shaft):

Balancing Type	Rotor Condition / L/D Ratio	Method	Notes

Static (single-plane)	Disc-type rotors: L/D ≤ 0.5 AND operating speed ≤ 1,000 RPM	Single correction plane; may use knife-edge support for machinery < 150 RPM	Corrects static (resultant) unbalance only; couple unbalance not detected
Dynamic (two-plane)	L/D > 0.5 OR any speed > 1,000 RPM	Two-plane dynamic balancing on rotating balancing machine	Corrects both static and couple (dynamic) unbalance
Multi-plane	Flexible rotors; rotors that deform at operating speed	Balance at operating speed in situ or on high-speed balancing machine; >2 correction planes	Required when rigid-rotor assumption cannot be met
Knife-edge (static only)	Machinery rated < 150 RPM only	Rotor supported symmetrically on two knife edges; static correction applied	Exception to rotation-based balancing requirement

NOTE L represents the length of the rotor exclusive of the shaft; D represents the outer diameter of the rotor exclusive of the shaft. For machinery below 150 RPM, knife-edge static balancing is permitted unless otherwise specified in the acquisition document (Annex B para 2g(2)).

2f. Balancing Machine Minimum Detectable Unbalance

The balancing machine used must be capable of resolving unbalance below the specified residual tolerance:

Balancing Machine Requirement | Minimum Detectable Unbalance

$$U_{per}\ \text{(machine)} < U_{per}\ \text{(specification)}$$

Uper (machine) = Minimum detectable unbalance of the balancing machine (g·mm)
Uper (spec) = Permissible residual unbalance from the G-grade specification (g·mm)

NOTE This is a formal requirement of MIL-STD-167-1A § 5.2.2.1. A balancing machine that cannot resolve below the required tolerance will give false acceptance results. The machine's minimum detectable unbalance must be verified and documented before use.

3. Flexible Rotor Balancing — MIL-STD-167-1A § 5.2.3

Flexible rotors — those whose unbalance distribution changes with speed due to rotor deflection — cannot be fully corrected by two-plane balancing alone and require the more complex procedures of Section 5.2.3. Their acceptance is verified by vibration displacement, not by residual unbalance measurement.

Flexible Rotor | Mounting for Vibration Test

$$f\_mount < f\_min\_op / 4$$

`f_mount` = Natural frequency of the elastic test mounting (Hz)
`f_min_op` = Minimum operational speed of the unit (Hz = RPM / 60)
`< 1/4` = Mounting natural frequency must be below one-quarter of minimum operating frequency

Flexible Rotor Acceptance | Vibration Displacement at Rotational Frequency

$$S_{per}\ (1\times) \leq S\_limit\ (\text{Figure 2})$$

`Sper (1x)` = Vibration displacement amplitude at rotational frequency (mils single-amplitude)
`S_limit` = Speed-dependent limit from MIL-STD-167-1A Figure 2 (mils)

MIL-STD-167-1A Figure 2 defines a speed-dependent vibration displacement envelope. Key reference values from the Figure 2 curve are:

Operating Speed (RPM)	Max Vibration Displacement (mils, single amplitude)	Equivalent (mm, single amplitude)
150	5.0	0.127
300	3.0	0.076
600	2.0	0.051
900	1.5	0.038
1,200	1.2	0.030
1,800	0.85	0.022
3,000	0.60	0.015
3,600	0.50	0.013

NOTE These values represent the Figure 2 envelope shape; always refer to the original standard document for precise values. The curve is not linear — it approximates a constant vibration velocity (velocity = displacement × 2πf) relationship across the speed range.

4. Type I Environmental Vibration Limits — MIL-STD-167-1A Table I

Type I vibration tests verify that all shipboard equipment (rotating and non-rotating) can survive the external vibration environment generated by the ship's propulsion system. The standard vibratory displacement is applied across three orthogonal axes, separately:

Frequency Range (Hz)	Vibratory Displacement (in, single amplitude)	Vibratory Displacement (mm, single amplitude)	Velocity (in/s, approx.)
4 – 13.2	0.010 ± 0.002	0.254	0.32
13.2 – 33	0.010 ± 0.002	0.254	0.32–0.83

NOTE Testing is performed in three orthogonal directions (longitudinal, transverse athwartship, vertical) separately. The exploratory vibration test sweeps 4–33 Hz to identify resonances. The endurance test runs for at least 2 hours at the most critical resonance frequency identified. For mast-mounted equipment, an additional 2.5g static load (1.5g over gravity) is applied vertically and transversely.

5. Elastic Mount Isolation Requirement — MIL-STD-167-1A Figure 3

For Type II flexible-rotor vibration testing, the test unit must be mounted on an elastic support whose natural frequency is below one-quarter of the minimum operating frequency. The required minimum static deflection of the mounting is:

MIL-STD-167-1A Figure 3 | Minimum Elastic Mounting Deflection

$$Z_{per} = (a^2 \times g) / \Omega^2 \times 1000 \quad [mm]$$

- **Zper** = Minimum static deflection of elastic mounting (mm)
- **a** = Frequency ratio $f_1 / f_{no} \geq 4$ (MIL requirement; ISO requires ≥ 3)
- **g** = Gravitational acceleration = 9.81 m/s²
- **Ω** = Minimum operating angular velocity (rad/s) = $2\pi \times N_{per} / 60$

CAUTION MIL-STD-167-1A requires a frequency separation ratio a ≥ 4 (compared to ISO 21940-11 / NEMA MG 1 which require a ≥ 3). This means military isolation mounts must provide greater static deflection than equivalent commercial mounts. Standard Navy isolation mounts (e.g., MIL-M-17185 type) are designed to meet this requirement.

6. MIL-STD-810 — Environmental Engineering Considerations

MIL-STD-810 is the DoD standard for environmental engineering and laboratory testing of military equipment. While it does not specify balance tolerances directly, it establishes the vibration environment profiles that balanced equipment must survive in service. Method 514.8 (Vibration) and Method 528.1 (Mechanical Vibrations of Shipboard Equipment) are the most relevant to rotating machinery balance.

MIL-STD-810 Method	Title	Relevance to Balancing
514.8	Vibration	General vibration survivability testing for Army / Air Force ground and airborne equipment; Category 4 (materiel on ships) references MIL-STD-167-1A for balance requirements
528.1	Mechanical Vibrations of Shipboard Equipment	Naval equipment-specific method; incorporates MIL-STD-167-1A Type I and Type II procedures in full, including G1.0 / G2.5 balance grades and Figure 2 limits
516.8	Shock	Verifies equipment survivability under shock; balanced equipment must retain acceptable residual unbalance after shock events (overhaul/re-balancing criteria may apply)

NOTE MIL-STD-810H Method 528.1 is effectively a restatement of MIL-STD-167-1A within the MIL-STD-810 framework for shipboard materiel. For rigid rotors, it carries forward the same G1.0 (≥1,000 RPM) and G2.5 (<1,000 RPM) grade requirements and the 2:1 plane allocation rule.

7. MIL-HDBK-17 — Aerospace Rotating Equipment

MIL-HDBK-17 (Composite Materials Handbook) and associated aerospace technical orders govern balancing of composite and metallic rotating components in military aircraft. Airborne equipment must meet more stringent balance grades due to the dynamic sensitivity of aircraft airframes:

Application	Typical Balance Grade Required	Standard / Authority	Notes
Turbine engine rotors (gas turbines)	ISO G1.0 or finer (G0.4 for HPT blades)	TO (Technical Order) 2J-1-18; OEM CMP	High-speed gas turbine rotors subject to OEM Component Maintenance Procedures (CMP); balance to half-tolerance of ISO G1.0 common
Helicopter rotor systems (main / tail rotor)	G1.0 to G2.5 per blade; track-and-balance in service	AR 70-38; MIL-HDBK-1559; OEM Maintenance Manual	Final acceptance requires airborne vibration measurement; ground balance is preliminary only
Auxiliary power units (APU rotors)	G1.0	TO 2J-1-18; DEF STAN 05-123 (UK)	APU speed typically 40,000–90,000 RPM; small mass residuals have large centrifugal force impact
Aircraft engine fans (turbofan)	G1.0 to G0.4	OEM CMP; FAR Part 33 / MIL-E-5007	Fan rotor balance critical for NVH; OEM

			specifications often more stringent than MIL minimum
Naval propulsion gas turbines	G1.0	MIL-STD-167-1A; NSTM Chapter 231	LM2500, LM500, MT30 class; overhaul balance typically at G1.0 or better

8. Overhaul and In-Service Balance Criteria

MIL-STD-167-1A explicitly states that its balance limits may be used as overhaul tolerance criteria, but must not by themselves constitute a criterion for determining whether overhaul is needed. The following principles govern in-service and overhaul balancing:

Condition	Requirement
Post-repair balance	Any rotor that has had material removed or added (repair, replacement of components) shall be re-balanced to the applicable G-grade before return to service
Overhaul balance check	Upon disassembly, the as-found residual unbalance is measured and recorded; if it exceeds 2× the acceptance limit, an investigation of the cause is required before re-balancing
Replacement component fitment	When a key, coupling hub, impeller, or similar component is fitted, the shaft-key-fitment assembly shall be balanced as an assembly, not just the individual component
Low-speed < 150 RPM machines	Knife-edge static balancing is acceptable for overhaul unless the acquisition document specifies rotation-based balancing
Special acoustic requirement	Shipboard equipment in quiet spaces (sonar rooms, CIC) or on acoustic-sensitive platforms shall be balanced to G1.0 at all speeds, regardless of RPM
Propulsion shafting	Covered by MIL-STD-167-2A (not MIL-STD-167-1A); propulsion shaft balancing governed by NAVSEA technical manuals (NSTM 231)

9. Worked Examples

9a. Naval Pump Motor, 1,800 RPM, G1.0 Requirement

Example: A shipboard centrifugal pump motor rotor, mass = 35 kg, operating speed = 1,800 RPM, MIL-STD-167-1A requirement (G1.0 at ≥ 1,000 RPM).

Step	Formula / Reference	Result
1. Select grade	MIL-STD-167-1A § 5.2.2.2 (≥1,000 RPM)	G = 1.0 mm/s
2. Total Uper	Uper = (1.0 × 9549 × 35) / 1800	185.5 g·mm

3. Eccentricity check	eper = 9549 × 1.0 / 1800	5.31 μm
4. Per plane (symmetric)	185.5 / 2	92.8 g·mm per plane
5. 2:1 ratio check (symmetric)	92.8 : 92.8 = 1:1	PASS — ratio ≤ 2:1
6. Correction mass @ 80 mm radius	m = 92.8 / 80	1.16 g max per plane
7. Compare to G2.5 (ISO default)	G2.5 → Uper = (2.5 × 9549 × 35) / 1800	463.7 g·mm — MIL spec is 2.5× tighter

9b. Asymmetric Rotor with 2:1 Allocation Constraint

Example: A rotor, total Uper = 200 g·mm, correction planes at b = 300 mm apart; CG is 240 mm from plane L and 60 mm from plane R. Proportional allocation gives:

Step	Formula	Result
Proportional U_L	200 × (60 / 300)	40 g·mm
Proportional U_R	200 × (240 / 300)	160 g·mm
Ratio check	160 / 40 = 4:1	FAIL — exceeds 2:1 MIL limit
Adjusted U_L (MIL-STD limit)	200 × 1/3 = 66.7 g·mm	66.7 g·mm (minimum 1/3)
Adjusted U_R (MIL-STD limit)	200 × 2/3 = 133.3 g·mm	133.3 g·mm (maximum 2/3)
Ratio check (adjusted)	133.3 / 66.7 = 2:1	PASS — exactly at MIL limit

CAUTION The 2:1 allocation adjustment CHANGES the rotor's residual unbalance distribution relative to the pure proportional method. This is intentional — the military constraint prevents extreme unbalance concentration in a single plane, which could cause bearing overload even when the total unbalance is within specification.

10. Unit Conversions

Unbalance | oz·in ↔ g·mm

`1 oz·in = 720 g·mm`

`oz·in` = Ounce-inch (imperial — legacy MIL documents and API standards)
`g·mm` = Gram-millimetre (SI — MIL-STD-167-1A uses SI units)

Vibration Displacement | mils ↔ mm

$$1 \text{ mil} = 0.001 \text{ in} = 0.0254 \text{ mm}$$

`mil` = Thousandths of an inch (MIL-STD unit for displacement)
`mm` = Millimetres (SI equivalent)

Angular Velocity | RPM to rad/s

$$\Omega = 2\pi N / 60 \approx N / 9.549$$

Ω = Angular velocity (rad/s)
N = Rotational speed (RPM)

11. Military vs. Commercial Standards Comparison

Standard	Grade (≥1,000 RPM)	Grade (<1,000 RPM)	2:1 Plane Rule	Flexible Rotor Acceptance	Basis
MIL-STD-167-1A (DoD / NAVSEA)	G1.0	G2.5	YES — mandatory	Figure 2 displacement vs. speed curve	Vibration displacement + G-grade
ISO 21940-11 (International)	G2.5 – G6.3 (type dependent)	G2.5 – G16	No — proportional only	ISO 21940-12 procedure	G-grade eccentricity
API 610 (Petroleum)	~G0.7 (4W/N formula)	~G0.7	No specific rule	Not in scope (rigid only)	4W/N formula (oz·in)
NEMA MG 1 (Motors)	G2.5 implied	G2.5 implied	No	Not addressed	Vibration velocity (in/s)
VDI 2060 (Germany, withdrawn)	G2.5 typical	G6.3 typical	No	Not covered	Eccentricity + centrifugal force %

12. Related Military Standards & Cross-References

Standard	Title / Relevance
MIL-STD-167-1A (2005)	PRIMARY: Mechanical Vibrations of Shipboard Equipment — Type I (Environmental) and Type II (Internally Excited / Balance). Active.

MIL-STD-167-2A (2012)	Mechanical Vibrations of Shipboard Equipment — Propulsion System and Shafting. Covers propeller shaft, line shafting, and reduction gear balance. Companion to 167-1A.
MIL-STD-810H (2019)	Environmental Engineering Considerations; Method 514.8 (Vibration) and Method 528.1 (Shipboard Vibration). References 167-1A for balance grades.
MIL-S-901D	High-Impact Mechanical Shock, Shipboard Equipment. Complementary to 167-1A — balanced equipment must also survive shock events.
MIL-DTL-901E	High-Impact Shock, Submarines. Similar to MIL-S-901D for submarine-specific requirements.
MIL-M-17185	Mounts, Resilient (Shipboard Application). Navy standard isolation mounts referenced by 167-1A § 5.1.2.3.1 for Type I testing.
NAVSEA NSTM Chapter 231	Propulsion Shafting and Bearings. Detailed balance and alignment requirements for main propulsion shafting.
NAVSEA NSTM Chapter 244	Propulsion Turbines. Balance requirements for naval steam and gas turbines.
ISO 21940-11	Balance Quality Requirements for Rigid Rotors — referenced by MIL-STD-167-1A for the G-grade definition and grade assignment tables.
ANSI S2.19	Mechanical Vibration — Balance Quality Requirements of Rigid Rotors — referenced by MIL-STD-167-1A for grade guidance.
ISO 10816-3	Evaluation of machine vibration by measurements on non-rotating parts — referenced by MIL-STD-167-1A for in-situ (installed) machine evaluation.
DEF STAN 05-123 (UK)	Mechanical Vibration and Shock. British Defence Standard equivalent for UK Royal Navy platforms; uses NATO-equivalent grades aligned with MIL-STD-167.
STANAG 4121 (NATO)	Mechanical Vibrations and Shock — NATO Standardisation Agreement. Governs interoperability of equipment vibration requirements across NATO navies.

NOTE MIL-STD-167-1A and MIL-STD-810H Method 528.1 are approved for public release with no distribution restrictions (Distribution Statement A). All references to NAVSEA technical manuals (NSTM) are unclassified but may require a DoD CAC or contractor access to retrieve from official repositories.