Designation: D 2508 – 93

An American National Standard

Standard Test Method for Solid Rocket Propellant Specific Impulse Measurements[1]

This standard is issued under the fixed designation D 2508; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of solid propellant specific impulse values.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

D 2506 Terminology Relating to Solid Rocket Propulsion[2]

2.2 *Military Specification:*

MIL-STD-292C[3]

3. Terminology

3.1 *Definitions*—Refer to Terminology D 2506 or Military Specification MIL-STD-292C.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *mass of propellant, m*—$_p$, to be used in the calculation of specific impulse, shall be the mass of propellant charged into the motor.

3.2.1.1 An igniter correction shall be made, determined either by experiment or calculation, when the theoretical value of this correction exceeds 0.1 %.

3.2.1.2 The difference between before and after firing weights shall be recorded as expended weight.

3.2.1.3 The percentage difference between expended weight and propellant weight shall be recorded as either inerts expended (if the expended weight is higher) or residue retained. Values less than 0.2 % may be ignored.

3.3 *Symbols:*

3.3.1 *total impulse*— $I = \int_A^G F\mathrm{d}t$.

3.3.2 *burning time*— t_b = time from "*B*" to "*E*".

3.3.3 *action time*— t_a = time from "*B*" to "*F*".

3.3.4 *average pressure over burning time*— $\bar{P}_b = \int_B^E P\mathrm{d}t/t_b$.

3.3.5 *average pressure over action time*— $\bar{P}_a = \int_B^E P\mathrm{d}t/t_a$.

3.3.6 *measured specific impulse*—$I_{sp} = I/m_p$, which is corrected to standard conditions in accordance with Section 8.

4. Summary of Test Method

4.1 This test method sets forth the following:

4.1.1 A set of uniform designations to be used for the calculations.

4.1.2 Precautions to be taken in experimental techniques.

4.1.3 Acceptable ranges of experimental conditions to assure good results.

4.1.4 Uniform procedures for correcting measured values to a standard of set conditions.

4.1.5 Limited thrust coefficient values for use with this practice.

5. Significance and Use

5.1 It is recognized that the size and design of ballistic test motors affect the determination of propellant specific impulse, and it is not intended that results from this test method be used to predict performance in motors of size or design widely different from that tested.

6. Procedure

6.1 Assume a pressure-time or thrust-time trace as shown in Fig. 1.

6.2 The following experimental criteria is recommended to ensure meaningful values of I_{sp}:[4]

6.2.1 Use a geometry that gives a relatively neutral pressure-time trace, be essentially sliverless, and provides a nominal 50-lb grain. A suggested method for achieving these conditions is to use a thin-webbed cylindrical geometry with ends uninhibited.

6.2.2 Use a geometry that also gives a value for throat-to-port area ratio of $J = A_t/A_p$ of less than 0.35.

6.2.3 Use nozzles that give values of $\bar{P}_a$ between 5.52 and 7.58 MN/m^2 (900 and 1100 psia) to minimize the pressure correction.

6.2.4 Use nozzles with an expansion ratio near optimum, but such that no separation due to over-expansion takes place during the *equilibrium* burning time (see Fig. 1, *C* to *D*).

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[1] This test method is under the jurisdiction of ASTM Committee F-7 on Aerospace Industry Methods and is the direct responsibility of Subcommittee F07.02 on Propellant Technology.

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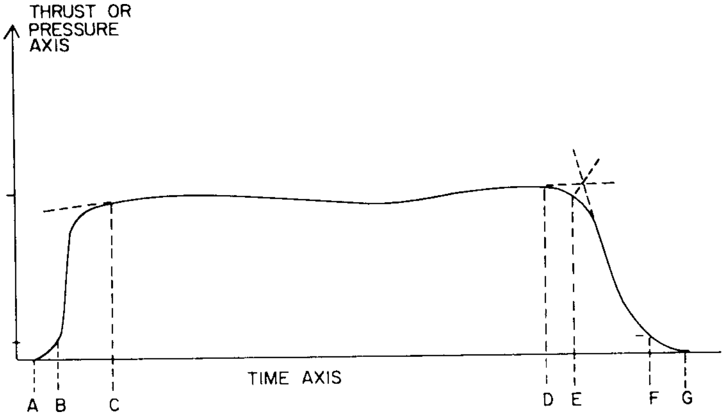
[2] *Annual Book of ASTM Standards*, Vol 15.03.

[3] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094.

[4] Procedures (except for specific impulse corrections in Section 6) used in this practice were released by the Chemical Propulsion Information Agency, Johns Hopkins University, Applied Physics Laboratory, Johns Hopkins Rd., Laurel, MD 20707 in August 1968, and are identical in substance to Publication No. 174, "Recommended Procedures for the Measurement of Specific Impulse of Solid Propellants."



All point and average pressure values shall be expressed and used in psia.

A = zero time, t_0.
B = time at which the chamber pressure, P_c, reaches 5 % of nominal value of P_a.
C and D = points of tangency with the "equilibrium" portion of the trace essentially as illustrated.
E = point on the pressure-time curve found by the intersection with the bisector of the angle between the two tangent lines at web burn-out.
F = time that the pressure reaches 5= % of nominal value of P_a on the decaying portion of the curve.
Gv= time at the end of thrust, t_f.

FIG. 1 Locations of Points on the Pressure/Thrust-Time Curve

6.2.5 Use nozzles that have a conical nozzle with exit cone half-angle of 15 ± 1°.

6.2.6 Use nozzles that have graphite inserts.

6.2.7 Use nozzles that have a conical approach half angle of 40 ± 10°.

6.2.8 Use nozzles that have a nozzle convergence ratio (inlet area/throat area) greater than three.

6.2.9 Use nozzles that have a ratio of wall radius of curvature at the throat-to-throat diameter greater than two.

6.2.10 Use nozzles that are insulated.

6.2.11 Use weighing equipment and techniques that assure accuracy to within 0.1 % of the propellant weight.

6.2.12 Record and use barometric pressure at time of firing as the basis for conversion to psia.

6.3 Specific impulse results are dependent upon care in making measurements, weighing (including calibration of scales and balances), alignment of the motors in test cells, calibration of the load cells, pressure gages, and test instruments, and data reduction.

7. Calculation

7.1 To obtain a standard value for the propellant specific impulse, the measured specific impulse shall be corrected to 6.55 MN/m^2 (1000 psia) average chamber pressure (based on $\bar{P}_a$), 0° exit cone half-angle, and optimum expansion at 101.354 kN/m^2 (14.7 psia) absolute. It is recommended that the symbol for the standard specific impulse be I_{sps} and that this symbol be used *only* for those tests which conform to *all* aspects of the correction procedure as follows:

$$I_{sps} = I_{sp}\,[C_F\ (\text{standard})/C_F\ (\text{test})]$$

7.2 C_F (standard) is a function only of the specific heat ratio (γ), and can be taken from Table 1 or calculated as in the Annex A1. C_F(test) can be calculated as in Annex A1, or can be taken from the following relationship:

$$C_F\ (\text{test}) = C_F\ (\text{vacuum}) - \epsilon\,(P_{amb} / \bar{P}_a)$$

C_F (vacuum) = function of γ and ϵ obtained from Table 1, Fig. 2, or Fig. 3,
ϵ = nozzle expansion ratio A_e/A_t,
P_{amb} = barometric pressure measured at time of firing, and

$\bar{P}_a$ is defined in 3.3.5.

8. Interpretation of Results

8.1 Data may not be acceptable because of aberrations in the traces due to one of many causes. It is therefore recommended that the following tests be applied to each trace and only those traces which meet all criteria to be used for computation of I_{sps} (the suggested symbol for standardized I_{sp}).

8.1.1 The trace should be neutral within the limits $0.90 \leq P/\bar{P}_b \leq 1.10$ over the time C to D (see Fig. 1).

8.1.2 The value of $\bar{P}_a$ should be between 5.52 and 7.58 MN/m^2 (900 and 1100 psi).

8.1.3 The tail-off portion of the trace should be limited by the following: $t_b \geq 0.87\, t_a$, and $\int_B^E$, $P dt \geq 0.95 \int_B^F P dt$ (See Fig. 1).

9. Report

9.1 Report the propellant specific impulse.

10. Precision and Bias

10.1 Due to the complex nature of this test method and the expensive equipment involved in the initial setup of the apparatus, there is not a sufficient number of volunteers to permit a cooperative laboratory program for determining the precision and bias of this test method. If the necessary volunteers can be obtained, a program will be undertaken at a later date.

11. Keywords

11.1 propellant; solid; solid rocket propellants; specific impulse

TABLE 1 Thrust Coefficients

NOTE 1—The following table presents the vacuum thrust coefficients as a function of nozzle expansion ratio for a range of gamma values. These vacuum thrust coefficients were calculated for conical nozzles with 15° exit half-angles and were obtained from the *AGC Solid Design Handbook*, edited by J. M. Haygood. The standard condition thrust coefficients for each gamma value are also included in the following table. Standard conditions are defined as 6.55-MN/m^2 (1000-psia) chamber pressure, an optimum expansion nozzle to 101.354 kN/m^2 (14.7 psia) and 0° exit cone half-angle.

	$\{\alpha = 0^\circ$	$\epsilon = 0$	$C_{F(\text{standard})} = 1.62049$		$\{\alpha = 0^\circ$	$\epsilon = 0$	$C_{F(\text{standard})} = 1.59666$
$\gamma = 1.6$	$\{\ \alpha = 15^\circ$	$\epsilon = 7.0$	$C_{F(\text{vacuum})} = 1.68811$	$\gamma = 1.20$	$\{\ \alpha = 15^\circ$	$\epsilon = 7.0$	$C_{F(\text{vacuum})} = 1.66835$
		7.5	1.69851			7.5	1.67776
		8.0	1.70804			8.0	1.68637
		8.5	1.71682			8.5	1.69428
		9.0	1.72496			9.0	1.70160
		9.5	1.73253			9.5	1.70840
		10.0	1.73960			10.0	1.71474
	$\{\alpha = 0^\circ$	$\epsilon = 0$	$C_{F(\text{standard})} = 1.60813$		$\{\alpha = 0^\circ$	$\epsilon = 0$	$C_{F(\text{standard})} = 1.58583$
$\gamma = 1.18$	$\{\ \alpha = 15^\circ$	$\epsilon = 7.0$	$C_{F(\text{vacuum})} = 1.67801$	$\gamma = 1.22$	$\{\ \alpha = 15^\circ$	$\epsilon = 7.0$	$C_{F(\text{vacuum})} = 1.65912$
		7.5	1.68790			7.0	1.65912
		8.0	1.69695			7.5	1.66808
		8.5	1.70529			8.0	1.67626
		9.0	1.71300			8.5	1.68378
		9.5	1.72018			9.0	1.69072
		10.0	1.72687			9.5	1.69716
						10.0	1.70316

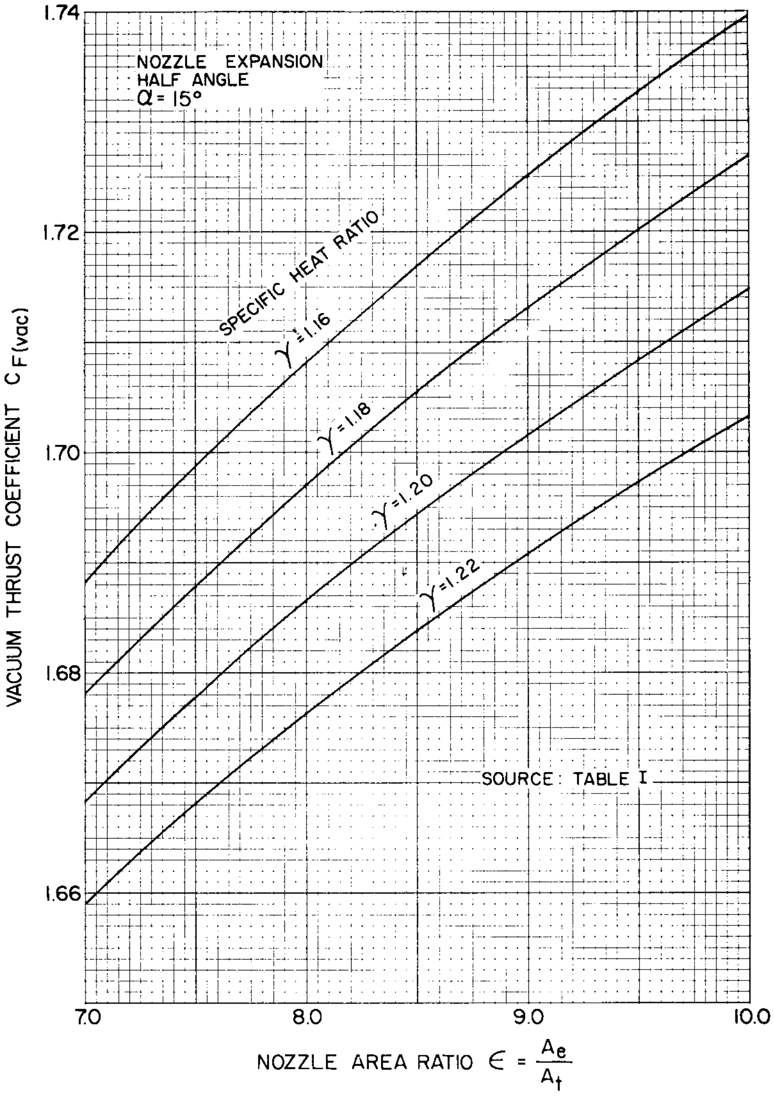


FIG. 2 Vacuum Thrust Coefficient Graph

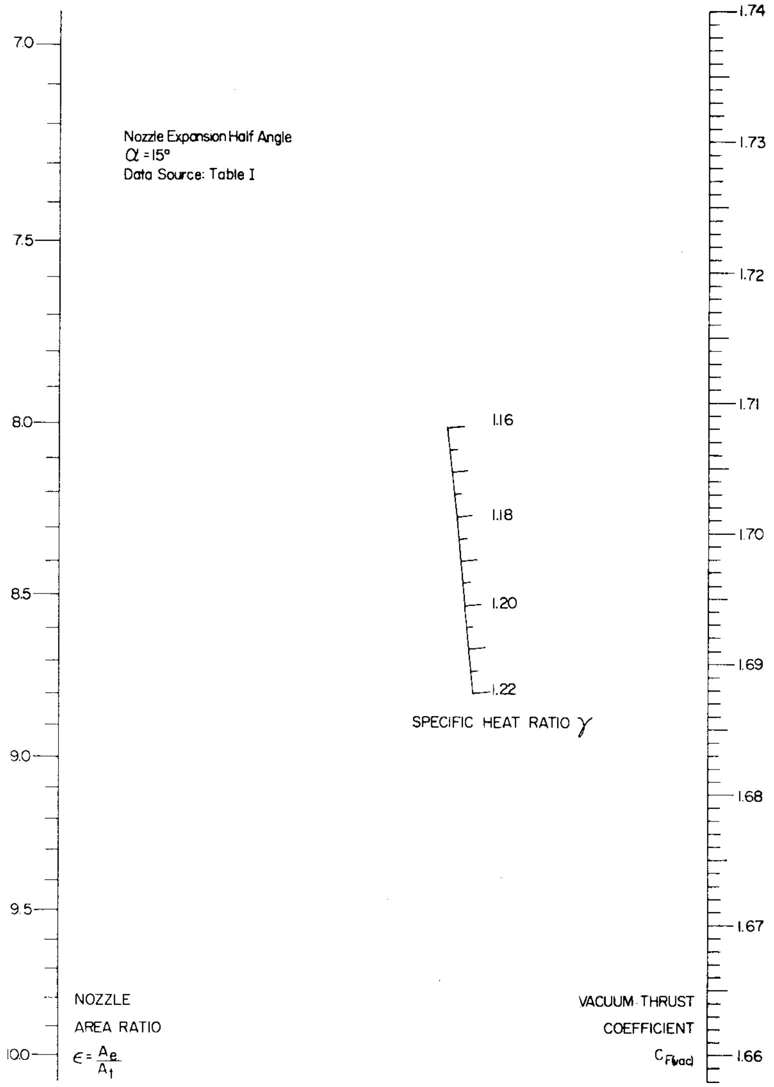


FIG. 3 Vacuum Thrust Coefficient Nomograph

ANNEX

(Mandatory Information)

A1. CALCULATION OF THRUST COEFFICIENT

A1.1 C_F is as calculated in Sutton, *Rocket Propulsion Elements,* 2nd Ed., p. 67, Eq 3 to 30 or Warren, *Rocket Propellants,* p. 81, Eq 4 to 35, modified by the divergence factor λ as follows:

$$C_F = \lambda \left\{ f(\gamma) \left[1 - \left(\frac{P_e}{P_c} \right)^{(\gamma-1)/\gamma} \right] \right\}^{1/2} + \left(\frac{P_e}{P_c} - \frac{P_{amb}}{P_e} \right) \frac{A_e}{A_t}$$

where:

λ = $(1 + \cos \alpha)/2$,

α = nozzle divergence half-angle,

γ = specific heat ratio,

$$f(\gamma) = \frac{2\gamma^2}{(\gamma - 1)} \times \left(\frac{2}{\gamma + 1} \right)^{(\gamma+1)/(\gamma-1)}$$

P_e = exit pressure,

P_{amb} = ambient pressure, and P_c

P_c = chamber pressure.

A1.2 $C_{F\ (\text{standard})}$ then reduces to:

$$C_{F(\text{standard})} = \left\{ f(\gamma) \left[1 - \left(\frac{14.7}{1000} \right)^{(\gamma-1)/\gamma} \right] \right\}^{½}$$

A1.3 $C_{F(\text{test})}$ then reduces to:

$$C_{F(\text{test})} = \frac{(1 + \cos 15°)}{2} \left\{ f\,(\gamma) \left[1 - \left(\frac{P_e}{\bar{P}_a} \right)^{(\gamma-1)/\gamma} \right] \right\}^{½} + \left(\frac{P_e}{\bar{P}_a} - \frac{P_{amb}}{\bar{P}_a} \right) \frac{A_e}{A_t}$$

where:

P_{amb} = barometric pressure measured at the time of test, and

$P_e/\bar{P}_a$ is determined from

$$\left(\frac{A_e}{A_t} \right) \left(\frac{1}{\lambda} \right) = \frac{\left(\dfrac{2}{\gamma + 1} \right)^{(\gamma+1)/[2(\gamma-1)]}}{\left(\dfrac{P_e}{\bar{P}_a} \right)^{1/\gamma} \left\{ \dfrac{2}{\gamma - 1} \left[1 - \left(\dfrac{P_e}{\bar{P}_a} \right)^{(\gamma-1)/\gamma} \right] \right\}^{½}}$$

and $P_e/\bar{P}_a$ can be obtained from one-dimensional isentropic flow tables by looking under an area ratio is numerically equal to

$$(A_e/A_t)(1/\gamma).$$

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