Designation: F3498 – 21

Standard Practice for Developing Simplified Fatigue Load Spectra[1]

This standard is issued under the fixed designation F3498; 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 practice provides data to develop simplified loading spectra that can be used to perform structural durability analysis for aeroplanes, specifically for wings of small aeroplanes. The material was developed through open consensus of international experts in general aviation. The information was created by focusing on Level 1, 2, 3, and 4 Normal Category aeroplanes. The content may be more broadly applicable; it is the responsibility of the applicant to substantiate broader applicability as a specific means of compliance.

1.2 An applicant intending to propose this information as Means of Compliance for a design approval must seek guidance from their respective oversight authority (for example, published guidance from applicable civil aviation authorities, or CAAs) concerning the acceptable use and application thereof. For information on which oversight authorities have accepted this standard (whole or in part) as an acceptable Means of Compliance to their regulatory requirements (hereinafter "the Rules"), refer to the ASTM Committee F44 web page (www.astm.org/COMMITTEE/F44.htm).

1.3 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1049 Practices for Cycle Counting in Fatigue Analysis

F3060 Terminology for Aircraft

F3115/F3115M Specification for Structural Durability for Small Aeroplanes

2.2 *EASA Standard:*[3]

CS-23 Normal, Utility, Aerobatic and Commuter Aeroplanes

2.3 *FAA Documents:*

14 CFR 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes[4]

AC 23-13A Fatigue, Fail-Safe, and Damage Tolerance Evaluation of Metallic Structure for Normal, Utility, Acrobatic, and Commuter Category Airplanes[5]

ACE-100-01 Fatigue Evaluation of Empennage, Forward Wing and Winglets/Tips Fins on Part 23 Airplanes[6]

Report No. AFS-120-73-2 Fatigue Evaluation of Wing and Associated Structure on Small Airplanes[7]

DOT/FAA/AR-96/46 User's Guide for FAR23 Loads Program[6]

DOT/FAA/CT-91/20 General Aviation Aircraft – Normal Acceleration Data Analysis and Collection Project[6]

3. Terminology

3.1 The following are a selection of terms relevant to this practice. See Terminology F3060 for more definitions and abbreviations.

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[1] This practice is under the jurisdiction of ASTM Committee F44 on General Aviation Aircraft and is the direct responsibility of Subcommittee F44.30 on Structures.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from European Aviation Safety Agency (EASA), Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, https://www.easa.europa.eu/.

[4] Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, http://www.faa.gov.

[5] Available from U.S. Government Publishing Office (GPO), 732 N. Capitol St., NW, Washington, DC 20401, http://www.gpo.gov.

[6] Available from National Technical Information Service (NTIS), 5301 Shawnee Rd., Alexandria, VA 22312, http://www.ntis.gov.

[7] Available from Clearinghouse for Federal Scientific and Technical Information, Springfield, VA 22151.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *fatigue, n*—the process of progressive, localized, permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses and strains at some point or points, which may result in damage or complete fracture after a sufficient number of fluctuations.

3.2.2 *safe-life, n*—the safe-life of a structure is that number of events, such as flights, landings, or flight hours, during which there is a low probability that the strength will degrade below its design ultimate value due to fatigue-induced damage.

3.2.3 *scatter factor, n*—statistically derived divisor applied to fatigue test results to account for the variation in fatigue performance of built-up or monolithic structures and usage variability. A scatter factor can also be used in a fatigue analysis to address the uncertainties inherent in a fatigue analysis; also called "life reduction factor."

4. Significance and Use

4.1 This standard practice provides one means for determining fatigue load spectra for aeroplane durability assessments. This information can be used in conjunction with Specification F3115/F3115M, Section 5, Load Considerations.

4.1.1 Users of this practice may propose alternate spectra, subject to the approval of their CAA.

4.2 The methods are applicable to the durability evaluation of wings of small aeroplanes. Additional calculation (such as methods noted in ACE-100-01) are needed to properly develop load spectra for fatigue evaluation of empennage and/or configurations with canards (or forward wings) and/or winglets (or tip fins), fuselage, and potentially other components, with approval from appropriate regulatory agency.

4.3 Much of the material presented herein is directly taken from AC 23-13A. The FAA developed the flight load spectra, presented herein, based on a statistical analysis of the data presented in DOT/FAA/CT-91/20. The ground load spectra are directly from AFS-120-73-2.

4.4 The flight load spectra, presented in Section 7, includes an adjustment (1.5 standard deviations) to the average measured load frequency. The adjustment accounts for the variability in the loading spectra experienced by individual aeroplanes, as well as across aeroplane types. The magnitude of the adjustment was selected to maintain the probability that a component will reach its safe-life without a detectable fatigue crack established by scatter factor (see paragraph 2–15 of AC 23-13A).

5. Load Spectra

5.1 The flight load (that is, gust and maneuver) along with ground load (that is, landing impact and taxi) spectra presented herein are for the following types of aeroplanes and usages:

5.1.1 Single-engine executive usage (non-pressurized, engine size greater than 185 hp).

5.1.2 Single-engine personal usage (non-pressurized, engine size less than or equal to 185 hp).

5.1.3 Single-engine instructional usage (non-pressurized).

5.1.4 Single-engine acrobatic (non-pressurized).

5.1.5 Twin-engine general usage (non-pressurized).

5.1.6 Twin-engine instructional usage (non-pressurized).

5.1.7 Pressurized usage.

5.1.8 Special usage (including survey and aerial application).

5.2 If the wing center section skin panels are affected by cabin pressurization or external aerodynamic pressure, the wing loading spectrum should include these effects.

5.3 Loading spectra should include the ground-air-ground cycle (GAG), where applicable. The GAG cycles represent the range of the maximum and minimum loads expected to occur on a per flight basis. Typically, the minimum load results from landing or taxi conditions, and the maximum load results from the gust or maneuver spectra. For typical aeroplanes certificated in the normal category, two-thirds to three-fourths of the total fatigue damage on the wing may be caused by the GAG cycle.

5.3.1 Cycle counting methods to re-order the load sequence across an entire flight history may be employed instead of using the GAG cycle for each flight. The cycle counting should be performed on a single flight spectrum with all appropriate flight and ground cycles included.

5.3.2 Cycle counting may be performed in accordance with Practices E1049.

5.4 While positive and negative load cycles are considered to occur randomly in service, the high positive and negative loads of a given type of repeated loading tend to occur close together during the flight.

6. Mission Profile

6.1 In developing the mission profile, the following assumptions should be considered:

6.1.1 *Flight Time:*

6.1.1.1 Single-engine and twin-engine (non-pressurized) – 0.65 h.

6.1.1.2 Pressurized – 1.10 h.

6.1.1.3 Single-engine special usage (low level survey) – 2.00 h.

6.1.1.4 Twin-engine special usage – 3.00 h.

6.1.2 *Aeroplane Speed:*

6.1.2.1 The speed for determining miles flown should not be less than $0.9V_{NO}$ or $0.9V_{MO}$.

6.1.2.2 For special usage, the speed for determining miles flown may be 100 knots or $0.9V_A$, whichever is less.

6.1.3 *Gross Weight and Load Distribution:*

6.1.3.1 Estimates of the gross weight and distribution of disposable load should be based on conservative estimates of typical operating conditions.

6.1.3.2 It is acceptable to use the weight condition that gives the highest 1-g stress for 1-g and per-g calculations (a segment-by-segment analysis would, therefore, not be necessary).

6.1.4 The mission profile of certain aeroplanes should consider any unique aspects of the usage. Some examples are as follows:

6.1.4.1 *Instructional Usage*—Takeoff and landing training, or "touch-and-go" training, is a significant portion of the student pilot training curriculum. Incorporate "touch-and-go" training into the mission profiles of any aeroplane used for instructional purposes. Each "touch-and-go" should be treated as a short duration flight, 6 min to 10 min in length.

6.1.4.2 *Mixed Usage*—Some aeroplanes are designed for more than one type of usage. In general, the spectrum should be based on the usage that results in the shorter life. It is acceptable to estimate a mix of missions, the percent of time spent operating in the different usages, as a way of accounting for the overall usage spectrum. In using this approach, it is not acceptable to use a mix of missions within a single flight. For purposes of fatigue evaluation, a single flight is operated within a single category and within a single type of usage.

6.1.4.3 *Severe Usage*—Some aeroplanes may be used more severely than assumed in the fatigue evaluation. Common examples of this include aeroplanes normally considered to be in the single-engine personal or executive usage type, but are used for pipeline and utility patrol, for instruction, or for short duration commuter and air taxi flights. Such severe usage may be addressed by placing a statement in the Limitations Section of the Instructions for Continued Airworthiness, in accordance with Specification F3115/F3115M, noting that certain types of usage require a re-evaluation of the structure by the type certificate (TC) holder. The instructions list these types of usage and requests the owner to contact the TC holder regarding the usage.

7. Flight and Ground Load Spectra

7.1 Table 1 summarizes the flight and ground load spectra presented herein.

7.2 Method to compute limit (see Note 1) gust load factor used in the gust load equation.

NOTE 1—The limit, in gust load factor, indicates being a subset of the envelope/design limit load case.

7.2.1 The limit (see Note 1) gust load factor (for use in developing fatigue loading spectra only) must be calculated using the same equation used to derive the gust spectra.

7.2.2 Equation for computing the incremental limit (see Note 1) gust load factor:

$$a_{nLLF} = \frac{UKVm}{498\frac{W}{S}} \quad (1)$$

where:

U = 30.0, nominal gust velocity in ft/s,

K = $\frac{1}{2}\left(\frac{W}{S}\right)^{\frac{1}{4}}$ for W/S < 16 lb/ft^2

= $1.33 - \frac{2.67}{\left(\frac{W}{S}\right)^{\frac{3}{4}}}$ for W/S > 16 lb/ft^2,

W/S = wing loading at maximum *gross* weight, lb/ft^2,

V = aeroplane structural design cruise speed, V_C, knots equivalent air speed (KEAS), and

m = wing lift curve slope, $C_{L\alpha}$, rad^{-1}.

7.3 Method to determine maneuver limit load factor. The maneuver limit load factor depends on the aircraft usage types, as prescribed in Section 7.1 of DOT/FAA/AR-96/46.

Usage Type	Positive Load Factor	Negative Load Factor
Normal	{2.1 + [24 000 ⁄ (Maximum Gross Weight + 10 000)]}≤3.8	–0.4 × positive load factor
Special/Utility	4.4	–0.4 × positive load factor
Acrobatic	6.0	–0.5 × positive load factor

7.4 Method to "normalize" the gust and maneuver load spectra.

7.4.1 Normalize the gust spectra to the incremental limit (see Note 1) gust load factor computed in 7.2 to derive the gust spectra in terms of the gust load factor ratio:

$$\frac{a_n}{a_{nLLF}} = \frac{\text{Incremental Gust Load Factor at Operating Weight}}{\text{Incremental Design Limit Gust Load Factor at Maximum Gross Weight}} \quad (2)$$

7.4.2 Normalize the maneuver spectra to the incremental maneuver limit load factor computed in 7.3 to derive the maneuver spectra in terms of the maneuver load factor ratio:

$$\frac{a_n}{a_{nLLF}} = \frac{\text{Incremental Maneuver Load Factor at Operating Weight}}{\text{Incremental Design Limit Maneuver Load Factor at Maximum Gross Weight}} \quad (3)$$

8. Correlation of Standard-Content and Rules

8.1 *Means of Compliance Correlation Sorted by Standard:*

	14 CFR 23	CS-23
4	§2240(a)	§2240(a)
5	§2240(a)	§2240(a)
6	§2240(a)	§2240(a)
7	§2240(a)	§2240(a)

8.2 *Means of Compliance Correlation Sorted by Rule:*

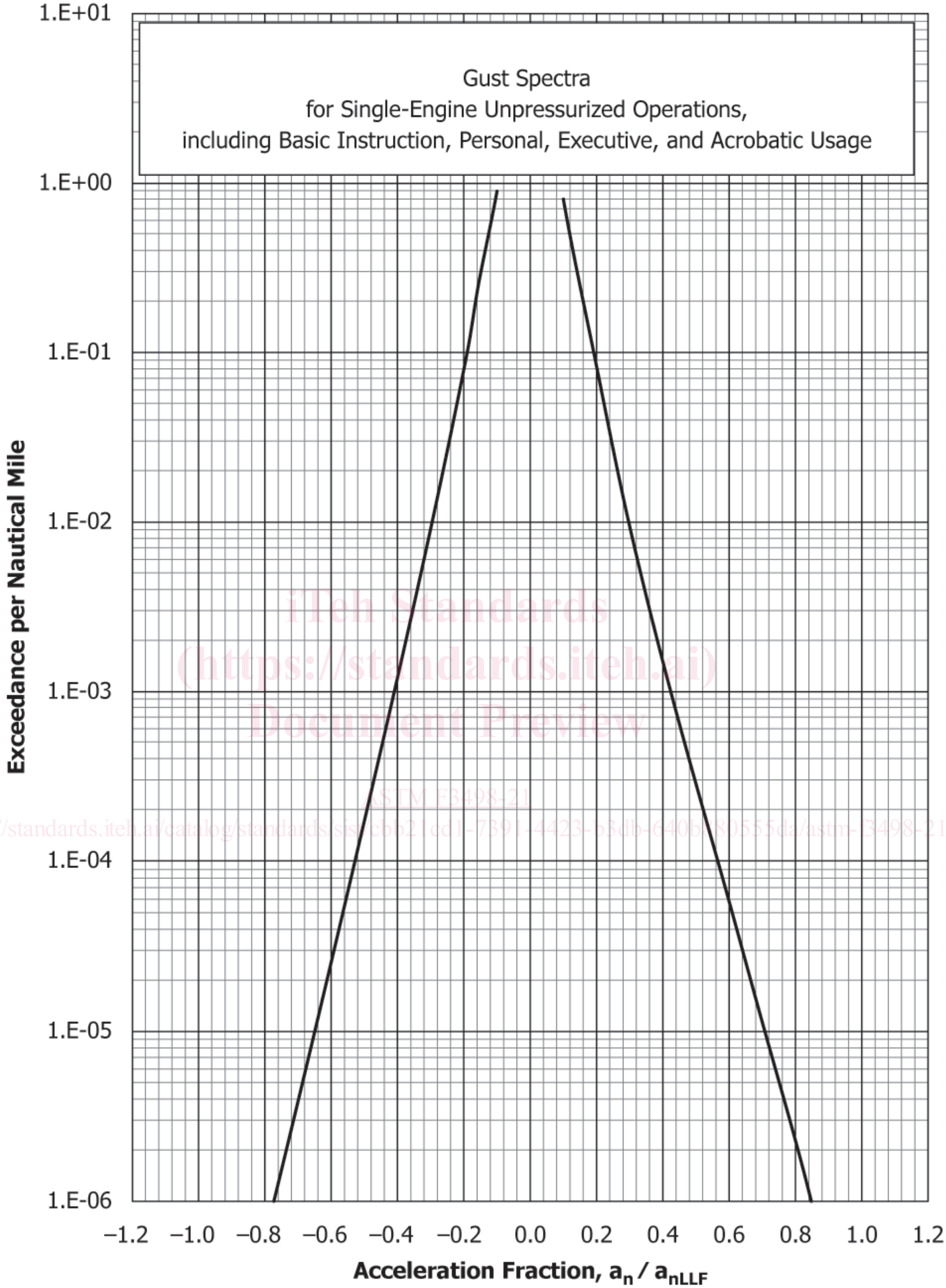
14 CFR 23	CS-23	
§2240(a)	§2240(a)	4, 5, 6, 7

9. Keywords

9.1 airframe structure; fatigue; fatigue spectra; gust; load; maneuver; spectra; taxi

TABLE 1 Flight and Ground Load Spectra

	Description	Graphic Data	Tabulated Data	Comments
Flight Spectra, General Usage, Single-Engine Unpressurized	Gust spectra for single-engine, unpressurized operations, including basic instruction, personal, executive, and acrobatic usage	Fig. 1	Table 2	These spectra should also be used for pressurized single-engine aeroplanes that spend a significant amount of flight time at low altitude.
	Maneuver spectra for single-engine basic instruction usage	Fig. 2	Table 3	No comments.
	Maneuver spectra for single-engine personal usage	Fig. 3	Table 4	An aeroplane in the personal usage category has a single, reciprocating engine with 185 hp or less.
	Maneuver spectra for single-engine executive usage	Fig. 4	Table 5	An aeroplane in the executive usage category has a single, reciprocating engine with more than 185 hp. The executive usage category also includes unpressurized, single-engine turboprop aeroplanes.
	Maneuver spectra for single-engine acrobatic usage	Fig. 5	Table 6	Applicable to typical acrobatic category aeroplane, n_z = +6g/–3g.
Flight Spectra, General Usage, Twin-Engine Unpressurized	Gust spectra for twin-engine, unpressurized operations, including instruction and general usage	Fig. 6	Table 7	These spectra should also be used for pressurized twin-engine aeroplanes that spend a significant amount of flight time at low altitudes, 7000 ft and below. An example of this type of operation is short flight duration commuter and air taxi operations.
	Maneuver spectra for twin-engine instruction usage	Fig. 7	Table 8	No comments.
	Maneuver spectra for twin-engine general usage	Fig. 8	Table 9	These spectra should also be used for pressurized and unpressurized twin-engine aeroplanes that may be operated in short flight duration commuter and air taxi operations.
Flight Spectra, General Usage, Single-Engine and Twin-Engine Pressurized	Gust spectra for pressurized usage	Fig. 9	Table 10	No comments.
	Maneuver spectra for pressurized usage	Fig. 10	Table 11	No comments.
Flight Spectra, Special Usage – Agricultural (Aerial Application)	Gust spectra for agricultural or aerial application usage	Fig. 11	Table 12	No comments.
	Maneuver spectra for agricultural or aerial application usage	Fig. 12	Table 13	No comments.
Flight Spectra, Special Usage – Survey (Pipeline Patrol)	Gust spectra for low-level survey or pipeline patrol usage	Fig. 13	Table 14	No comments.
	Maneuver spectra for low-level survey or pipeline patrol usage	Fig. 14	Table 15	No comments.
Ground Spectra	Landing impact	Fig. 15	...	No comments.
	Taxi	Fig. 16	...	No comments.

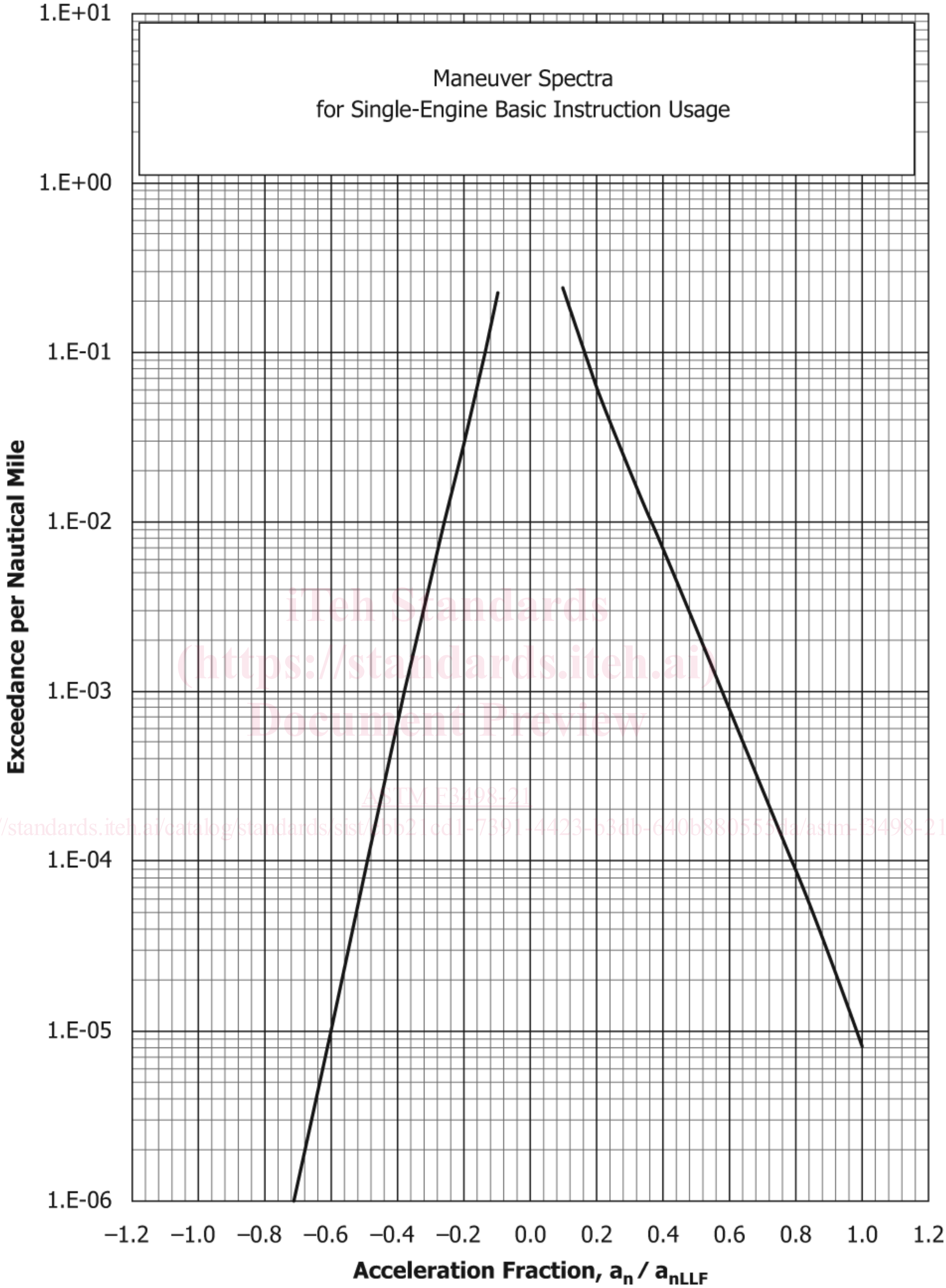


See Table 2 for tabulated spectra.

FIG. 1 Gust Spectra for Single-Engine Unpressurized Operations, including Basic Instruction, Personal, Executive, and Acrobatic Usage

TABLE 2 Gust Spectra for Single-Engine Unpressurized Operations, including Basic Instruction, Personal, Executive, and Acrobatic Usage

Acceleration Fraction	Exceedance per Nautical Mile	Acceleration Fraction	Exceedance per Nautical Mile
0.10	7.99040E-01	–0.10	8.86903E-01
0.15	2.39762E-01	–0.15	2.90400E-01
0.20	8.26537E-02	–0.20	7.93185E-02
0.25	2.59957E-02	–0.25	2.50615E-02
0.30	9.43437E-03	–0.30	8.64457E-03
0.35	3.74392E-03	–0.35	3.13716E-03
0.40	1.56672E-03	–0.40	1.17560E-03
0.45	6.76810E-04	–0.45	4.49619E-04
0.50	2.96910E-04	–0.50	1.74053E-04
0.55	1.31101E-04	–0.55	6.77344E-05
0.60	5.79043E-05	–0.60	2.63806E-05
0.65	2.55611E-05	–0.65	1.02760E-05
0.70	1.12764E-05	–0.70	4.00187E-06
0.75	4.97072E-06	–0.75	1.55782E-06
0.80	2.18708E-06	–0.80	6.05622E-07
0.85	9.58226E-07	–0.85	2.34685E-07
0.90	4.15769E-07	–0.90	9.01733E-08
0.95	1.76305E-07	–0.95	3.38733E-08
1.00	7.05919E-08	–1.00	1.19395E-08

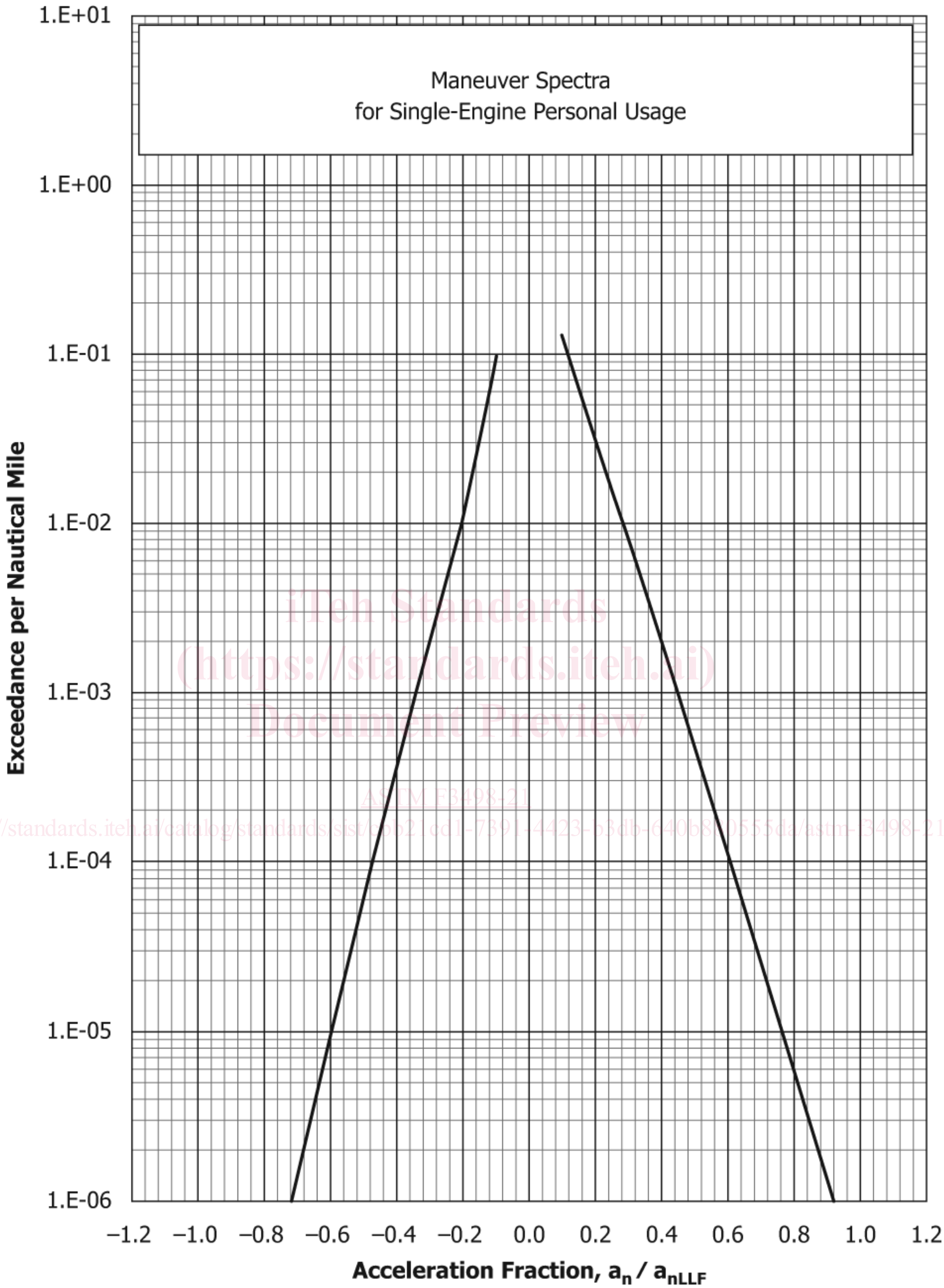


See Table 3 for tabulated spectra.

FIG. 2 Maneuver Spectra for Single-Engine Basic Instruction Usage

TABLE 3 Maneuver Spectra for Single-Engine Basic Instruction Usage

Acceleration Fraction	Exceedance per Nautical Mile	Acceleration Fraction	Exceedance per Nautical Mile
0.10	2.37466E-01	–0.10	2.22202E-01
0.15	1.20023E-01	–0.15	7.79188E-02
0.20	6.20605E-02	–0.20	2.89635E-02
0.25	3.45611E-02	–0.25	1.18361E-02
0.30	1.99278E-02	–0.30	4.73564E-03
0.35	1.16586E-02	–0.35	1.81743E-03
0.40	6.84325E-03	–0.40	6.69379E-04
0.45	4.01154E-03	–0.45	2.39525E-04
0.50	2.34706E-03	–0.50	8.45918E-05
0.55	1.38682E-03	–0.55	2.98155E-05
0.60	7.93694E-04	–0.60	1.04723E-05
0.65	4.59287E-04	–0.65	3.66958E-06
0.70	2.65584E-04	–0.70	1.28565E-06
0.75	1.53197E-04	–0.75	4.50315E-07
0.80	8.79528E-05	–0.80	1.57610E-07
0.85	5.01008E-05	–0.85	5.50454E-08
0.90	2.81951E-05	–0.90	1.91064E-08
0.95	1.55016E-05	–0.95	6.51330E-09
1.00	8.15702E-05	–1.00	2.10063E-09

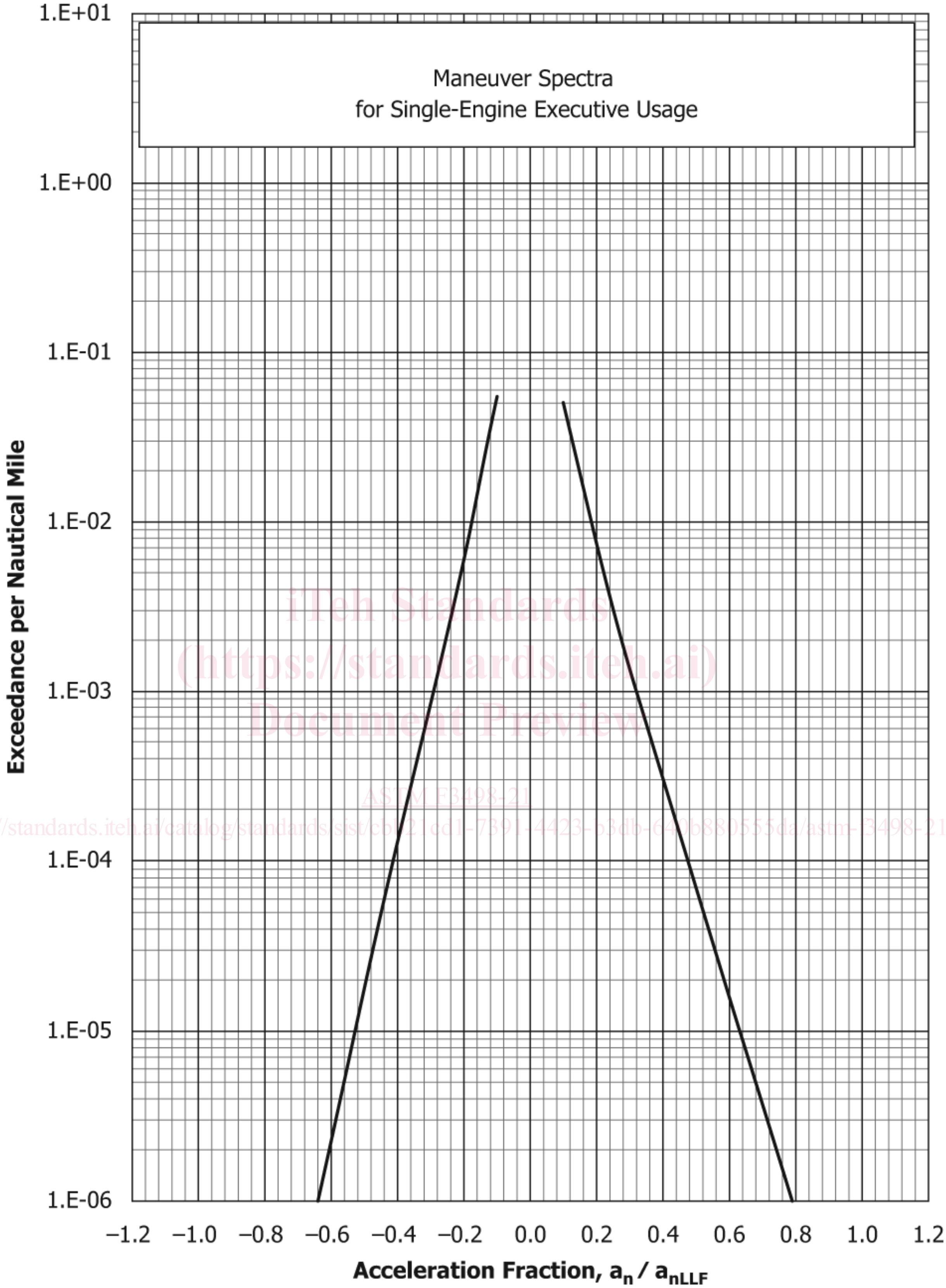


See Table 4 for tabulated spectra.

FIG. 3 Maneuver Spectra for Single-Engine Personal Usage

TABLE 4 Maneuver Spectra for Single-Engine Personal Usage

Acceleration Fraction	Exceedance per Nautical Mile	Acceleration Fraction	Exceedance per Nautical Mile
0.10	1.28156E-01	–0.10	9.71117E-02
0.15	6.27614E-02	–0.15	3.13880E-02
0.20	3.09500E-02	–0.20	1.09533E-02
0.25	1.58120E-02	–0.25	4.71523E-03
0.30	8.12433E-03	–0.30	2.07230E-03
0.35	4.12127E-03	–0.35	8.91211E-04
0.40	2.04241E-03	–0.40	3.75403E-04
0.45	9.97803E-04	–0.45	1.55129E-04
0.50	4.83819E-04	–0.50	6.29010E-05
0.55	2.33291E-04	–0.55	2.50877E-05
0.60	1.12320E-04	–0.60	9.84679E-06
0.65	5.40555E-05	–0.65	3.80374E-06
0.70	2.59889E-05	–0.70	1.44615E-06
0.75	1.24766E-05	–0.75	5.41094E-07
0.80	5.97051E-06	–0.80	1.99191E-07
0.85	2.83754E-06	–0.85	7.20825E-08
0.90	1.32888E-06	–0.90	2.55778E-08
0.95	6.02384E-07	–0.95	8.83264E-09
1.00	2.52545E-07	–1.00	2.89847E-09



See Table 5 for tabulated spectra.

FIG. 4 Maneuver Spectra for Single-Engine Executive Usage

TABLE 5 Maneuver Spectra for Single-Engine Executive Usage

Acceleration Fraction	Exceedance per Nautical Mile	Acceleration Fraction	Exceedance per Nautical Mile
0.10	5.10093E-02	–0.10	5.54495E-02
0.15	1.97508E-02	–0.15	1.88747E-02
0.20	7.38092E-03	–0.20	6.05428E-03
0.25	3.13527E-03	–0.25	2.32888E-03
0.30	1.40483E-03	–0.30	9.20494E-04
0.35	6.60426E-04	–0.35	3.59308E-04
0.40	3.12393E-04	–0.40	1.35529E-04
0.45	1.48798E-04	–0.45	4.99636E-05
0.50	7.13657E-05	–0.50	1.81837E-05
0.55	3.43582E-05	–0.55	6.53422E-06
0.60	1.65390E-05	–0.60	2.31853E-06
0.65	7.96002E-06	–0.65	8.12393E-07
0.70	3.82975E-06	–0.70	2.81096E-07
0.75	1.84127E-06	–0.75	9.60362E-08
0.80	8.83928E-07	–0.80	3.23840E-08
0.85	4.23025E-07	–0.85	1.07639E-08
0.90	2.01127E-07	–0.90	3.51182E-09
0.95	9.42952E-08	–0.95	1.10946E-09
1.00	4.28623E-08	–1.00	3.23514E-10