U.S. Department of Transportation **Federal Aviation Administration**

| **Subject:** AIRPLANE FUEL EFFICIENCY CERTIFICATION | **Date:** 12/13/2023 | AC No: 38-1 |
| | Initiated By: AEE-300 | |

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2 This advisory circular (AC) contains information and provides guidance on the implementation of the fuel
3 efficiency certification requirements for airplanes that are required by Title 14 of the Code of Federal
4 Regulations (14 CFR) part 38.
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AC 38-1: 14 CFR Part 38 Airplane Fuel Certification

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1. Purpose

This AC provides guidance on the implementation of fuel efficiency certification requirements for airplanes. These guidelines provide an acceptable means of demonstrating compliance with the regulations of Title 14 of the Code of Federal Regulations (14 CFR) part 38. The methods and procedures described herein have been proposed as recommended certification practice for showing compliance with the fuel efficiency requirements.

See Appendix 1 for definitions and Appendix 2 for acronyms, abbreviations, and symbols used throughout this AC.

1.1 Contents

This Advisory Circular (AC) contains information describing the standards and requirements for new aircraft fuel efficiency regulations in 14 CFR part 38. The information contained in this document sets forth acceptable means, but not the sole means, by which compliance may be shown with the requirements of 14 CFR part 38 (part 38).

In this AC, the word "paragraph" is used to refer to a part of the AC. The word "section" (or the symbol "§") is used to refer to a part of a regulation or statute.

Pursuant to §§ 231 and 232 of the Clean Air Act Amendments of 1970 (42 USC §§ 7571-7572), FAA's part 38 fuel efficiency regulations implement the standards adopted by U.S. Environmental Protection Agency (EPA) in 40 CFR part 1030 (see paragraphs 4.1 - 4.3 of this AC) by enforcing the EPA regulations at the time of certification. Any deviations from the procedures required under 14 CFR part 38 or 40 CFR part 1030 must be coordinated and approved by the Administrators of both the EPA and FAA (see paragraphs 4.2 and 4.3 of this AC). Users of this AC, and those subject to the regulations of part 38, are responsible for cognizance of any later amendments to 40 CFR part 1030 that may not be reflected immediately in 14 CFR Part 38 or this AC. In such instances, applicants may contact the AEE-300 Emissions Division Manager with the FAA Office of Environment and Energy at ralph.iovinelli@faa.gov for further guidance.

1.2 Advisory Nature

The contents of this AC do not have the force and effect of law and are not meant to bind the public in any way. This AC is intended only to provide information to the public regarding compliance with existing requirements under the law or agency policies. The use of mandatory language, such as "must" and "require" in this AC describe a mandatory requirement established by statute or regulation that exists independent of the material in this AC. The term "should" is used in this AC to indicate a recommendation described in this document and not a requirement. This AC describes one or more acceptable means, but not the only means, of complying with part 38 fuel efficiency certification standards. If an applicant chooses to use the guidance presented here as an acceptable means of compliance, it must be followed in all respects to be considered a valid means of compliance.

1.3 Audience

The intended audience for this AC includes airplane performance engineers, engine specialists, and propulsion engineers from the FAA's Aircraft Certification Service (AIR) and Aircraft Certification Branches; aircraft and aircraft engine industry specialists; aircraft certification applicants; other certification authorities, airlines, airport operators, engineering and scientific communities; and other persons that are interested in the certification of airplanes to the fuel efficiency standards of part 38.

1.4 Intent

The intent of this AC is to provide guidance for complying with the fuel efficiency requirements of part 38.

1.5 Approval of Equivalent Procedures

As provided in § 38.21, applicants may submit equivalent testing, measurement, and data reduction procedures to comply with part 38 airplane fuel efficiency regulations that apply to their airplane. Any such alternatives must be approved, in advance of part 38 compliance document submittals, by the FAA's Office of Environment and Energy (AEE), at FAA Headquarters in Washington DC. Further information on equivalent procedures is provided in paragraph 6.4 of this AC. If you have further questions, please contact the AEE-300 Emissions Division Manager with the Office of Environment and Energy at ralph.iovinelli@faa.gov.

1.6 FAA Certification Process

As of publication of AC38-1, the fuel efficiency certification requirements of part 38 are newly adopted in 2023, and it is expected that the FAA and U.S. manufactures will gain experience with their application through ongoing findings of compliance with part 38. The FAA-AIR line of business will work directly with the applicant in this process, and FAA's environmental office, AEE-300, is to remain fully involved with the FAA-AIR line of business in all fuel efficiency compliance efforts to provide guidance as experience is gained. Questions about part 38 from applicants should be submitted to the FAA-AIR line of business, that will then confer with the FAA-AEE environmental office for their resolution.

1.7 Related Documents

Part 38 contains the fuel efficiency certification requirements for certain airplanes. These regulations reference or are related to the following:

- Clean Air Act (CAA) §§ 231-232 (Aircraft Emissions Standards) Title 42 USC §§ 7571-7572.
- 40 CFR part 1030, Control of Greenhouse Gas Emissions from Engines Installed on Airplanes

Part 38 requirements are also referenced in the following regulations in 14 CFR:

- Part 21, Certification Procedures for Products and Articles including §§ 21.5, 21.17, 21.21, 21.29, 21.31, 21.93, 21.101, 21.115, 21.183, and 21.187,
- Part 121, Operating Requirements: Domestic, Flag, and Supplemental Operations including § 21.141, and
- Part 125, Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6,000 Pounds or More; and Rules Governing Persons on Board such Aircraft including § 125.75.

1.8 Definitions and Abbreviations/Acronyms/Symbols

Definitions are provided in Appendix 1 and abbreviations, acronyms, and symbols in this AC are provided in Appendix 2.

2. References

This AC references the following:

- Clean Air Act Amendments of 1970 (CAA), 42 U.S.C. § 7571 *et seq.*
- Control of Greenhouse Gas Emissions from Engines Installed on Airplanes; Emission Standards and Test Procedures, 40 CFR part 1030.
- International Civil Aviation Organization (ICAO) International Standards and Recommended Practices, Annex 16 — Volume III — Aeroplane CO_2 Emissions, May 2019
- International Civil Aviation Organization (ICAO) Environmental Technical Manual (Doc 9501),

185   Volume III — Procedures for the CO_2 Emissions Certification of Aeroplanes, May 2019
186
187   Additional references are provided in Appendix 5.
188
189   **3. [Reserved]**
190
191   **4. Development of Airplane Fuel Efficiency Regulations**
192
193   The United States is one of 193 signatory states to International Civil Aviation Organization's (ICAO)
194   Convention on International Civil Aviation (the Chicago Convention). Article 12 of the Chicago Convention
195   requires signatory states to keep their own regulations uniform, to the greatest extent possible, with those
196   established under the Chicago Convention. In March of 2017, the ICAO Council adopted a new CO2
197   Emissions Certification Standard with an effective date of July 2017. The ICAO considered three
198   categories of technology associated with the fuel efficiency of an airplane design (propulsion,
199   aerodynamics, and structures) in its adoption of a CO2 emissions certification standard for airplanes.
200
201   **4.1 Establishment of Airplane Fuel Efficiency Regulations**
202
203   49 USC § 40105(b)(1)(A) states that the Secretary of Transportation and FAA Administrator shall act
204   consistently with obligations of the United States Government under international agreements. For
205   development of aviation emissions standards, the FAA leads the U.S. delegation at ICAO meetings with
206   assistance from the EPA.
207
208   **4.2 Relationship Between the EPA and the FAA**
209
210   The Clean Air Act authorizes the EPA to set standards for aircraft engine emissions in the United States
211   (42 USC § 7571), while the FAA is authorized to enforce those standards. Section 7571 states the
212   following:
213
214   (2)(A) The Administrator shall, from time to time, issue proposed emission standards applicable to the
215   emission of any air pollutant from any class or classes of aircraft engines which in his
216   judgment causes, or contributes to, air pollution which may reasonably be anticipated to
217   endanger public health or welfare.
218   (B)(i) The Administrator shall consult with the Administrator of the Federal Aviation Administration
219   on aircraft engine emission standards.
220   (ii) The Administrator shall not change the aircraft engine emission standards if such change
221   would significantly increase noise and adversely affect safety.
222
223   The standards promulgated by the EPA in 40 CFR part 1030 apply to certain classes of engines used by
224   certain civil subsonic jet and propeller-driven airplanes (40 CFR part 1030.1). In developing airplane
225   emissions regulations, the CAA requires that the EPA consult with the FAA Administrator and ensure
226   that changes to emission standards do not significantly increase noise and adversely affect safety.
227
228   **4.3 Relationship Between 14 CFR Part 38 and 40 CFR Part 1030**
229
230   The fuel efficiency standards in 14 CFR part 38 implement those adopted by the EPA in 40 CFR part
231   1030. Accordingly, if the EPA takes any action to change any regulation or standard in 40 CFR part 1030
232   that is also promulgated in 14 CFR part 38, the Administrator of the FAA will grant a general
233   administrative waiver of those outdated requirements in 14 CFR part 38 until 14 CFR part 38 can be
234   amended to reflect the changes in 40 CFR Part 1030. (14 CFR § 38.9) The FAA will enforce the 40 CFR
235   part 1030 requirements, for which a waiver has been granted, as part of the 14 CFR part 38 fuel
236   efficiency certification. Under these circumstances, the certification documentation will reflect that it
237   complies with both 40 CFR part 1030 and 14 CFR part 38.
238
239

4.4 Differences Between ICAO Annex 16 Volume III and 14 CFR Part 38

Under the Chicago Convention, the FAA is obligated to notify ICAO of any U.S. regulatory differences between the ICAO standards and those adopted in the United States. The EPA refers to its regulations as greenhouse gas emissions in part 1030; FAA refers to its regulations as airplane fuel efficiency; and the ICAO standard is titled "Certification Standard for Aeroplane CO_2 Emissions Based on the Consumption of Fuel." The FAA, EPA, and ICAO each use different terminology to reference the same standards and there are no substantive differences with the meaning of these terms. The FAA has not identified any substantive differences between U.S. regulations and Annex 16 Volume III.

5. Part 38 Subpart A – General

5.1 Section 38.1 Applicability

Section 38.1(a) requires fuel efficiency certification for certain subsonic jets, propeller-driven airplanes, and modified airplanes. Fuel efficiency certification applicability is based on the date for which an application for a type certificate is submitted. In general, the standards apply to airplanes with new type designs (submitted on or after January 11, 2021); airplanes that were type certificated before January 11, 2021, but continue production with certain modifications on or after January 1, 2023; and all airplanes that are in production on and after January 1, 2028. The exact terms of applicability should be determined using the language of § 38.1, not from this brief description.

For subsonic jet and propeller-driven airplanes for which an application for a type certificate is submitted on or after January 11, 2021, part 38 applies as specified in Table 5.1. *See* § 38.1(a)(1)-(3).

Table 5.1.

Fuel Efficiency Certification Applicability for New Airplane Designs

For an airplane that is a:	With a passenger seating capacity of:	With a maximum takeoff mass (MTOM) in kg of:	For which an application for original type certification is submitted:
Subsonic Jet	20 or more	> 5,700	On or after January 11, 2021
Subsonic Jet	19 or fewer	> 60,000	On or after January 11, 2021
Subsonic Jet	19 or fewer	> 5,700 and < 60,000	On or after January 1, 2023
Propeller-driven	---	> 8,618	On or after January 11, 2021

Table 5.2 shows part 38 applicability to newly produced modified versions of airplanes (i.e. airplanes receiving their first certificate of airworthiness that are newly built with the modified type design) whose type design was not required to have fuel efficiency certification under part 38, and for which an application by the type certificate holder for a type design change is submitted on or after January 1, 2023. *See* § 38.1(a)(4)-(5)

Table 5.2.

Fuel Efficiency Certification Applicability for Modified Version of an Airplane Whose Type Design was not certificated under part 38

For an airplane that is a:	With a maximum takeoff mass (MTOM) in kg of:	For which an application by a type certificate holder for a type design change is submitted:
Subsonic Jet	> 5,700	On or after January 1, 2023

Propeller-driven	> 8,618	On or after January 1, 2023

281

282 Table 5.3 shows part 38 applicability to the production of individual airplanes for which the airplane type
283 design was not originally required to meet 14 CFR part 38. *See* §§ 38.1(a)(6)-(7).

284
285 **Table 5.3.**
286
287 Fuel Efficiency Certification Applicability for Airplanes issued Airworthiness Certificates
288 on or after January 1, 2028
289

For an airplane that is a:	With a maximum takeoff mass (MTOM) in kg of:	For which the first certificate of airworthiness is issued:
Subsonic Jet	> 5,700	On or after January 1, 2028
Propeller-driven	> 8,618	On or after January 1, 2028

290
291 *Note: 14 CFR 38 and 40 CFR 1030 requirements apply based on aircraft thresholds such as MTOM*
292 *"greater than 8,618 kg," while airworthiness applicability thresholds such as those of parts 21 and 23*
293 *might otherwise be expressed as 8,618 kg (19,000 lb). The FAA acknowledges that conversion from*
294 *8,618 kg to lbs is approximately 0.5 lbs less than the 19,000 lbs threshold of other FAA regulations.*
295 *However, when applying the conversion in reverse, going from 19,000 lbs to kg, the result is*
296 *approximately 0.25 kg greater than 8,618 kg. This less than 1 lb or 1 kg difference is extremely small*
297 *and it is unlikely that an airplane would fall within this conversion difference. Importantly, differences less*
298 *than 1 lb or 1 kg would not be reflected in either a type certificate data sheet (TCDS) or an airplane flight*
299 *manual. Additionally, the use of kilograms as the applicability threshold is consistent with the EPA*
300 *standard.*

301
302 Table 5.4, below, provides examples of the applicability of part 38.
303
304
305 **Table 5.4.**
306
307 Examples of Part 38 Applicability
308

Individual Airplane Status	Applicability Today	Effective Dates for Applicability of part 38	Applicability when modified	Fuel Efficiency Metric (FEM) Limit
In service, and type is no longer being produced EX: 757	None	None	None	None
Airplanes still being produced EX: 787-9	None	1/1/2023 for newly built modified airplanes § 38.1(a)(4) - (5); or 1/1/2028 for all newly built airplanes § 38.1(a)(6) - (7)	Must comply with the in-production limit if: (1) produced after 1/1/2023 (§ 38.1(a)(4) – (5)); and (2) includes a modification that changes the FEM value (§ 38.19(c)).	In-production limit § 38.17(b)(5) - (8)
New (Original) Type: large jet	§ 38.1(a)(1) and (3)	1/11/2021	All airplanes; New certification	New type limit § 38.17(b)(1) -

airplanes and propeller-driven airplanes			required if triggered by change criteria (§ 38.19(a))	(4)
New (Original) Type: small airplanes	§ 38.1(a)(2)	1/1/2023	All airplanes; New certification required if triggered by change criteria (§ 38.19(a))	New type limit § 38.17(b)(1)

5.1.1 *Modified Airplanes*

Section 38.1(b) states that part 38 fuel efficiency requirements apply to an airplane for which an application in type design is submitted that incorporates a modification that meets the change criteria in § 38.19. A new airplane produced with modifications meeting the change criteria may not exceed the applicable fuel efficiency limit of part 38. The applicability criteria for modified airplanes is described in § 38.19 and guidance is provided in paragraph 6.8 of this AC. A modified airplane is subject to the same fuel efficiency metric value limit in § 38.17 as the airplane was prior to modification.

Applicants may choose to apply for a new fuel efficiency metric certification value even when not required by part 38.

5.1.2 *Non-Applicability of the Fuel Efficiency Metric*

Part 38 fuel efficiency certification requirements do not apply to:

(1) Subsonic jet airplanes having a MTOM at or below 5,700 kg.

(2) Propeller-driven airplanes having a MTOM at or below 8,618 kg.

(3) Amphibious airplanes.

(4) Airplanes initially designed, or modified and used, for specialized operations. These airplane designs may include characteristics or configurations necessary to conduct specialized operations that the FAA and the United States Environmental Protection Agency (EPA) have determined may cause a significant increase in the fuel efficiency metric value.

   The FAA shares some examples of specialized operations from the ICAO Environmental Technical Manual, Volume 3, (ETM) that include:

   • Airplanes with mission requirements for carrying cargo that is not possible by using less specialized airplanes (e.g., ramped back cargo door);[1]
   • Airplanes with mission requirements for conducting very short or vertical takeoffs and landings; or
   • Airplanes with mission requirements for conducting scientific, research or humanitarian missions exclusive of commercial service.

(5) Airplanes designed with a reference geometric factor of zero.

(6) Airplanes designed for, or modified and used for, firefighting *(i.e. dispensing firefighting materials)*.

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[1] Example includes hinged fuselage sections such as Airbus' Beluga [A300-600].

353
354 (7) Airplanes powered by reciprocating engines.
355
356 Generally, airplanes in categories (3), (4), (5) and (6) are designed or modified in such a way that their
357 designs are significantly different from the typical passenger or cargo-carrying airplanes. See
358 § 38.1(c).
359
360 **5.2 Certification of Lower Takeoff Mass Variant**
361
362 The calculation of specific air range (SAR) is based on reference masses that are a function of the
363 MTOM, which is defined in §38.3 as the maximum certified takeoff mass, expressed in kilograms, for an
364 airplane type design. The MTOM is intended to mean the maximum takeoff mass an airplane type
365 design is certificated to that is stated in the TCDS. The TCDS may contain several maximum takeoff
366 masses for different variants of the same airplane type design, and the MTOM is the highest of these
367 maximum takeoff masses. In other words, for a specific airplane type design, applicants may develop
368 multiple take-off mass (TOM) variants for operational purposes. The highest TOM variant of an
369 airframe/engine combination for which certification of that variant under part 38 will be sought must
370 demonstrate compliance with part 38.17. All lesser TOMs are considered to have the same fuel
371 efficiency certification value as at MTOM.
372
373 However, applicants may also apply for certification of fuel efficiency metric values for TOM variants
374 lower than MTOM. For such a case, the calculated reference airplane mass required by §38.13(b) and
375 the maximum permitted fuel efficiency certification limits shown in §38.17 would be based on the TOM
376 variant requested to be certified. The FEM value determined for such a lower TOM variant can be also
377 used for any TOM variants that are even lower than for that specific airplane type design.
378
379 If an applicant chooses to certify a lower TOM variant, the applicant should be aware that the FEM at the
380 highest weight variant (MTOM) of an airplane has the lowest margin to the regulatory limit level.
381 Certification at MTOM is required regardless of the certification of any lower TOM variants. The 1/SAR
382 value used in the FEM determination is calculated as an average of 1/SAR values that are established at
383 three reference masses (high, medium, and low).
384
385 In establishing the reference specifications for specific air range (SAR) determination, the highest SAR
386 value usually will be sought at the maximum range cruise condition at the reference specifications. A
387 greater non-linearity in the 1/SAR versus mass relationship could be introduced by a constraint unrelated
388 to the aerodynamic and propulsive efficiency of the airplane (e.g., an altitude pressurization limitation). In
389 this instance, particular care should be taken to ensure that the principle of the highest weight variant
390 having the lowest margin to the regulatory limit level continues to hold.
391
392 **5.3 Exemptions**
393
394 Pursuant to 49 U.S.C. § 44701(f), the Administrator may grant an exemption from a regulatory
395 requirement if the Administrator finds the exemption is in the public interest. An application for an
396 exemption from any requirements of part 38 must be submitted to the Administrator in accordance with
397 part 11. For all § 38.5 exemption requests, denials, or grants, AEE will be the responsible FAA office and
398 will consult with EPA's Designated Program Officer and other FAA offices as needed before taking any
399 action. Petitioners for part 38 exemptions are encouraged to contact AEE prior to filing exemption
400 requests.
401
402 **5.4 Incorporation by Reference**
403
404 Section 38.7 incorporates, by reference, ICAO Doc 7488/3, *Manual of the ICAO Standard Atmosphere*
405 *(extended to 80 kilometres (262 500 feet))*, 1993. ICAO Doc 7488/3 provides the standard values of
406 atmospheric parameters, the values of constants and coefficients, and the underlying equations used in
407 the calculation of the atmospheric parameters. The manual is intended for use in calculations in the
408 design of airplanes, in presenting test results of airplanes and their components under identical

409   conditions, and in facilitating standardization in the development and calibration of instruments. ICAO
410   Doc 7488/3 is referenced in the Appendix to part 38, paragraphs A38.2.1.3.1, A38.5.2.2.1.9, and
411   A38.5.2.2.1.10. In these paragraphs, the applicant must use ICAO Doc 7488/3 to establish certain
412   reference specifications when determining SAR. Interested persons can purchase ICAO Doc 7488/3
413   from the ICAO Store at 999 Robert-Bourassa Boulevard Montréal (Quebec) Canada H3C 5H7,
414   (www.store.icao.int).
415
416   **5.5 Fuel Efficiency Compliance Demonstration Plans**
417
418   Prior to undertaking a demonstration of fuel efficiency, the applicant must submit procedures, weights,
419   configurations, and other information or data that are used to establish a fuel efficiency level to the FAA.
420   This submission must contain a complete description of the methodology and procedures by which an
421   applicant proposes to demonstrate compliance with part 38. This submission must be approved by an
422   FAA certification office in accordance with §38.21.
423
424   Use of any equivalent procedures or technical procedures not otherwise specified in part 38 must be
425   approved by AEE and documented in the submission as stated in §38.21. The submission should
426   include the following information:
427
428   a. A description of the applicable sections of part 38 for the airplane
429   b. Airplane description, including type, model number, and if applicable, the specific design
430   being certificated. The applicant should demonstrate and document the conformity of the test
431   airplane, particularly with regard to those parts which might affect the test airplane's fuel
432   efficiency metric (FEM).
433   c. FEM certification methodology which should include the means of compliance and proposed
434   equivalent procedures.
435   d. Test plan that would include:
436
437   i.   Test description. Test methods to comply with the test stability conditions in Appendix
438   A § A38.4.2.2.2 of part 38;
439   ii.   Test points. The planned number of test points and the planned test conditions in
440   terms of weight or mass, center of gravity position, altitude, and speed;
441   iii. Airplane mass. The procedures for determining the mass of the airplane is in
442   Appendix A § A38.4.2.3 of part 38; and
443   iv.   Test fuel properties. The procedures for determining the test fuel properties is in
444   Appendix A § A38.4.2.1.3 through A38.4.2.1.5 of part 38.
445
446   e. Deliverables: List the documents that should show compliance with Appendix A § 38.6 of part
447   38.
448
449   **5.6 Fuel Efficiency Compliance Demonstration for Airplanes with Intermixed Engines**
450
451   Typically, an applicant demonstrates compliance with part 38 for an airplane type design in which all
452   engines are of the same design. If there are engines of different design on an airplane, the design is
453   commonly referred to as having an "engine intermix" configuration, An applicant may choose to
454   demonstrate compliance of an airplane type design that includes an engine intermix.
455   In such a case, the applicant may, subject to the approval of the FAA, demonstrate compliance in one of
456   three ways:
457
458   a. In accordance with the test procedures defined in part 38, the test airplane must be
459   representative of the intermix arrangement for which certification is requested; or
460   b. In cases where the FEM value has been established for airplanes on which each of the
461   intermix engine models has been exclusively installed, compliance can be demonstrated on
462   the basis of either:
463   i. The average of the fuel efficiency evaluation metrics for identical airplanes on which each
464   of the intermix engine models has been exclusively installed; or

465   ii.   The highest fuel efficiency evaluation metric for identical airplanes on which each of the
466   intermix engine models has been exclusively installed.
467
468
469   **6. Expanded Discussion of 14 CFR part 38 Subpart B Requirements**
470
471   **6.1 Fuel Efficiency Metric**
472
473   The fuel efficiency metric (FEM) in § 38.11 is a transport capability neutral measure of airplane fuel
474   efficiency. The FEM system is intended to promote advances in technologies that contribute to
475   improvements in fuel efficiency (structural, propulsive, and aerodynamic efficiencies) as well as
476   differentiate among generations of such technologies. In addition, the fuel efficiency metric system was
477   designed to accommodate a wide range of technologies and designs that manufacturers may employ to
478   improve the fuel efficiency of an airplane in a manner that is transport capability neutral. The FEM
479   system is based on three elements associated with airplane technology and design:
480
481   1. Cruise point fuel burn performance;
482   2. Airplane size; and
483   3. Airplane mass.
484
485   Section 38.11 requires that, for each airplane subject to part 38, a fuel efficiency metric value is
486   calculated using the following equation (rounded to three decimal places):
487

$$Fuel\ Efficiency\ \text{metric value}\ =\ \frac{\left(\frac{1}{SAR}\right)_{avg}}{RGF^{0.24}}$$

489
490   The specific air range (SAR) is determined in accordance with § 38.13. The reference geometric factor
491   (RGF) is determined in accordance with § 38.15. SAR is expressed in units of km traveled per kg of fuel
492   burned, while RGF is dimensionless. The FEM value uses the inverse of SAR, $(1/SAR)_{avg}$, so FEM is
493   expressed in units of kg of fuel burned per km of flight. The fuel efficiency metric is determined using an
494   average of three SAR test points that are normalized by RGF, which is a geometric factor representing
495   the physical size of an airplane. A lower FEM value represents greater fuel efficiency. An overview of the
496   fuel efficiency metric system elements is shown in Figure 6-1, below.
497
498   **Fig. 6-1.**
499
500   Overview of the fuel efficiency metric system elements

Metric		Correlating Parameter
(1/SAR) / RGF^{0.24}		**Certified MTOM**
Specific Air Range (1/SAR)	**Reference Geometry Factor (RGF)**	**Airplane Maximum Take-Off Mass (MTOM)**
Specific Air Range is the distance an airplane travels per unit of fuel consumed.	Reference Geometric Factor is a non-dimensional number derived from a two-dimensional projection of the fuselage.	Maximum Take-Off Mass is the maximum certified takeoff mass, expressed in kilograms, for an airplane type design.

501
502
503   Unlike the specific fuel consumption (SFC) of an engine, which provides the engine's fuel consumption
504   per unit of thrust (i.e., fuel efficiency of thrust production by an individual engine), SAR is a measure of
505   fuel efficiency at the airplane level. Specifically, SAR provides the distance an airplane can travel per

506 unit of fuel (i.e., fuel efficiency of an airplane in level cruise flight). Airplane fuel efficiency defined by
507 SAR is commonly used by airplane manufacturers when describing airplane fuel efficiency performance
508 to customers (e.g., airlines).
509
510
511 **6.2 Specific Air Range**
512
513 As discussed in paragraph 6.1, Specific Air Range (SAR) is a measure of airplane cruise performance
514 that provides the distance an airplane can travel on a unit of fuel.
515
516 In accordance with § 38.13(a), for each airplane subject to part 38, the SAR value is calculated by using
517 either direct flight test measurements or using a performance model that is (i) validated by actual SAR
518 flight test data; and (ii) approved by the FAA before any SAR calculations are submitted.
519
520 The value of 1/SAR varies with airplane gross mass and is measured at three certification test points
521 based on gross mass. Section 38.13(b) provides that for each airplane model, a 1/SAR value is
522 determined at each of the following reference airplane masses:
523
524   1. High Gross Mass: 92 percent MTOM.
525   2. Low Gross Mass: (0.45 * MTOM) + (0.63 * (MTOM^0.924)).
526   3. Mid Gross Mass: simple arithmetic average of high gross mass and low gross mass
527
528 where all reference masses are expressed in kilograms (kg).
529
530 The three reference airplane masses were chosen with the objective of making the evaluation of fuel
531 burn performance relevant to day-to-day aircraft operations, and to make sure that the entire envelope of
532 cruise operations is accounted for. These three 1/SAR values, calculated at each of three certification
533 test points in accordance with §38.13(b), are weighted equally to give a single metric value. Section
534 38.13(c) requires that the value for $(1/SAR)_{avg}$ be obtained from the three 1/SAR points calculated in §
535 38.13(b), and subsequently used to determine the fuel efficiency metric value described in §38.11. An
536 illustrative example of the three representative cruise points is shown in the Figure 6-2.
537
538
539
540   **Fig. 6-2.**
541
542   An illustration of the three representative cruise points.
543

544
545
546
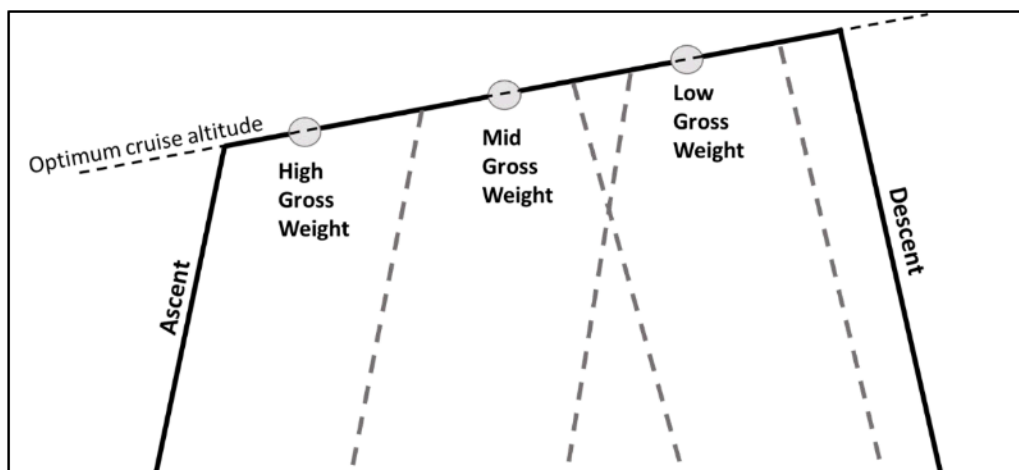
547   The SAR values for each of the three reference masses defined in § 38.13(b) are to be calculated either
548   directly from flight measurements taken at each valid test point adjusted to reference specifications, or
549   indirectly from a performance model that has been validated by the test points, as required by §
550   38.13(a). The final SAR value for each reference mass is the simple arithmetic average of all valid test
551   points at the gross mass, or derived from a validated performance model as stated in § A38.5.2.3.1. No
552   data acquired from a valid test point shall be omitted unless approved by the FAA, as stated in Appendix
553   A § 38.5.2.3.1.
554
555   *Note: Extrapolations consistent with accepted airworthiness practices to masses other than those tested*
556   *may be allowable using a validated performance model (for example, to validate new, higher MTOMs or*
557   *to validate the low gross weight range if it is not obtained during flight tests). The performance model*
558   *must be based on data covering an adequate range of lift coefficient, Mach number, and thrust specific*
559   *fuel consumption. No extrapolations of lift coefficient, Mach number, and thrust specific fuel consumption*
560   *are allowed. Use of any performance model is subject to AEE approval. See Appendix A § A38.5.2.3.2.*
561
562   **6.3 SAR Data Analysis**
563
564   SAR data used to demonstrate compliance must consider both the selection of flight test data gathered
565   during each test condition used for each individual SAR point, as well as the distribution of the resulting
566   corrected SAR points relative to the three reference masses and the reference specifications.
567
568   **6.3.1 SAR Measurement System**
569
570   As stated in § A38.5.1.6 of part 38 Appendix A, the SAR measurement system consists of the
571   instruments and devices, including any associated procedures, used to acquire the parameter values
572   that are necessary for determination of the SAR for each flight test condition. Section A38.5.1.8
573   prescribes an accuracy level (1.5%) that must be achieved by the measurement system for the
574   resulting SAR values to be used without penalty. If this accuracy level is not achieved, the resulting
575   SAR values will be penalized by the amount the measurement system error exceeds the 1.5% accuracy
576   level.
577
578   Section A38.5.1.7 defines the accuracy level of the measurement system to be the root sum of squares
579   (RSS) of the accuracies of the individual elements that make up the measurement system. The
580   individual elements of the measurement system are identified in § A38.5.1.6. The RSS of the
581   measurement system is determined from the equation, $RSS = \sqrt{A^2 + B^2 + C^2 + \cdots Z^2}$ where A, B, C, $\cdots$
582   Z, are the accuracies of each of the individual elements of the measuring system. The individual
583   elements must meet the accuracy requirements when showing compliance with part 38.
584
585   **6.3.2 Selection of Flight Test Data**
586
587   There are a number of methods that may be used by different airplane manufacturers in selecting flight
588   test data for analysis, reflecting a variety of tools and practices used within the industry. Whichever
589   method is chosen, the flight test data chosen by an applicant within a selected time frame for an
590   individual SAR data point must meet the stability criteria detailed in § A38.4.2.2.2 or alternative stability
591   criteria approved by the FAA as described in § A38.4.2.2.3. Test data that do not meet these stability
592   criteria would normally be discarded if not needed. However, if such test data appear to be valid when
593   compared with data that meet the stability criteria, and the overall stability of the conditions is
594   reasonably bounded, these data can be used, subject to FAA approval.
595
596   One acceptable method is to employ an algorithm that automatically selects the data that meet all the
597   stability criteria and discards data that do not. This method could be used to select the longest possible
598   duration SAR point that meets the required stability criteria, or to select multiple SAR points of the
599   minimum requirement duration (one minute), provided that these points are separated by a minimum of
600   two minutes or by an exceedance of the stability criteria, as specified in § A38.4.2.2.2.
601
602   Using a defined algorithm to select data in an automated process allows repeatable and consistent

603   application to other SAR points. This method may also yield a greater number of SAR points to be used
604   in defining the FEM value and should represent a good statistical distribution. However, because the
605   amount of test data included in each SAR point is maximized, the resulting SAR points could exhibit
606   more scatter than if additional selection criteria are used.
607
608   Another method for the selection of flight test data is to more closely examine the collected flight test
609   data and select the time frame to be used to define the SAR point by choosing the best or most stable
610   data available and ignoring less stable data that technically still meet the stability criteria. Examples of
611   this are presented in Figures 6-3 and 6-4.
612
613   Figure 6-3 shows that the plotted parameters stay within the tolerances allowed by the stability criteria
614   for the duration of the test condition. (The changing altitude after the end of the condition reflects pilot
615   input to leave steady flight and transition to the next test condition.) While all parameters are within the
616   required tolerances as specified in § A38.4.2.2.2, fluctuations in ambient temperature and Mach are
617   evident. Figure 6-4 shows the same data, but with a manually selected range of shorter duration where
618   the parameters are more stable.
619
620
621   **Figure 6-3.**
622
623   Flight test data time interval selection – Example 1
624

625
626
627
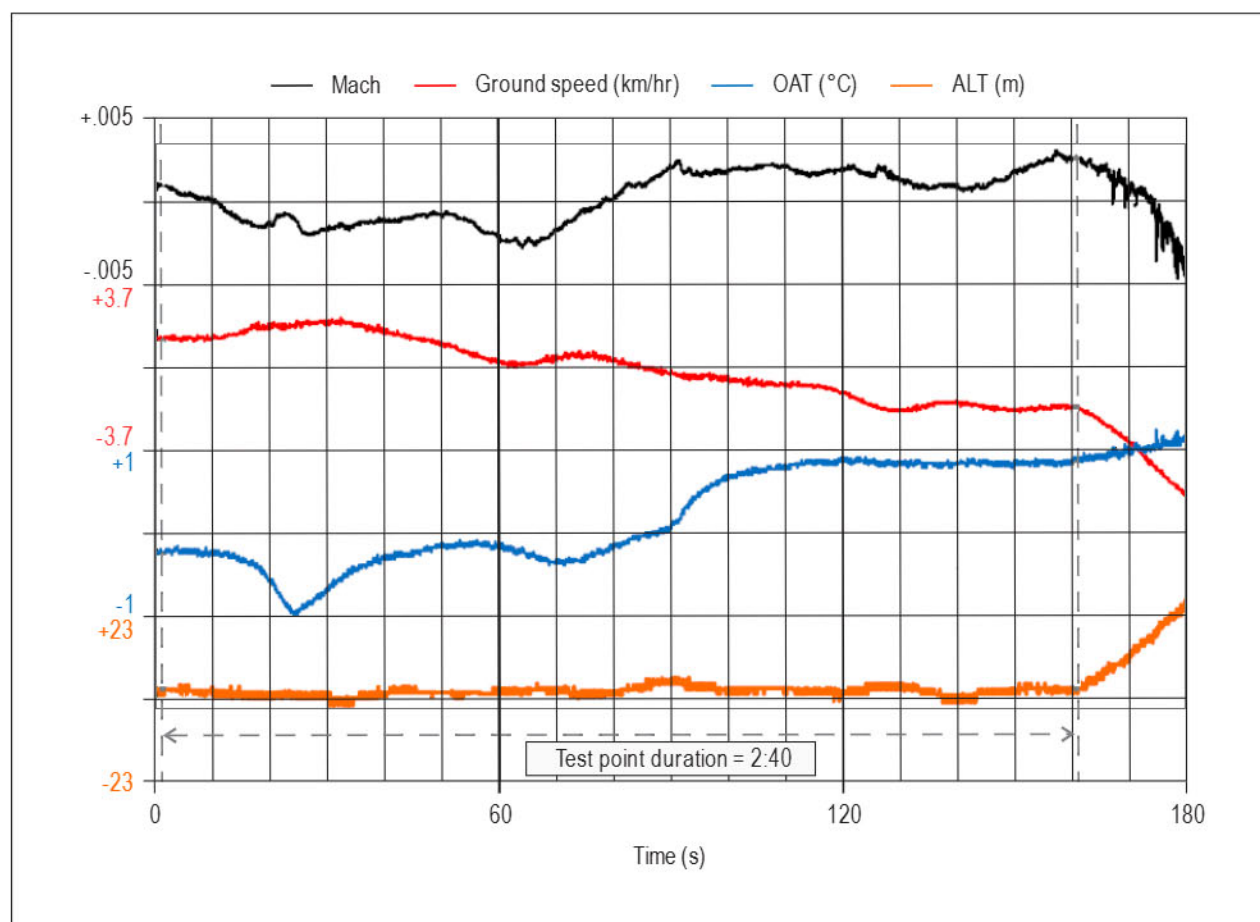
628
629   **Figure 6-4.**
630
631   Flight test data time interval selection – Example 2
632
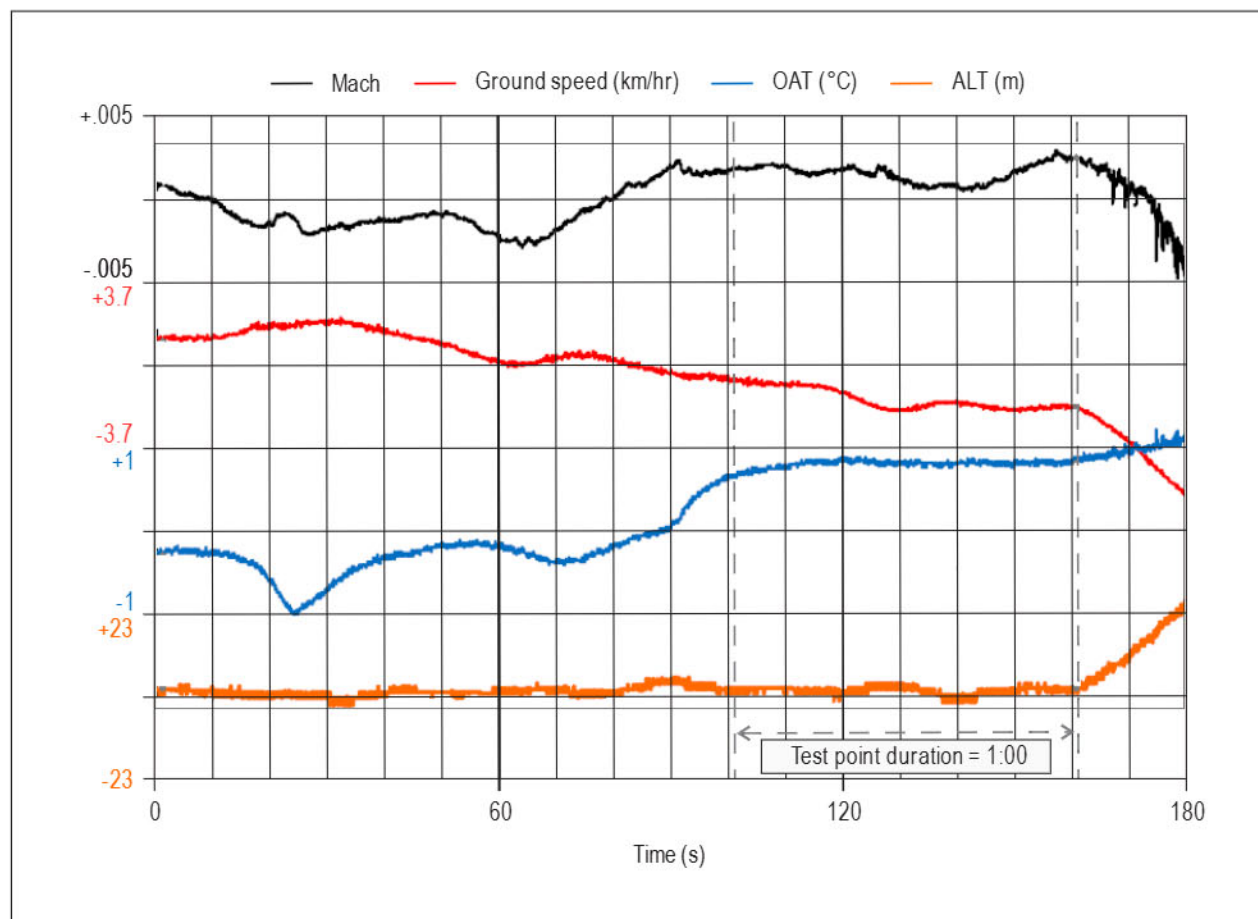
633
634
635   Selecting data that meet more demanding stability criteria, instead of using all data that meet the
636   stability criteria indicated in § A38.4.2.2.2, may allow the applicant to filter out observed instabilities
637   caused by air quality, changing environmental conditions, flight control inputs, and airplane system
638   dynamics. This could result in a SAR point that is more representative of actual airplane performance.
639   Whichever approach the applicant takes to select data to define SAR points, the methodology needs to
640   be applied as consistently as possible to minimize potential unseen bias in the resulting distribution of
641   SAR points.
642
643   Another important aspect to consider when selecting data is to ensure that the time interval chosen is
644   representative of the airplane's performance and not indicative of a larger trend. For example, the first
645   plot in Figure 6-3 shows a trend line drawn through ground speed data over a 60-second time interval.
646   This ground speed data meets the stability criteria and taken alone, would indicate the need for an
647   energy correction, which is used to correct for excess or inadequate potential or kinetic energy (i.e., a
648   deviation from the reference condition of steady, unaccelerated flight; see
649   *Acceleration/deceleration (energy)* in A38.5.2.2.1.1).
650
651   However, if the ground speed data trace was continued over a longer time interval, it becomes apparent
652   that it exhibits cyclical behavior. Cyclical data need not necessarily be discarded, but the applicant

653 should ensure that an appropriate time interval is selected such that the arithmetic average is
654 representative. In the example shown in Figure 6-5, below, an energy correction would be
655 inappropriate.
656
657   **Figure 6-5.**
658
659   Cyclical behavior example
660
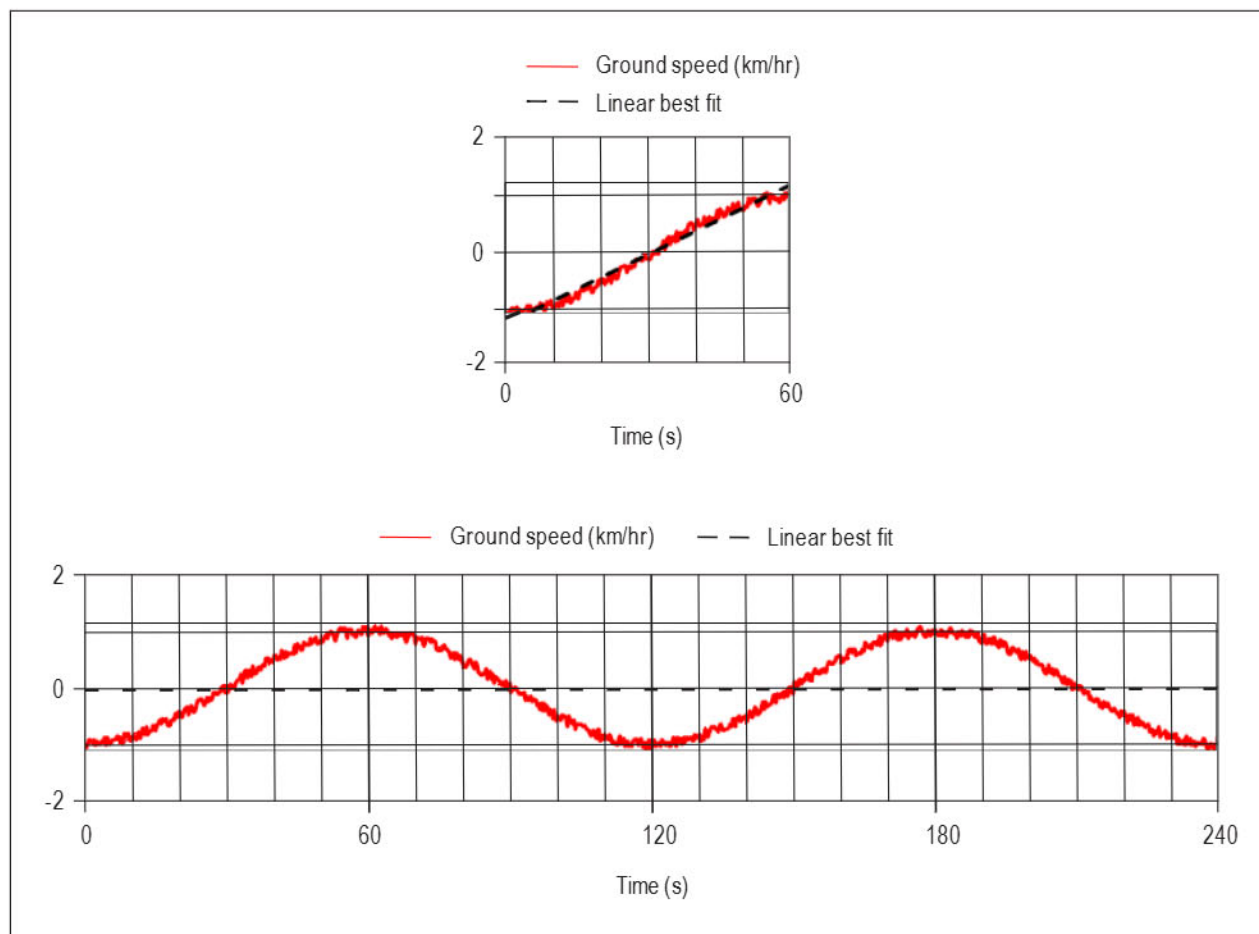
661
662
663 **6.3.3 Distribution of Resulting SAR Points**
664 Once the individual SAR points have been selected and corrected to reference specifications, they
665 need to be examined to ensure they reflect an accurate representation of the airplane's performance.
666 This is described in the following paragraphs.
667
668 For example, if direct flight test is being used to collect 6 SAR points targeting one reference mass,
669 those 6 points, when corrected to reference specifications, should result in a reasonable grouping. If 5
670 of the points form a reasonable grouping and one point is a clear outlier, the outlier may require closer
671 scrutiny to ensure it is actually representative. In such a situation, collection of additional data may be
672 warranted or, if appropriate, and subject to the approval of the FAA, the offending data point could be
673 discarded.
674
675 If the applicant conducts tests across a range of weights to build a regression line of SAR versus
676 weight, the collected SAR points should be reasonably distributed across the weight range. If a large
677 portion of the regression line is unsupported by data, or is anchored by a single SAR point, then the

678   SAR determined for one of the reference masses may be an outlier. This is an important aspect to
679   consider during the development of the certification plan and flight test program. As with the direct test
680   method, if a single SAR point appears to be an outlier compared to the rest of the data points, it needs
681   to be examined more closely and may potentially be discarded.
682
683   The applicant should investigate the collection of SAR points for potential sources of unintended bias.
684   An example would be where all of the data points collected were during periods when ground speed
685   was increasing. If all of the test points require a large energy correction in one direction, resulting in all
686   SAR points being significantly increased (or decreased), further scrutiny may be needed to ensure that
687   a bias is not introduced, depending on the test data and correction techniques being used.
688

689   **6.3.4 Correction of SAR Data to Reference Specifications**
690

691   To ensure that the SAR data has a consistent baseline for use in determining the FEM, the SAR data
692   must be corrected to a set of reference specifications as required in part 38 by § A38.2. One set of
693   methods for correcting the SAR data to reference specifications, but not the only acceptable set of
694   methods, is provided in Appendix 3 to this AC.
695

696   **6.4 Equivalent Procedures**
697   Use of equivalent procedures must be approved by AEE, in advance, and on a case-by-case basis in
698   accordance with § 38.21. Section 38.13(a) establishes the methods of compliance as being direct flight
699   test or by use of a validated performance model that is approved before any SAR calculations are
700   submitted.
701

702   Examples of equivalent procedures are the following:
703

704   **6.4.1 Example 1: FAA Approval based on existing data**
705   Applicants could develop a regression curve approach for SAR values across the gross weight (MTOM)
706   range based on existing data. This regression curve approach using existing data could be used in
707   situations such as:
708

709   a) The existing performance model used company test data that may have not been witnessed
710   by the FAA or documentation of the conformity of the airplane type design may not have
711   been provided to the FAA, but the data obtained are found acceptable by the FAA at the time
712   of certification, or
713   b) The accuracy of the instrumentation and the data reduction processes may not have been
714   documented sufficiently for certification, or the original documentation may not have been
715   retained, but the data available are found acceptable by the FAA at the time of certification.
716

717

718   **6.4.2 Example 2: FAA Approval of a change based on back-to-back testing**
719   The use of back-to-back test data may be requested by applicants as an equivalent procedure for
720   determining the FEM for a relatively small type design change (e.g., antenna installations or other
721   simple drag changes). Back-to-back testing for determining a FEM value change means that a test is
722   first completed without the change applied to the airplane, and then the test is repeated with the change
723   made to the airplane. The difference in the FEM values of the before and after tests is presumed to be
724   the result of the change on the airplane FEM value. This approach may not be appropriate for engine
725   changes where the specific fuel consumption (SFC) of the engine may change due to internal changes.
726   This compliance approach will likely be especially useful for supplemental type certificate (STC)
727   modifiers who do not have access to the original flight test data from the airplane manufacturer, such
728   as:
729

730   a)   Back-to-back testing should be performed on the same airplane and engines with the
731   modification installed and not installed.
732   b)   Instrumentation adequate to provide data meeting the accuracy requirements of the standard
733   should be installed in the test airplane.

734   c) The data reduction and comparison processes must be approved by the FAA in accordance
735   with § 38.21.
736

6.4.3 Example 3: FAA Approval of a change based on analysis

739   The use of analytical processes may be requested by an applicant to evaluate a change to the FEM of
740   a previously approved airplane type design and establish compliance with § 38.17, and the analytical
741   processes must be approved by the FAA in accordance with § 38.21. Paragraphs 6.4.3.1 and 6.4.3.2,
742   below, provide a non-exclusive list of possible analytical methods, but do not preclude the use of other
743   equivalent procedures.

6.4.3.1 *Changes affecting characteristics of airplane aerodynamics*

747   Subject to approval by the FAA, methods available to evaluate the effect of aerodynamic changes on
748   airplane drag could include:

750   • Semi-empirical methods (SEM),
751   • Computational fluid dynamics (CFD),
752   • Computational fluid dynamics combined with computational structural mechanics (CFD-CSM),
753   and
754   • Wind tunnel testing.

756   The FAA's approval for the use of the above analytical methods to evaluate a change to the FEM
757   value may depend on the type of airplane modification as listed below.

759   For design changes affecting parasitic drag and/or profile drag (e.g., friction drag and/or viscous
760   pressure drag), SEM, CFD, or wind tunnel testing could be used. In this case, it is assumed that
761   airplane aeroelastics are not affected.

763   For all other design changes, CFD could be used for items not affecting airplane aeroelastics,
764   CFD-CSM could be used for items affecting airplane aeroelastics, and wind tunnel testing could be
765   used in all cases.

6.4.3.2 *Changes to specific fuel consumption (SFC) affected by a change to the propulsion system:*

770   Possible methods available to evaluate the effect of propulsion system design changes on specific fuel
771   consumption (SFC) are:

773   a. Thermo dynamical models (engine performance decks),
774   b. Computational fluid dynamics (CFD),
775   c. Component testing,
776   d. Full engine testing, and
777   e. A combination of a. through d.

6.4.4 Example 4: FAA Approval based on first principle models

782   *Introduction*

784   Section 38.13(a) requires that the specific air range must be determined by direct flight test
785   measurements or the use of a performance model that is:-

787   I. validated by actual SAR flight test data and
788   II. approved by the FAA before any specific air range calculations are submitted.
789

790   A performance model is defined in 38.3 as "an analytical tool (or a method) validated using corrected
791   flight test data that can be used to determine the specific air range values for calculating the fuel
792   efficiency metric value."
793
794   Guidance on the approval of SAR values based on specific types of performance models known as
795   "first principle models" is provided below. A first principle model is defined as a tool that enables the
796   derivation of a SAR value, in given flight conditions, from flight mechanics equations using airplane
797   aerodynamics and engine performance data.
798
799   First principle models should be validated by actual SAR flight test data that is acquired in a manner
800   consistent with § A38.1.2 and as described in paragraph 6.3 of this AC. Validity of the model need only
801   to be shown for the test points and conditions relevant to demonstrating compliance with § 38.17.
802
803   The method proposed in this paragraph, 6.4.4, represents one possible method to show compliance
804   with § 38.17.
805
806   **6.4.4.1 Selection of relevant flight test points for the model validation**
807
808   First principle SAR models developed by airplane manufacturers typically cover most of the flight
809   envelope to provide many different operational fuel planning requirements. The range of flight test data
810   from these models typically spans large Mach and weight/δ ranges.
811
812   The example shown in Figure 6-6, below, illustrates the wide distribution of the flight test data across
813   the model, and that none of the test points generally fall exactly at the three SAR conditions defined in
814   § 38.13(b).
815
816   **Figure 6-6.**
817

818   Test points range
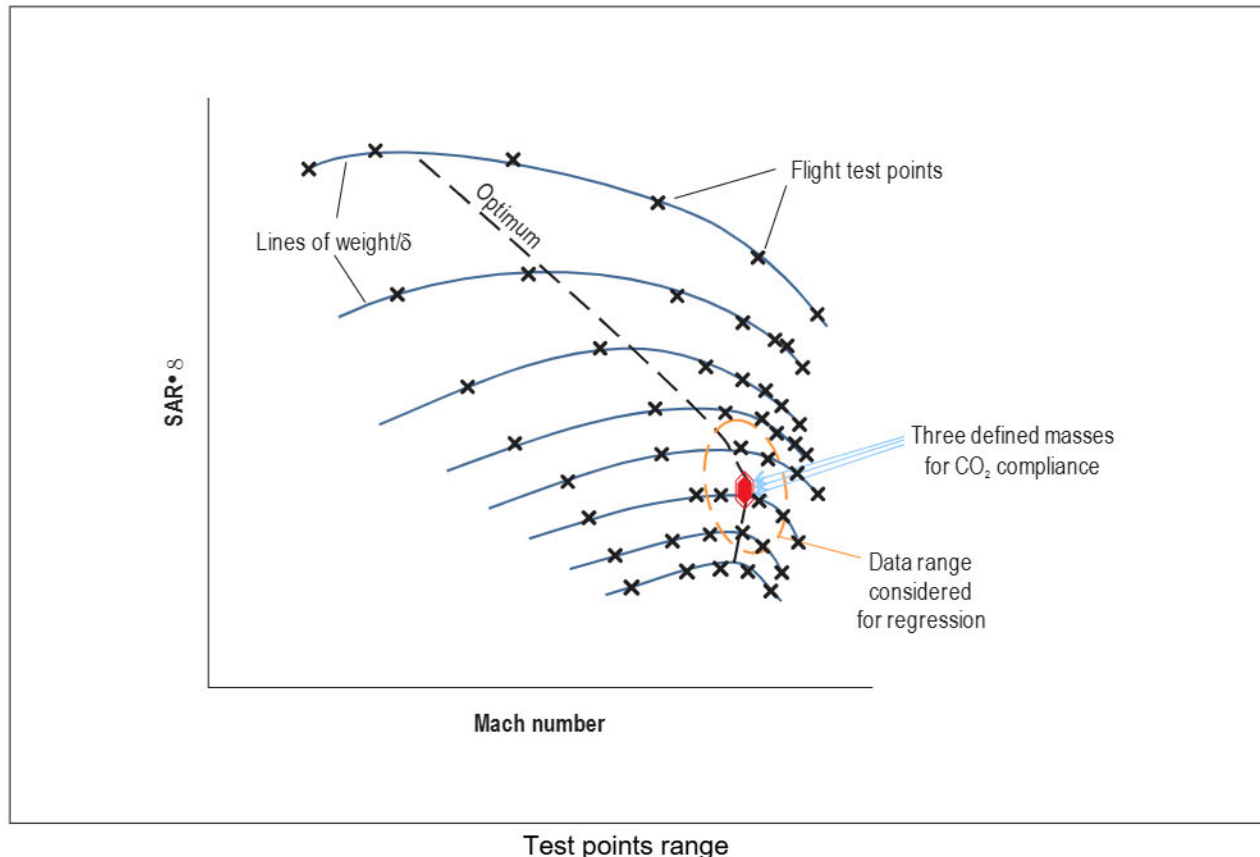
819
820   Figure 6-6 shows that the three SAR conditions required by § 38.13(b) are relatively close to each
821   other in terms of Mach and weight/δ because they represent the same optimum aerodynamic
822   conditions for achieving the best (lowest) 1/SAR values. Although these three SAR conditions may not
823   have been specifically flight tested, they are generally well framed by other relevant flight test data in a
824   local Mach and weight/δ range.
825
826   In order to validate the performance model in conditions relevant to demonstrating compliance with §
827   38.17, flight test points around the optimum Mach number and optimum weight/δ would be selected
828   based on the following criteria:
829
830   a) Weight/δ between ±5 percent of the optimum weight/δ; and
831   b) Mach number between -0.02 and +0.015 of the optimum Mach number.
832
833   *Note 1.— The ±5 percent value in a) is used to capture flight test points on weight/δ lines above and*
834   *below the optimum weight/δ included in the airplane manufacturer's flight test practices.*
835
836   *Note 2.— The density of test points is generally lower at Mach numbers below the optimum Mach*
837   *number and higher at Mach numbers above the optimum Mach number. Additionally, the Mach effect*
838   *on SAR is generally less at Mach numbers below the optimum Mach number than above, and a sharp*
839   *SAR decrease may occur when approaching high Mach numbers. For this reason, the Mach range for*
840   *the test point selection is larger at Mach numbers below the optimum Mach number (-0.02) than above*
841   *(+0.015).*
842
843   *Note 3.— Testing target weight/δ values non-dimensionalizes the pressure altitude so that weight/δ*
844   *varies as $C_L M^2$. Therefore, weight/δ at a given Mach varies similarly to C_L at that Mach number.*
845
846   ### 6.4.4.2 SAR model justification
847
848   ### 6.4.4.2.1 Flight test SAR versus SAR model
849
850   In order to use first principle models to determine the SAR values for calculating the FEM,
851   manufacturers are expected to explain their modelling validation principles and show that their
852   modelling correctly matches flight test data acquired in a manner consistent with part 38 Appendix A,
853   as described in paragraph 6.3 of this AC.
854
855   As shown in Figures 6-7 and 6-8, below, one possible method is to present plots of percent ΔSAR
856   (i.e. Measured SAR minus Computed SAR) versus Mach and versus weight/δ (or C_L). These should
857   be shown in the Mach and weight/δ (or C_L) range of the cruise envelope.
858
859   An increased number of test points, when available, may be used to qualitatively show that the test
860   point selection, described in paragraph 6.4.4.1 above (red points selected for optimum SAR in
861   Figures 6-7 and 6-8 below, which are within the orange dashed circle in Figure 6-6), is not differently
862   scattered or biased than other test points in the cruise envelope (green points that are all the flight
863   test data in Figures 6-7 and 6-8 below, and these are outside the orange dashed circle in Figure 6-6).
864   Figures 6-7 and 6-8 are examples of a set of data that show no significant biases or differences in
865   scatter inside and outside the cruise envelope.
866
867
868
869
870
871
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873

874
875
876
877

Figure 6-7

ΔSAR versus Mach number

878
879
880
881
882
883
884
885
886

Figure 6-8.

ΔSAR versus C_L

887
888
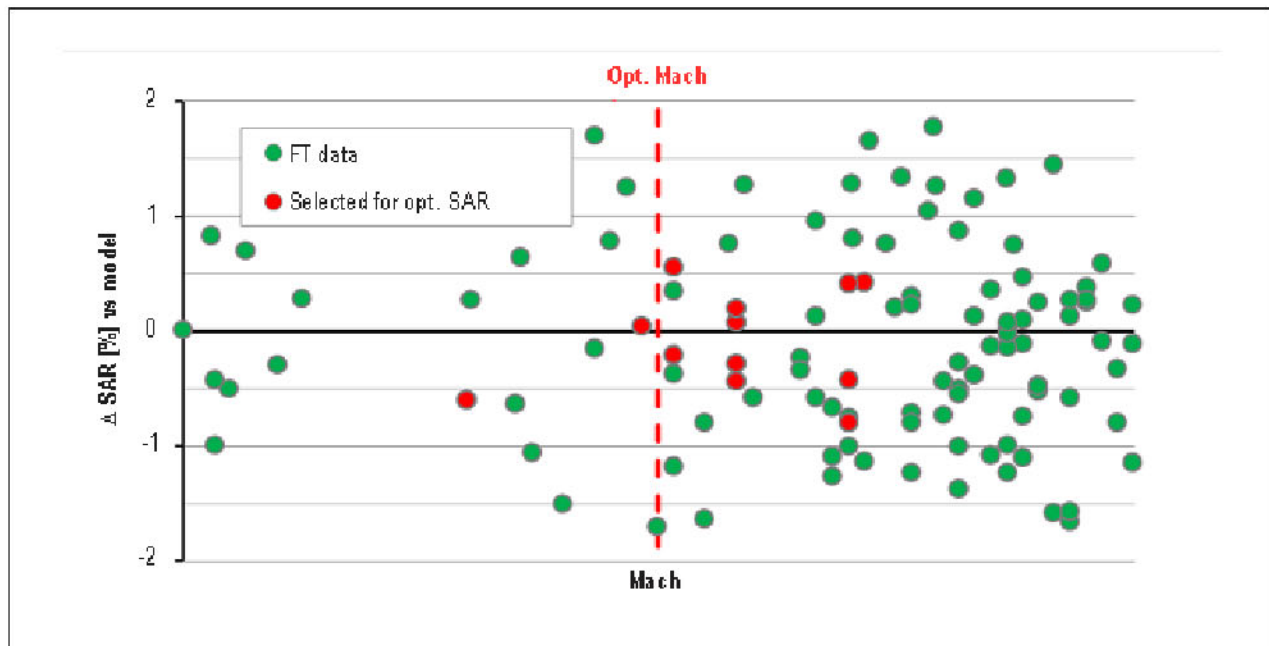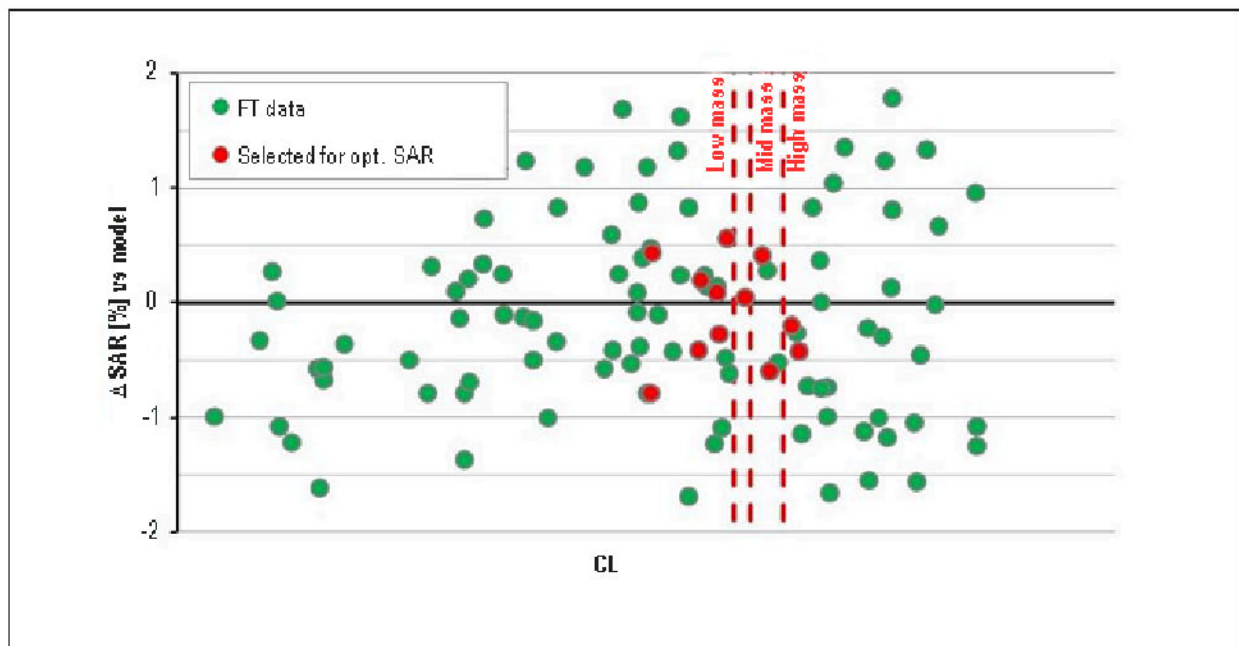
889
890
891   **6.4.4.2.2 SAR model presentation**
892
893   The comparison of flight test points with a model does not validate how that model is built and how
894   the optimum conditions represent the FEM. Accordingly, the SAR model used to demonstrate
895   compliance with § 38.17 must be approved by FAA per § 38.13(a)(2).
896
897   One possible method to present the SAR model is to present plots of computed SAR versus Mach
898   and computed SAR versus C_L for the three masses referenced in § 38.13(b). Figures 6-9 and 6-10
899   show that there are no abnormal discontinuities in the Mach and C_L ranges selection around SAR
900   conditions used for the FEM determination.
901
902
903
904
905   **Figure 6-9**
906
907   Computed SAR (model) versus Mach at optimum altitude
908

909
910
911
912
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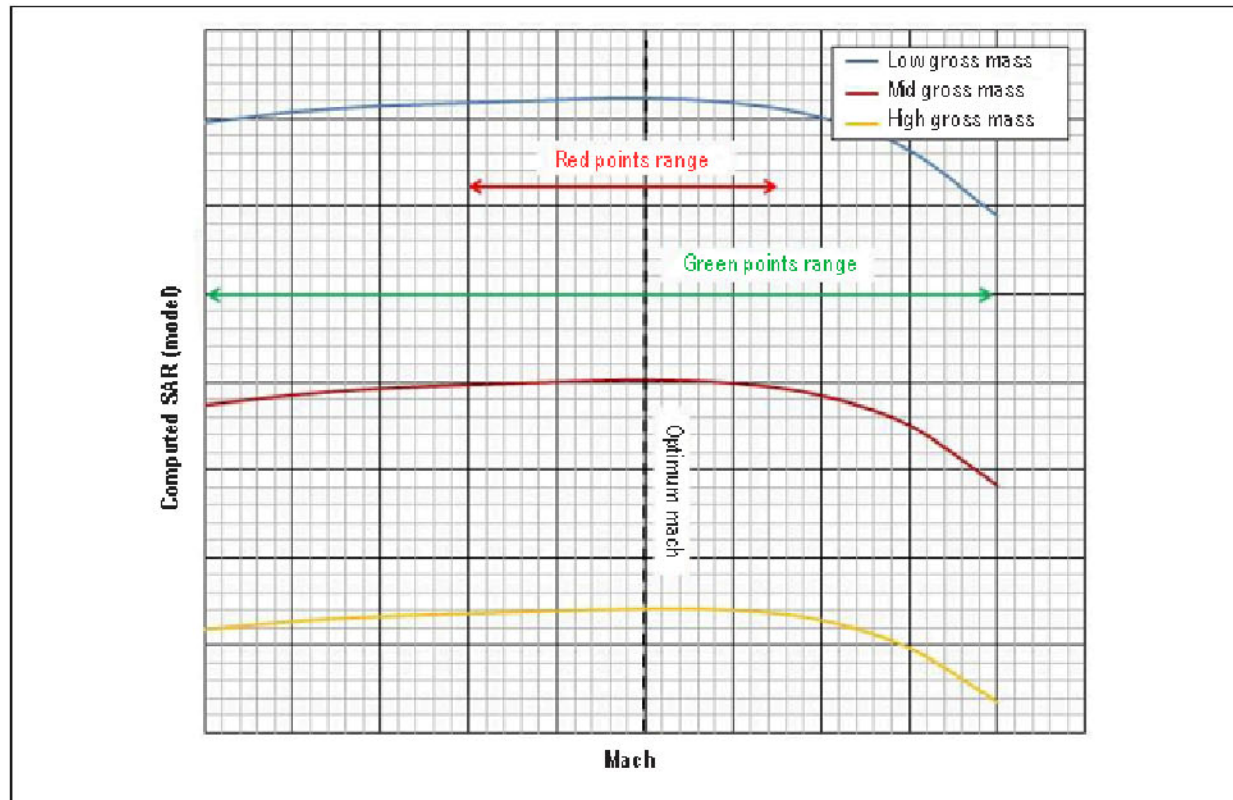
914   **Figure 6-10**
915
916   Computed SAR (model) versus C_L at optimum Mach
917
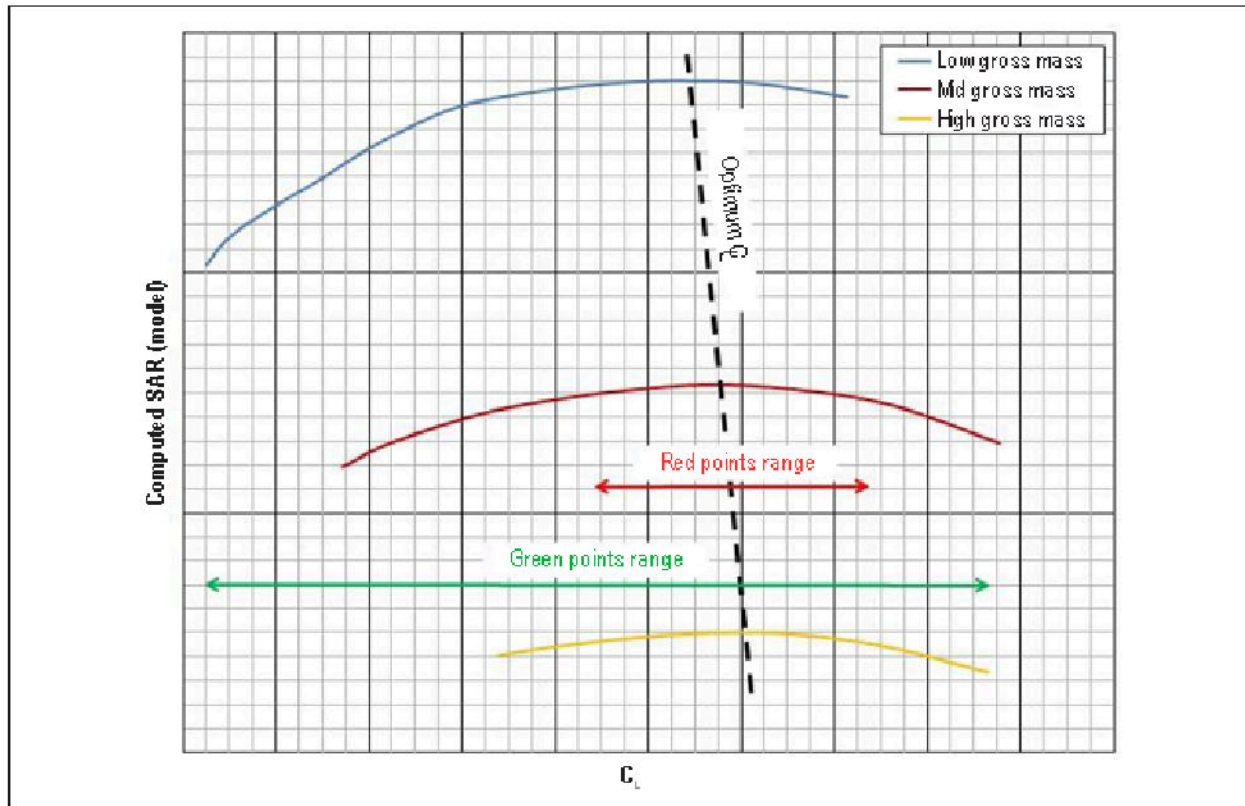
918
919
920
921   **6.4.4.3 SAR model validation – confidence interval determination**
922
923   As explained in paragraph 6.4.4 above, the SAR model needs to be validated under the conditions
924   relevant to demonstrating compliance with § 38.17. To be used for validation, flight test points need to
925   be selected using the criteria described in paragraph 6.4.4.1 above. The number of flight test points
926   selected will represent n measurements (number of data points) of SAR (SAR_1, SAR_2, …, SAR_n)
927   obtained in approximately the same conditions of Mach and C_L.
928
929   Step 1 — Estimate of the mean ΔSAR value and of the standard deviation
930   For each flight test point (i), the SAR difference $\Delta SAR_{(i)}$ between the measured SAR and the computed
931   SAR can be determined as follows (in percent):
932
933          $\Delta SAR_{(i)}(\%) = [(\text{Measured } SAR_{(i)} - \text{Computed } SAR_{(i)}) / \text{Computed } SAR_{(i)}] \times 100 \ (\%)$.
934
935   The estimate of the mean ΔSAR value in percent, $\Delta SAR_{AVG}(\%)$, can then be determined for the n
936   measurements as follows:
937
938          $$DSAR_{AVG}(\%) = estimate\ of\ the\ mean\ DSAR\ (\%) = \frac{1}{n}\left\{\sum_{i=1}^{i=n} DSAR_{(i)}\right\}(\%).$$
939
940   The estimate of the standard deviation of the mean is found as follows:
941          $$s = estimate\ of\ the\ standard\ deviation\ of\ the\ mean = \sqrt{\frac{\sum_{i=1}^{i=n}\left(DSAR_{(i)} - DSAR_{AVG}\right)^2}{n-1}}\ (\%).$$

942
943   Step 2 — Confidence interval determination
944
945   The low number of test points in a small range of Mach and C_L results in a statistical population that
946   follows the Student law, and allows the 90 percent confidence interval to be defined in accordance with
947   the methodology for Direct Flight Testing, as described in appendix 4 of this AC. The objective is to
948   determine an average ΔSAR value (%) and its associated 90 percent confidence interval. The
949   minimum acceptable sample size is twelve points (see § A38.5.3.4.).
950
951   Following this step and using the Student t-distribution, the 90 percent confidence interval (CI_{90}) for the
952   estimate of the mean ΔSAR$_{AVG}$ can be determined as:
953
954     $$CI_{90}\,(\%) = \left[DSAR_{AVG} \pm t_{(.95,n-1)}\,\frac{s}{\sqrt{n}}\right](\%)$$
955
956   where $t_{(.95,\,n-1)}$ = Student t-distribution (for 90 percent confidence) for the degrees of freedom (i.e., n-1,
957   where n is number of data points). (See Table A4-1 in Appendix 4 of this AC).
958
959   Step 3 — Validity of results
960
961   Section A38.5.3.2 contains the following requirements:
962
963   "A38.5.3.2 If the 90 per cent confidence interval of the SAR value at any of the three reference
964   airplane masses –
965
966   A38.5.3.2.1 Is less than or equal to ±1.5 per cent, the SAR value may be used.
967
968   A38.5.3.2.2 Exceeds ±1.5 per cent, a penalty equal to the amount that the 90 per cent confidence
969   interval exceeds ±1.5 per cent must be applied to the SAR value, as approved by the FAA."
970
971   Applying those requirements to a use of a first principle model for showing compliance:
972
973   a)   If the 90 percent confidence interval remains within the ±1.5 percent limits, then the ΔSAR$_{AVG}$
974   (%) value can be retained as the reference deviation for model correction.
975   b)   If the 90 percent confidence interval exceeds the ±1.5 percent limits, then a penalty equal to
976   the amount that the 90 percent confidence interval exceeds ±1.5 percent should be applied to
977   the ΔSAR$_{AVG}$(%) value, subject to the approval of AEE. For example, if the 90 percent
978   confidence interval is 5 percent, then the corrected ΔSAR$_{AVG}$(%) is 3.5 percent (5 percent -1.5
979   percent). The corrected ΔSAR$_{AVG}$(%) value then becomes the reference deviation for the
980   model correction.
981
982   Step 4 — SAR Model correction
983
984   When used to determine the FEM, the SAR values computed with a first principle model at each of the
985   three reference airplane masses must be corrected by a percentage amount that is equal to the
986   reference deviation determined in Step 3.
987
988
989   **6.4.4.4. Example of the determination of 90 percent confidence intervals**
990
991   The set of 12 flight test points are presumed to meet the selection criteria of paragraph 6.4.4.1 above.
992   The difference between the measured SAR and the computed SAR has been established as follows:
993
994
995
996

997
998
999
1000

Table 6-1

Test point selection

Selected test point number	ΔSAR (%)
1	0.08
2	-0.6
3	-0.42
4	0.19
5	-0.43
6	0.23
7	-0.28
8	0.45
9	0.10
10	-0.28
11	-0.80
12	-0.64

1001
1002
1003 a) The number of data points (n) = 12.
1004 b) The degrees of freedom (n-1) = 11.
1005 c) The Student t-distribution for 90 percent confidence and 11 degrees of freedom ($t_{(.95,11)}$) = 1.797.
1006   (See examples in Table A4-1 in Appendix 4 to this AC.).
1007
1008
1009 Step 1 — Estimate of the mean ΔSAR (%) and of the standard deviation(s)
1010
1011 $$DSAR_{AVG}(\%) = \frac{1}{12} \left\{ \sum_{i=1}^{i=12} DSAR_{(i)} \right\} = \text{-0.200 \%}$$
1012

1013 $$s = \sqrt{\frac{\sum_{i=1}^{i=12}\left(DSAR_{(i)} - DSAR_{AVG}\right)^2}{n-1}} = 0.39950 \ \%$$

1014
1015 Step 2 — 90 percent confidence interval (CI$_{90}$)
1016
1017 $$CI_{90} = DSAR_{AVG} \pm t_{(.95,11)} \frac{s}{\sqrt{12}} = -0.200 \pm 0.207 \ \%$$
1018
1019 Step 3 — Check of confidence interval limits
1020
1021 The confidence interval extends to ±0.207 percent around the mean ΔSAR value (-0.200 percent),
1022 which is within the confidence interval limit of ±1.5 percent. As a result, a ΔSAR value of -0.200
1023 percent can be retained for model correction.
1024
1025 Step 4 — SAR Model correction
1026
1027 The SAR value calculated for each reference mass of the FEM can be determined by computation
1028 with the first principle model and would be corrected by the -0.200 percent value determined in Step 3

1029   as follows:

1030

1031 $SAR_{corrected} = SAR_{computed} \times 0.998$

1032

1033   **6.5 Validity of Results – Confidence Interval**

1034

1035   Section A38.5.3.1 requires the 90 percent confidence interval to be calculated for each of the SAR
1036   values at the three reference masses. Appendix 4 of this AC provides guidance regarding confidence
1037   interval evaluation, including examples.

1038

1039   **6.6 Reference Geometric Factor**

1040

1041   **6.6.1 RGF General Guidelines**

1042

1043   The reference geometric factor (RGF) is a non-dimensional parameter used to adjust the value of
1044 $(1/SAR)_{AVG}$. RGF is based on a measure of fuselage size normalized with respect to 1 m², and is derived
1045   as prescribed in §38.15.

1046

1047   The basic concept of RGF, and the exponent of 0.24 for RGF in the fuel efficiency metric, is to give
1048   appropriate credit for the size of the cabin. The RGF represents the area that is available for the
1049   transport of passengers or cargo on the main deck, and on an upper deck. §§ 38.15 and A38.3 provide
1050   a description of RGF and list some areas that are to be included in the RGF calculation, including
1051   figures cross-sectional and longitudinal views of notional RGF boundary conditions. This list of included
1052   areas is not comprehensive; RGF also includes, for example, any space in the cabin used for
1053   wardrobes, or for cabinets containing equipment such as passenger entertainment systems or life
1054   rafts.

1055

1056   Most airplanes have a single deck, or floor, for passengers or cargo. Many single-deck airplanes also
1057   have an underfloor cargo bay, but that does not mean that they should be considered as two-deck
1058   airplanes.

1059

1060   **6.6.2 Orthogonal Projection and Width Boundary**

1061

1062   For a single-deck airplane, the RGF is determined by making an orthogonal projection of the outer mold
1063   line (OML) of the fuselage pressure shell, onto a plane that is parallel to the main deck floor. The term
1064   orthogonal means that the projection is made using theoretical lines of projection which are orthogonal,
1065   or perpendicular, to the main deck floor, and also orthogonal to the plane where the projection is made.
1066   In the case of an airplane in which the main deck is perfectly horizontal when it stands on the ground,
1067   the projection is similar to the 'shadow area' on the ground, or the top view area of the fuselage. The
1068   terms 'shadow area' and 'top view' can be misleading however, and orthogonal projection is the proper
1069   term for obtaining a true projection. The term 'shadow area' could imply projection lines emanating
1070   from a single point, effectively like the sun. It is possible to make a projection using lines which emanate
1071   from any single point, but that is not intended, and would not be a true projection for RGF. The term
1072   'top view' can be misleading for an airplane in which the main deck is not perfectly horizontal when it
1073   stands on the ground. Typically the main deck of an airplane is at a constant height (or constant Z
1074   station) in terms of the X, Y, Z coordinate system for the airplane, and in that case the orthogonal
1075   projection is the same as a plan view drawing, viewing either up or down along the Z axis. However,
1076   there is no requirement for any deck to be at a constant Z station.

1077

1078   Typically the maximum width of the fuselage cross section is above the main deck for a single-deck
1079   airplane, and if the fuselage has a constant cross section for part of its length, then the maximum width
1080   will be at the same height above the main deck (i.e. at the same Z station) for part of the fuselage
1081   length. At the aft end of the fuselage however, there will no longer be a constant cross section, and it is
1082   common for the point of maximum width to rise up higher above the main deck towards the tail, with
1083   fuselage upsweep. Towards the nose, typically the point of maximum width descends closer to the main

1084   deck. For the orthogonal projection, the maximum external width of the OML is always 'captured' at
1085   whatever height above the deck that it occurs.
1086
1087   For an airplane that has a main deck and also an upper deck, the RGF for the main deck is determined
1088   using the fuselage OML as the width boundary, as for a single-deck airplane. The upper deck is
1089   considered separately, and the width boundary for the upper deck RGF is defined as the fuselage OML
1090   at or above the upper deck floor level. This means that to determine the upper deck RGF, all of the
1091   fuselage below the upper deck floor can be removed from consideration, and then an orthogonal
1092   projection should be made of the remaining part of the fuselage, the entire upper cabin, onto a plane
1093   that is parallel to the upper deck. This projection will capture the maximum width of the fuselage OML
1094   at any height at or above the upper deck floor. The upper deck may be parallel to the main lower deck,
1095   but there is no requirement for this to be the case. The total RGF is simply the sum of the RGF values
1096   for the two decks.
1097

6.6.3   Forward and Aft Boundaries

1098
1099
1100   The aft boundary to be used for calculating RGF is the aft surface of the aft pressure bulkhead skin.
1101   This bulkhead may be a flat or domed skin to take the pressure loads, and typically has supporting
1102   structure attached either to the forward or aft face of the bulkhead. This aft boundary definition is
1103   consistent with the concept of using the external surface of the pressure shell for the width boundary.
1104
1105   The forward boundary to be used for calculating RGF is the forward surface of the forward pressure
1106   bulkhead skin except for the cockpit crew zone. For all airplanes, a plane will need to be defined for the
1107   aft boundary of the cockpit crew zone. If there is a cockpit door, this aft boundary is the plane of the
1108   forward face of the cockpit door. If there is no cockpit door, a boundary plane will need to be defined
1109   that is aft of the cockpit crew seats. Some airplanes may have optional approved cockpit layouts, for
1110   example to provide for one or two 'jump seats' aft of the two standard pilot seats; in that case the RGF
1111   should be based on the smallest approved cockpit layout (see § A38.3).
1112
1113   Some airplanes are certified for single-pilot operations, as illustrated in Appendix A38.3 Figure A38-
1114   2. This figure shows that a passenger may be in the right cockpit seat, and the right side of the cockpit
1115   can be included in the RGF, even if a cockpit door is standard equipment. In this case, the aft
1116   boundary of the cockpit crew zone applies to the left side of the fuselage only.
1117
1118   For an airplane with two decks, the cockpit may be accessed from the main deck, or the upper deck,
1119   but the two decks are considered separately. One deck may extend forward, above or below a cockpit
1120   crew zone, and in that case the aft boundary of the cockpit crew zone should only apply to the RGF of
1121   the deck that provides direct access to the cockpit, not to both decks.
1122

6.6.4   Floor Plane

1123
1124
1125   For the floor plane of the main deck, and any upper deck, it is assumed that most, or all, of the floor
1126   area is on the same flat plane. It is common to have some local anomalies, such as a step up in the
1127   floor of the cabin towards the tail, typically in a baggage area. If there is a relatively small, elevated
1128   floor it is usually flat and parallel to the main floor, but there is no requirement for it to be so. Some
1129   airplanes may have other local floor changes, possibly even changes in slope. Some smaller airplanes
1130   have a dropped aisle, with elevated seating areas on both sides of the aisle. There is no requirement
1131   for any deck floor to be parallel with the upper or lower skin of the fuselage, but this will usually be the
1132   case. For each deck, there should be no difficulty in identifying a nominal flat plane which should apply
1133   to it, which then allows for the identification of a true flat plane (with no local anomalies) parallel to the
1134   deck, for the purpose of the orthogonal projection.
1135

6.6.5   RGF Sensitivity

1136
1137
1138   Although RGF is an important component of the CO_2 emissions evaluation metric value, the exponent
1139   of 0.24 means that the metric value is less sensitive to a change in RGF as compared to a change in

the average 1/SAR value. As an example, if the average 1/SAR value is changed by a factor of 1.01, then the metric value will also change by a factor of 1.01 (a 1% increase). However, if the RGF changes by a factor of 0.99 (a 1% decrease) then the metric value will increase by only a factor of 1.0024150 (an increase of 0.2415%). The change in metric value as a result of a change in RGF, can be expressed as the reciprocal of the factor applied to RGF, with an exponent of 0.24 applied. For this example: (1 / 0.99) = 1.010101 ; and (1.010101)0.24 = 1.002415.

The RGF sensitivity may lead an applicant to declare positions for the forward boundary and aft boundary that are slightly conservative in order to avoid lengthy geometric explanations and justifications. Typically, a small amount of conservatism, by declaring a forward and/or aft boundary that is displaced by 1 or 2 cm will lead to a very small change in RGF, much less than 1%, and an extremely small penalty in the metric value of less than 0.1%.

An applicant may also consider the potential for future geometric changes, and the no-FEM-change criteria. It may be administratively easier to deal with a small geometric change in the future, if the RGF has been defined in a slightly conservative way.

6.6.6   Floor Plane

For the floor plane of the main deck, and any upper deck, it is assumed that most, or all, of the floor area is on the same flat plane. It is common to have some local anomalies, such as a step up in the floor of the cabin towards the tail, typically in a baggage area. If there is a relatively small, elevated floor it is usually flat and parallel to the main floor, but there is no requirement for it to be so. Some airplanes may have other local floor changes, possibly even changes in slope. Some smaller airplanes have a dropped aisle, with elevated seating areas on both sides of the aisle. There is no requirement for any deck floor to be parallel with the upper or lower skin of the fuselage, but this will usually be the case. For each deck, there should be no difficulty in identifying a nominal flat plane which should apply to it, which then allows for the identification of a true flat plane (with no local anomalies) parallel to the deck, for the purpose of the orthogonal projection.

6.6.7   RGF Sensitivity

Although RGF is an important component of the CO2 emissions evaluation metric value, the exponent of 0.24 means that the metric value is less sensitive to a change in RGF as compared to a change in the average 1/SAR value. As an example, if the average 1/SAR value is changed by a factor of 1.01, then the metric value will also change by a factor of 1.01 (a 1% increase). However, if the RGF changes by a factor of 0.99 (a 1% decrease) then the metric value will increase by only a factor of 1.0024150 (an increase of 0.2415%). The change in metric value as a result of a change in RGF, can be expressed as the reciprocal of the factor applied to RGF, with an exponent of 0.24 applied. For this example: (1 / 0.99) = 1.010101 ; and (1.010101)0.24 = 1.002415.

The RGF sensitivity may lead an applicant to declare positions for the forward boundary and aft boundary that are slightly conservative in order to avoid lengthy geometric explanations and justifications. Typically, a small amount of conservatism, by declaring a forward and/or aft boundary that is displaced by 1 or 2 cm will lead to a very small change in RGF, much less than 1%, and an extremely small penalty in the metric value of less than 0.1%.

An applicant may also consider the potential for future geometric changes, and the no-FEM-change criteria. It may be administratively easier to deal with a small geometric change in the future, if the RGF has been defined in a slightly conservative way.

6.7 Fuel Efficiency Limits

Section 38.17 provides the maximum permitted fuel efficiency metric values for airplanes defined under § 38.1(a), as determined pursuant to § 38.11. In accordance with § 38.17(b), the fuel efficiency metric value may not exceed the values detailed in the table with fuel efficiency limits in § 38.17. Notably, the

1196   values determined in accordance with the equations in the table with fuel efficiency limits in § 38.17
1197   should be rounded to three decimal places. The maximum permitted fuel efficiency metric values are
1198   based on the type of airplane as defined in § 38.1 (applicability section) and the airplane's MTOM. A
1199   more detailed discussion on the applicability of § 38.1 can be found in paragraph 5.1 of this AC.
1200
1201   **6.8 Change Criteria**
1202
1203   A modification requiring compliance with part 38 is determined by the change criteria in § 38.19. The
1204   requirements differ depending on whether an airplane has previously demonstrated compliance with part
1205   38 before a modification is made, or whether an airplane was type certificated before January 1, 2023,
1206   and was not required to demonstrate compliance with part 38.
1207
1208   The change criteria in § 38.19(a) specifies when a compliance demonstration to this new rule is required
1209   if a modification to an airplane, that has been shown to comply with § 38.17, will increase the MTOM of
1210   the airplane as written in § 38.19(a)(1) or increases the FEM value above the thresholds provided in §
1211   38.19(a)(2)(i) through (iii). Figure 6.11, below, illustrates the FEM change threshold limits of § 38.19 for
1212   any MTOM.
1213
1214   **Fig. 6.11**
1215
1216   FEM change threshold limits with variation in MTOM
1217

FEM Change Threshold Limits for any MTOM (kg)

- 1.35%, 5700 kg
- $y = -1.10497E\text{-}07x + 1.41298E\text{-}02$
- $y = -9.25926E\text{-}10x + 7.55556E\text{-}03$
- $y = 7.00E\text{-}03$
- 0.75%, 60000 kg
- 0.70%, 600000 kg

FEM Change Threshold Limit Value — Maximum Takeoff Mass (MTOM, kg)

—— FEM Change Threshold Limits
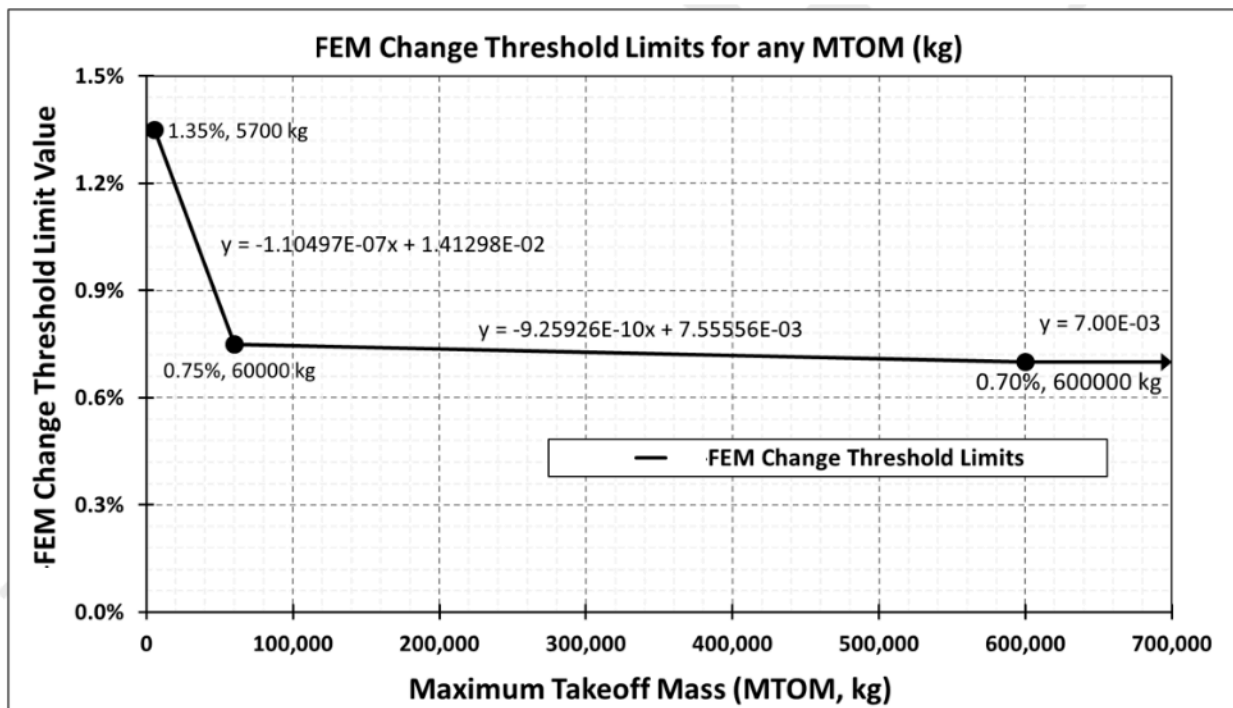
1218
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1220   Under § 38.19(b), where an airplane has been shown to comply with § 38.17, for a modification that
1221   does not increase either the MTOM or the FEM value, the airplane may retain the same FEM value as
1222   prior to modification.
1223
1224   Section 38.19(c) provides that an airplane, which meets the applicability provisions of § 38.1(a)(4) or (5)
1225   on or after January 1, 2023 and before January 1, 2028, must demonstrate compliance if the
1226   modification exceeds 1.5%. Alternatively, an airplane modification that is shown to have less than a
1227   1.5% increase in FEM does not have to demonstrate compliance. For an airplane whose type design
1228   was not previously certified to part 38, an applicant can estimate the change in the FEM value of the

1229   modified version of such an airplane by using one of the methods described in this AC38, if approved by
1230   the FAA. For example, for a change to the exterior of the airplane, the change in drag can be estimated
1231   using methods described in paragraph 6.4.3 of this AC, and this estimated change in drag can be
1232   directly related to changes in FEM value.
1233
1234
1235   **7. Additional Guidance**
1236
1237   If an applicant needs additional guidance, contact the AEE-300 Emissions Division Manager with the FAA
1238   Office of Environment and Energy at ralph.iovinelli@faa.gov.
1239

Appendix 1: Definitions

1240
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1243   The following terms are defined in § 38.3, which is reproduced here for convenience:
1244   *Amphibious Airplane* means an airplane that is capable of takeoff and landing on both land and water.
1245   Such an airplane uses its hull or floats attached to the landing gear for takeoff and landing on water, and
1246   either extendable or fixed landing gear for takeoff and landing on land.
1247
1248   *ICAO Annex 16, Volume III* means Volume III of Annex 16 to the Convention on International Civil
1249   Aviation (incorporated by reference in § 38.7).
1250
1251   *Maximum takeoff mass (MTOM)* is the maximum certified takeoff mass, expressed in kilograms, for an
1252   airplane type design.
1253
1254   *Performance model* is an analytical tool (or a method) validated using corrected flight test data that can
1255   be used to determine the specific air range values for calculating the fuel efficiency metric value.
1256   *Reference geometric factor (RGF)* is a non-dimensional number derived from a two-dimensional
1257   projection of the fuselage.
1258
1259   *Specific air range (SAR)* is the distance an airplane travels per unit of fuel consumed. Specific air range is
1260   expressed in kilometers per kilogram of fuel.
1261
1262   *Subsonic* means an airplane that has not been certificated under 14 CFR to exceed Mach 1 in normal
1263   operation.
1264
1265   *Type certificated maximum passenger seating capacity* means the maximum number of passenger seats
1266   that may be installed on an airplane as listed on its type certificate data sheet, regardless of the actual
1267   number of seats installed on an individual airplane.

Appendix 2: Abbreviations/Acronyms/Symbols

The abbreviations/acronyms/symbols used in this AC have the following meanings whether expressed in upper or lower case:

a	Earth's radius at the equator
A	Airplane reference wing area
b	Earth's radius at the poles
B	Value representing the variation of drag with Reynolds number
AEE	FAA's Office of Environment and Energy
AVG	Average
C_D	Drag coefficient
CFD	Computational fluid dynamics
CG	Center of gravity
CI	Confidence interval
CI_{90}	90% Confidence interval
C_L	Lift coefficient
CO_2	Carbon dioxide
EPA	United States Environmental Protection Agency
FAA	Federal Aviation Administration, United States Department of Transportation
FEM	Fuel Efficiency Metric
g	Gravitational acceleration
g_0	Standard acceleration due to gravity at sea level and a geodetic latitude of 45.5 degrees
g_{ref}	Gravitational acceleration, based on g_0, for an airplane travelling true north in still air at the reference altitude and a geodetic latitude of 45.5 degrees
$g_{Coriolis}$	Component of gravitational acceleration that is due to Coriolis effect
g_{cent}	Component of gravitational acceleration that is due to centrifugal effect
g_{test}	Gravitational acceleration at the test values of latitude, geometric altitude, true track, and ground speed
$g_{\varphi,alt}$	Component of the gravitational acceleration at the test altitude and latitude at zero ground speed
h	Altitude
ICAO	International Civil Aviation Organization
Kg	Kilogram(s)
LHV	Lower heating value
m	Meters
M	Mach number
MTOM	Maximum Takeoff Mass
n	Number of data points
N	Newtons
OML	Outer Mold Line
Pa	Pascals
P_S	Static pressure
r_e	Earth's radius
RE	Reynolds number
RGF	Reference Geometric Factor
s	Time in seconds or estimate of the standard deviation of the mean
SAR	Specific Air Range
SEM	Semi-empirical methods
SFC	Specific fuel consumption
STC	Supplementary type certificate
T	Temperature
$t_{(.95,\ n-1}$	Student t-distribution for 90 percent confidence for n degrees of freedom
TAS	True airspeed
TC	Type certificate

1324   TCDS   Type certificate data sheet
1325   TOM   Takeoff mass
1326   TSFC   Thrust Specific Fuel Consumption
1327   V   Speed
1328 V_g Ground speed
1329   δ   Ratio of atmospheric pressure at a given altitude to the atmospheric pressure at sea level
1330   Δ   Change in value of a parameter
1331   %   Percent
1332   μ   Mean value
1333   ρ   Density of air
1334   σ   Track angle
1335   φ   Latitude
1336   ∑   Summation of a series of values
1337   ζ   Degrees of freedom of confidence interval
1338 $ω_E$ Earth's rotation rate
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1354   **Appendix 3: Correcting SAR Data to Reference Specifications**
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1357   **A3-1. Corrections to Reference Specifications**
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1359   This appendix covers corrections that must be made to the tested values of airplane weight, drag, and
1360   fuel flow. These corrections address any differences between the conditions at which the airplane was
1361   tested and the reference specifications.
1362
1363   For steady-state cruise flight, it is a reasonable approximation to assume lift equals weight and thrust
1364   equals drag. Since drag is a function of lift, fuel flow is a function of thrust, SAR is a function of fuel flow,
1365   and the FEM is a function of SAR, any deviation from the reference specifications that affect weight, drag,
1366   or fuel flow will affect SAR and the FEM. Each of these corrections will result in either increasing or
1367   decreasing the test SAR and the resulting FEM.
1368
1369   As stated in Appendix A § A38.5.2.2, each correction method is subject to the approval by the FAA,
1370   including any time an applicant considers a particular correction to be unnecessary (with acceptable
1371   justification). Any correction that would result in an increase in SAR (i.e., a lower FEM value) may be
1372   considered optional by the applicant. The effect of not making such a correction would be to increase the
1373   FEM value.
1374
1375   Table A3-1 lists all the corrections and the conditions under which a given correction might be optional:
1376
1377   **Table A3-1.**
1378
1379   Corrections to reference specifications
1380

Correction	Paragraph of this appendix	Type of correction	Conditions under which correction may be optional	Remarks
Latitude effect on g	A3-1.2	Apparent gravity	Test latitude greater than 45.5 degrees	Gravitational acceleration is greatest at the poles and lowest at the equator. Testing at latitudes greater than 45.5 degrees will decrease SAR and increase the FEM as the airplane will be heavier.
Altitude effect on g	A3-1.2	Apparent gravity	Test altitude lower than reference altitude	Increasing the height above the Earth's surface reduces the gravitational acceleration. Therefore, testing at an altitude lower than the reference altitude will decrease SAR and increase the FEM due to the effect of altitude on gravitational acceleration.
Centrifugal effect on g	A3-1.2	Apparent	Headwind (negative	The reduction in velocity

Correction	Paragraph of this appendix	Type of correction	Conditions under which correction may be optional	Remarks
		gravity	wind)	(relative to the earth) provided by a headwind increases gravitational acceleration due to the centrifugal effect. This increases the airplane weight, which decreases SAR and increases the FEM.
Coriolis effect on g	A3-1.2	Apparent gravity	Test true track angles from 180 to 360 degrees	Flying in a westerly direction, the opposite direction as the Earth's rotation, will increase gravitational acceleration due to the Coriolis effect. This increases the airplane weight which decreases SAR and increases the FEM.
Acceleration/deceleration (energy)	A3-1.3	Drag	(dV_G/dT) greater than 0 (positive acceleration in terms of ground speed)	An accelerated flight condition (excess energy) results in a higher drag force, decreasing SAR and increasing the FEM.
Reynolds number	A3-1.4	Drag	Test outside air temperature higher than standard air temperature	Higher temperatures result in higher drag forces due to Reynold number effects. At temperatures higher than the reference temperature, SAR will be decreased and the FEM will increase.
CG position	A3-1.5	Drag	Test CG position forward of the reference CG position	A test CG position forward of the reference CG position results in higher drag, decreasing SAR and increasing the FEM.
Aeroelastics	A3-1.6	Drag	-	Wing aeroelastics may not be a concern depending on the size/weight/payload of the airplane and on wing stiffness.
Fuel lower heating value (LHV)	A3-1.7	Fuel flow	Test fuel LHV less than 43.217 MJ/kg	Testing with fuel that has an LHV lower than the reference value requires more fuel to

Correction	Paragraph of this appendix	Type of correction	Conditions under which correction may be optional	Remarks
				be burned to achieve the same engine thrust level, hence decreasing SAR and increasing the FEM.
Altitude effect on fuel flow	A3-1.8	Fuel flow	May always be considered optional	Testing at any altitude other than the optimum altitude will result in decreasing SAR and increasing the FEM due to higher fuel burn at off-optimum altitude.
Temperature effect on fuel flow	A3-1.9	Fuel flow	Test outside air temperature higher than standard day temperature	Testing at a temperature higher than the reference temperature will result in decreasing SAR and increasing the FEM due to higher fuel burn at higher temperatures.
Engine deterioration level	A3-1.10	Fuel flow	-	In general, this correction should not be made. See paragraph A3-1.10 of this AC.
Electrical and mechanical power extraction and bleed flow	A3-1.11	Fuel flow	Test electrical and mechanical power extraction and bleed flow higher than the reference electrical and mechanical power extraction and bleed flow	Testing with higher than reference power extraction and bleed flow will require more fuel to be burned, hence decreasing SAR and increasing the FEM.
Modifications and non-standard equipment that will not be included on the production airplane	A3-1.12	Drag and/or fuel flow	Any modification or non-standard equipment that reduces SAR	Not accounting for modifications or non-standard equipment that decreases SAR and increases the FEM.

The selection of a reference airspeed is used to determine the target airspeed for acquiring SAR test data for determination of the FEM. For applicants using either SAR data clustered around each of the three reference masses (see § A38.5.3.3) or SAR data obtained over a range of masses (see § A38.5.3.4), no correction is made for any differences between the target reference airspeed and the test airspeed. Since the reference airspeed is generally expected to be the optimum airspeed (see § A38.2), any difference

between the test airspeed and the reference airspeed will decrease SAR and increase the FEM. For applicants using a first principle model to show compliance (see paragraph 6.4.4 of this AC), the reference airspeed is used to identify the portion of the performance model to be validated. The reference airspeed is also used as the airspeed (or Mach number) at which the SAR value for each reference mass is to be computed from the performance model.

The overall process for determining SAR at the reference specifications for each test data point consists of the following steps:

Step 1) Determine the airplane weight from the airplane mass for both the test condition and the reference specifications for gravitational acceleration, as described in paragraph A3-1.1 below. Determine the drag correction due to the difference in lift between the test weight and the weight at the reference specifications for gravitational acceleration using the airplane's drag model and the relationship that lift equals weight for non-accelerated, level flight, as described in paragraph A3-1.2.1.

Note.— As described in paragraph A3-1.2.2, this step is not necessary when using method 2 for the gravitational acceleration correction.

Step 2) Determine all other applicable drag corrections as described in paragraphs A3-1.3, A3-1.4, A3-1.5, and A3-1.6, and sum them together with the drag correction from paragraph A3-1.2.1.

Step 3) Determine the airplane drag for the test condition. An approximation can be made that for these unaccelerated, level flight test conditions, the airplane drag for the test condition is equal to the engine thrust for the test condition. The engine thrust should be determined from:

- a calibrated engine or an engine performance model; and
- the average value of the parameters needed to determine thrust from the engine performance model measured during the test condition.

Step 4) Add the sum of drag corrections from Step 2 to the airplane drag for the test condition from Step 3 to obtain the airplane drag corrected to the reference specifications.

Step 5) Determine the change in engine fuel flow for the corrections that were made for drag. The change in engine fuel flow due to the drag corrections can be determined as follows:

$\Delta \text{Fuel Flow}_{\text{Drag}} = \text{Fuel Flow}_{\text{Ref Drag}} - \text{Fuel Flow}_{\text{Test Drag}}$

where:

Fuel Flow$_{\text{Ref Drag}}$ is the fuel flow from an engine performance model at the airplane drag corrected for the reference specifications (assuming thrust equals drag) at the average speed, altitude and temperature for the test condition; and

Fuel Flow$_{\text{Test Drag}}$ is the fuel flow from an engine performance model at the airplane drag for the test condition (assuming thrust equals drag) at the average speed, altitude and temperature for the test condition.

Step 6) Correct the measured test engine fuel flow to reference specifications as follows:

$\text{Fuel Flow}_{\text{ref}} = \text{Fuel Flow}_{\text{test}} + \Delta \text{Fuel Flow}_{\text{Drag}} + \Delta \text{Fuel Flow}_{\text{LHV}} + \Delta \text{Fuel Flow}_{\text{alt}} + \Delta \text{Fuel Flow}_{\text{temp}} + \Delta \text{Fuel Flow}_{\text{Corr bleed}}$

where:

Fuel Flow$_{\text{test}}$ is the average engine fuel flow measured during the test condition, corrected to the reference engine deterioration level (if applicable) in kg/h;

1444
1445   ΔFuel Flow_Drag is the fuel flow correction for drag from Step 5 in kg/h;
1446
1447   ΔFuel Flow_LHV is the fuel flow correction for fuel lower heating value calculated from paragraph A3-1.7 in
1448   kg/h;
1449
1450   ΔFuel Flow_alt is the fuel flow correction for altitude calculated from paragraph A3-1.8 in kg/h;
1451
1452   ΔFuel Flow_temp is the fuel flow correction for temperature calculated from paragraph A3-1.9 in kg/h; and
1453
1454   ΔFuel Flow_Corr bleed is the fuel flow correction for electrical and mechanical power extraction and bleed flow
1455   calculated from paragraph A3-1.10 in kg/h.
1456
1457   Step 7) The SAR value corrected to reference specifications is given by the following relationship:
1458

1459 $$SAR_{ref} = \left(\frac{TAS}{Fuel\ Flow_{ref}} \right)$$

1460
1461   where:
1462
1463 SAR_{ref} is the SAR for the reference specifications in km/kg;
1464
1465   TAS is the average airplane true airspeed for the test specifications in km/h; and
1466
1467 $Fuel\ Flow_{ref}$ is the engine fuel flow for the reference specifications from Step 6 in kg/h.
1468
1469   *A3-1.1 Test Weight.* Since the weight of the airplane during each test condition cannot be directly
1470   measured, it is determined using the following process, in accordance with §§ A38.4.2.1.2 and A38.4.2.3:
1471
1472   Begin with weighing the airplane on the ground, where the local gravitational acceleration can be readily
1473   determined using the process described in paragraph A3-1.2.1. The pre-flight airplane mass is
1474   determined from the following relationship:
1475

1476 $$Mass_{weighing} = \frac{Weight_{weighing}}{g_{weighing}}$$

1477
1478   where:
1479
1480 $Weight_{weighing}$ is the airplane weight from the scale weighing in N; and
1481
1482 $g_{weighing}$ is the gravitational acceleration at rest at the weighing site latitude and elevation in
1483   meters/second^2. See paragraph A-3.1.2.1 for determining $g_{weighing}$ using the weighing site latitude and
1484   elevation for the test latitude, φ, and test geometric altitude, h, respectively.
1485
1486   Any change in mass after the weighing, and prior to the test flight, should be accounted for to establish
1487   the mass of the airplane at the start of the test flight. The mass for each test condition can be determined
1488   by subtracting the integrated fuel flow (mass of fuel burned) from the mass of the airplane at the start of
1489   the test flight. The test weight, in N, for each test condition is determined from the following equation:
1490

1491 $$Weight_{test} = (Mass_{test})(g_{test})$$

1492
1493   where:
1494
1495 $Mass_{test}$ is the average mass of the airplane during the test condition in kg; and
1496

1497 g_{test} is the gravitational acceleration at the test latitude, test geometric altitude, test true track, and test
1498   ground speed in m/s^2. See paragraph A-3.1.2.1 for determining g_{test}.
1499
1500   *A3-1.2 Apparent gravity.* Acceleration, caused by the local effects of gravity and inertia, affects the test
1501   weight of the airplane. The apparent gravity at the test conditions varies with latitude, altitude, ground
1502   speed, and direction of motion, relative to the Earth's axis. The reference gravitational acceleration is the
1503   gravitational acceleration, based on g_0, for the airplane travelling in the direction of true north in still air at
1504   the reference altitude, a geodetic latitude of 45.5 degrees.
1505
1506   If the test conditions differ from the conditions for the reference gravitational acceleration, the airplane
1507   weight at the reference gravitational acceleration will be different than the airplane weight at the test
1508   conditions. This will result in a SAR and FEM that are not representative of the SAR and FEM at the
1509   reference gravitational acceleration. If the test conditions are at a gravitational acceleration that is less
1510   than the reference gravitational acceleration, then a correction will be necessary, as described below.
1511
1512   There are two methods provided below for determining the acceleration correction. Method 1 is a general
1513   method for determining the effect of gravitational acceleration on the airplane test weight, which is then
1514   used along with the airplane's drag model to determine the effect on airplane drag. This drag correction
1515   for gravitational acceleration is then combined with the other drag corrections to determine the effect on
1516   airplane fuel flow and the value of SAR.
1517
1518   Method 2 is a simplified approach that does not require use of an airplane drag model. This method is
1519   acceptable for FEM certification when SAR is determined by direct flight test measurement of SAR test
1520   points in accordance with § A38.1.2.1. Method 2 is based on the same equations for determining g as
1521   Method 1, and provides the same results for SAR data at (or near) optimum flight conditions. For SAR
1522   data that is not at (or near) reference specifications, Method 2 may result in small errors in the SAR
1523   correction for gravitational acceleration correction, but the overall SAR and FEM values will be
1524   conservative because these errors will be much smaller than the SAR decrease (thus FEM increase)
1525   resulting from testing outside optimum flight conditions.
1526
1527   A3-1.2.1 Method 1 for the gravitational acceleration correction
1528
1529   The overall process for determining the drag correction due to the effect of gravitational acceleration on
1530   airplane weight consists of the following steps:
1531
1532   Step 1) Determine the airplane test weight, as described in paragraph A3-1.1.
1533
1534   Step 2) Determine the airplane weight for the reference gravitational acceleration conditions from
1535   the airplane test mass and the reference gravitational acceleration:
1536
1537 $$Weight_{ref\ g} = (Mass_{test})(g_{ref})$$
1538   where:
1539
1540   Weight$_{ref\ g}$ is the airplane weight at the reference gravitational acceleration conditions in N;
1541
1542   Mass$_{test}$ is the average mass of the airplane during the test condition in kg;
1543
1544
1545 g_{ref} is the gravitational acceleration for the airplane travelling in the direction of true north in still air at the
1546   reference altitude and a geodetic latitude of 45.5 degrees, and based on g_0, in m/s^2; and
1547
1548 g_0 is the standard acceleration due to gravity at sea level and a geodetic latitude of 45.5 degrees, 9.80665
1549   m/s^2.
1550
1551   Step 3) Determine the drag correction for the difference between Weight$_{test}$ and Weight$_{ref\ g}$, as described
1552   later in this paragraph.

1553
1554   The value of gravitational acceleration, g, consists of the following components:

1555
1556   a) *Distance from the center of Earth's mass*. This is a function of the geometric altitude and the
1557   latitude of the airplane relative to a mathematical representation of the shape of the Earth.

1558
1559   b) *Centrifugal effect*. An airplane in flight will experience a force acting outwards in the radial
1560   direction that is proportional to the square of the ground speed of the airplane and inversely
1561   proportional to the distance of the airplane from the center of mass of the Earth.

1562
1563   c) *Coriolis effect*. An airplane in flight will experience a force that is proportional to its ground speed,
1564   the rotation rate of the Earth, the direction of travel, and the latitude of operation. For example, an
1565   airplane flying east, in the same direction that the Earth rotates, will experience a lower
1566   gravitational acceleration, while an airplane flying west will experience a higher gravitational
1567   acceleration. The effect will be greatest at the equator.

1568
1569   The following equations are based on the World Geodetic System 84 Ellipsoidal Gravity definition. Other
1570   formulations and simplifications may provide essentially equivalent results.

1571
1572   The gravitational acceleration experienced for each test data point (g_{test}) is determined as follows:

1573
1574 $$g_{test} = g_{\varphi,alt} + g_{cent} + g_{Coriolis}$$

1575
1576   where:

1577
1578 $g_{\varphi,alt}$ is the component of the gravitational acceleration at zero ground speed, at the test altitude and
1579   latitude in m/s^2;

1580
1581 g_{cent} is the component of the gravitational acceleration due to centrifugal effect in m/s^2; and

1582
1583 $g_{Coriolis}$ is the component of the gravitational acceleration due to Coriolis effect in m/s^2.

1584
1585   The gravitational acceleration for the test geometric altitude and latitude component at zero ground
1586   speed, $g_{\varphi,alt}$, is determined as follows:

1587
1588   First, determine the component of gravitational acceleration at the test latitude at sea level and zero
1589   ground speed from the following equation:

1590
1591 $$g_\varphi = \left(9.7803267714 \, \frac{1 + 0.00193185138639 \, sin^2\varphi}{\sqrt{1 - 0.00669437999013 \, sin^2\varphi}} \right)$$

1592
1593   where φ is the test latitude in degrees.

1594
1595
1596
1597   The component of gravitational acceleration at zero ground speed for the test geometric altitude and
1598   latitude is then determined from the following equation:

1599
1600 $$g_{\varphi,alt} = g_\varphi \left(\frac{r_e}{r_e + h} \right)^2$$

1601
1602
1603   where:

1604
1605 g_φ is the component of gravitational acceleration at the test latitude at sea level and zero ground speed;

1606
1607   h is the test geometric altitude in m; and
1608
1609 r_e is the radius of the Earth at the test latitude, which is determined from the following equation:
1610

1611
$$r_e = \sqrt{\frac{(a^2\cos\varphi)^2 + (b^2\sin\varphi)^2}{(a\cos\varphi)^2 + (b\sin\varphi)^2}}$$

1612
1613   where:
1614
1615   a is the Earth's radius at the equator = 6,378,137 m;
1616
1617   b is the Earth's radius at the pole = 6,356,752 m; and
1618
1619 φ is the test latitude in degrees.
1620
1621   As an alternative to using the equation for $g_{\varphi,alt}$ provided above, $g_{\varphi,alt}$ can be approximated by linear
1622   interpolation using Table A3-2:
1623
1624
1625

| 1626 |
| 1627 |
| 1628 |
| 1629 |

Table A3-2.

g$_{\varphi,alt}$

		g$_{\varphi,alt}$ (m/s²)										
		Geometric Height (ft)										
		0	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
Latitude (either North or South)	0	9.78033	9.77565	9.77099	9.76632	9.76166	9.75700	9.75234	9.74769	9.74304	9.73840	9.73376
	10	9.78188	9.77721	9.77254	9.76787	9.76321	9.75855	9.75389	9.74924	9.74459	9.73994	9.73530
	20	9.78637	9.78169	9.77702	9.77235	9.76768	9.76302	9.75836	9.75370	9.74905	9.74440	9.73975
	30	9.79325	9.78857	9.76302	9.77921	9.77454	9.76987	9.76521	9.76054	9.75588	9.75123	9.74658
	40	9.80170	9.79701	9.79232	9.78764	9.78296	9.77829	9.77362	9.76895	9.76428	9.75962	9.75496
	45.5	9.80665	9.80196	9.79727	9.79258	9.78790	9.78322	9.77855	9.77387	9.76920	9.76454	9.75988
	50	9.81070	9.80601	9.80132	9.79663	9.79194	9.78726	9.78258	9.77790	9.77323	9.76856	9.76390
	60	9.81918	9.81448	9.80978	9.80508	9.80039	9.79570	9.79101	9.78633	9.78165	9.77698	9.77230
	70	9.82610	9.82139	9.81668	9.81198	9.80728	9.80259	9.79790	9.79321	9.78853	9.78385	9.77917
	80	9.83062	9.82590	9.82120	9.81649	9.81179	9.80709	9.80240	9.79771	9.79302	9.78833	9.78365
	90	9.83219	9.82747	9.82276	9.81806	9.81336	9.80866	9.80396	9.79927	9.79458	9.78989	9.78521

1630
1631 The component of the gravitational acceleration due to centrifugal effect, g$_{cent}$, is determined from the
1632 following equation:
1633

1634
$$g_{cent} = -\frac{V_g{}^2}{r_e + h}$$

1635
1636 where:
1637
1638 V_g is the ground speed in m/s;
1639
1640 r_e is the radius of the Earth in m at the test latitude, which is determined from the same equation as
1641 provided above for how to determine g$_{\varphi,alt}$:
1642

1643 $r_e = \sqrt{\dfrac{(a^2\cos\varphi)^2 + (b^2\sin\varphi)^2}{(a\cos\varphi)^2 + (b\sin\varphi)^2}}$; and

1644
1645 h is the test geometric altitude in m.
1646
1647 As an alternative to using the equation for g$_{cent}$, g$_{cent}$ can be approximated by linear interpolation using
1648 Table A3-3:
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658   **Table A3-3.**

1659
1660   **g**cent
1661

gcent									
Ground Speed (kts)	0	100	200	300	400	500	600	700	800
gcent		0.00000	-0.00041	-0.00166	-0.00373	-0.00663	-0.01036	-0.01492	-0.02030	-0.02652

1662
1663   The component of the gravitational acceleration due to Coriolis effect, $g_{Coriolis}$, can be calculated using the
1664   following equation:
1665
1666 $$g_{Coriolis} = -2 \, \omega_E \, V_g \, \cos \varphi \sin \sigma$$
1667
1668
1669   where:
1670
1671 ω_E is the Earth's rotation rate = 7.29212 x 10^{-5} radians/s;
1672
1673 V_g is the airplane's ground speed in m/s;
1674
1675 φ is the test latitude in degrees; and
1676
1677 σ is the track angle of the airplane as measured from true north in degrees.
1678
1679   As an alternative to using the equation , $g_{Coriolis}$ can be approximated by linear interpolation using Table
1680   A3-4:
1681
1682   **Table A3-4**
1683
1684   **g**Coriolis
1685

gCoriolis for ground speeds from 200 to 400 knots											
GS (kts)	200				300				400			
Latitude (either N or S) (degrees)	0	30	60	90	0	30	60	90	0	30	60	90
0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
30	-0.00750	-0.00650	-0.00650	0.00000	-0.01125	-0.00975	-0.00563	0.00000	-0.01501	-0.01300	-0.00750	0.00000
60	-0.01300	-0.01125	-0.01125	0.00000	-0.01949	-0.01688	-0.00975	0.00000	-0.02599	-0.02251	-0.01300	0.00000
90	-0.01501	-0.01300	-0.01300	0.00000	-0.02251	-0.01949	-0.01125	0.00000	-0.03001	-0.02599	-0.01501	0.00000
120	-0.01300	-0.01125	-0.01125	0.00000	-0.01949	-0.01688	-0.00975	0.00000	-0.02599	-0.02251	-0.01300	0.00000
150	-0.00750	-0.00650	-0.00650	0.00000	-0.01125	-0.00975	-0.00563	0.00000	-0.01501	-0.01300	-0.00750	0.00000
180	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
210	0.00750	0.00650	0.00650	0.00000	0.01125	0.00975	0.00563	0.00000	0.01501	0.01300	0.00750	0.00000
240	0.01300	0.01125	0.01125	0.00000	0.01949	0.01688	0.00975	0.00000	0.02599	0.02251	0.01300	0.00000
270	0.01501	0.01300	0.01300	0.00000	0.02251	0.01949	0.01125	0.00000	0.03001	0.02599	0.01501	0.00000
300	0.01300	0.01125	0.01125	0.00000	0.01949	0.01688	0.00975	0.00000	0.02599	0.02251	0.01300	0.00000
330	0.00750	0.00650	0.00650	0.00000	0.01125	0.00975	0.00563	0.00000	0.01501	0.01300	0.00750	0.00000

True Track Angle (degrees)

1686   **Table A3-4 (continued)**
1687

g_Coriolis for ground speeds from 500 to 700 knots											
GS (kts)	500				600				700			
Latitude (either N or S) (degrees)	0	30	60	90	0	30	60	90	0	30	60	90

True Track Angle (degrees)

	0	30	60	90	0	30	60	90	0	30	60	90
0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
30	-0.01876	-0.01624	-0.00938	0.00000	-0.02251	-0.01949	-0.01125	0.00000	-0.02626	-0.02274	-0.01313	0.00000
60	-0.03249	-0.02814	-0.01624	0.00000	-0.03899	-0.03376	-0.01949	0.00000	-0.04548	-0.03939	-0.02274	0.00000
90	-0.03751	-0.03249	-0.01876	0.00000	-0.04502	-0.03899	-0.02251	0.00000	-0.05252	-0.04548	-0.02626	0.00000
120	-0.03249	-0.02814	-0.01624	0.00000	-0.03899	-0.03376	-0.01949	0.00000	-0.04548	-0.03939	-0.02274	0.00000
150	-0.01876	-0.01624	-0.00938	0.00000	-0.02251	-0.01949	-0.01125	0.00000	-0.02626	-0.02274	-0.01313	0.00000
180	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
210	0.01876	0.01624	0.00938	0.00000	0.02251	0.01949	0.01125	0.00000	0.02626	0.02274	0.01313	0.00000
240	0.03249	0.02814	0.01624	0.00000	0.03899	0.03376	0.01949	0.00000	0.04548	0.03939	0.02274	0.00000
270	0.03751	0.03249	0.01876	0.00000	0.04502	0.03899	0.02251	0.00000	0.05252	0.04548	0.02626	0.00000
300	0.03249	0.02814	0.01624	0.00000	0.03899	0.03376	0.01949	0.00000	0.04548	0.03939	0.02274	0.00000
330	0.01876	0.01624	0.00938	0.00000	0.02251	0.01949	0.01125	0.00000	0.02626	0.02274	0.01313	0.00000

1688
1689
1690 The reference gravitational acceleration, g_{ref}, is the gravitational acceleration for the airplane travelling in
1691 the direction of true north in still air at the reference altitude and a geodetic latitude of 45.5 degrees.
1692 Because the reference gravitational acceleration condition is for the airplane travelling in the direction of
1693 true north, the reference gravitational acceleration does not include any Coriolis effect. Because the
1694 reference specification is for the airplane travelling in still air, the effect of the centrifugal effect on the
1695 reference gravitational acceleration is determined using the airplane's true airspeed (which is the same as
1696 the zero wind ground speed). The reference gravitational acceleration can be determined for each test
1697 point as follows:
1698
1699 Determine the component of gravitational acceleration for the reference altitude and latitude at zero
1700 ground speed using the process defined above, using the reference altitude and 45.5 degrees latitude as
1701 the altitude and latitude, respectively, instead of the test values.
1702
1703 Determine the component of the reference gravitational acceleration due to centrifugal effect using the
1704 process above, using the airplane's true airspeed as the ground speed.
1705
1706 The reference gravitational acceleration, g_{ref}, is the sum of the component of gravitational acceleration for
1707 the reference altitude and latitude at zero ground speed, and the component of the reference gravitational
1708 acceleration due to centrifugal effect.
1709
1710 The drag correction for gravitational acceleration (due to the difference between the airplane test weight,
1711 ($Weight_{test}$) and the airplane weight at the reference gravitational acceleration conditions ($Weight_{ref\ g}$)) is
1712 determined from the airplane drag model. The airplane's drag model provides the drag coefficient (C_D) as
1713 a function of the lift coefficient (C_L) and Mach number. The lift coefficient for $Weight_{test}$ and $Weight_{ref\ g}$ can
1714 be determined from the following equation:
1715

1716
$$C_L = \left(\frac{Weight \, / \delta}{70927.5 \, M^2 A} \right)$$

1717
1718   where:
1719
1720 C_L is the lift coefficient;
1721
1722   Weight is the weight of the airplane in N (either Weight$_{test}$ or Weight$_{ref\,g}$, depending on which lift coefficient
1723   is being calculated);
1724
1725   δ is the ratio of the ambient air pressure at the test altitude to the ambient air pressure at sea level;
1726
1727   M is the airplane's average Mach number during the test condition; and
1728
1729   A is the airplane's reference wing area in m^2.
1730
1731   The drag correction for gravitational acceleration can be determined from the drag equation:
1732

$$\Delta Drag_{grav} = \frac{1}{2}\rho V^2 \left(C_{D_{ref\,g}} - C_{D_{test}}\right) A$$

1733

1734
1735   where:
1736
1737   ΔDrag$_{grav}$ is the drag correction in N for gravitational acceleration;
1738
1739   ρ is the density of air at the test altitude and test temperature in kg/m^3;
1740
1741   V is the airplane's average true airspeed during the test condition in m/s;
1742
1743   A is the airplane's reference wing area in m^2;
1744
1745   C$_{Dref\,g}$ is the drag coefficient from the airplane's drag model at the C_L for Weight$_{ref\,g}$; and
1746
1747   C$_{D\,test}$ is the drag coefficient from the airplane's drag model at the test C_L for Weight$_{test}$.
1748
1749   A3-1.2.2 Method 2 for the gravitational acceleration correction
1750
1751   The process for determining gravitational acceleration correction to SAR consists of the following steps:
1752
1753   Step 1) Determine the airplane test mass, as described in paragraph A3-1.1.
1754
1755   Step 2) Determine g$_{test}$/g$_{ref}$ for the test latitude by linear interpolation from Table A3-5:
1756
1757

1758
1759
1760
1761

Table A3-5.

g_{test}/g_{ref} for latitude (latitude correction)

g_{test}/g_{ref} for latitude (latitude correction)										
Test Latitude (either north or south) (degrees)	0	10	20	30	40	50	60	70	80	90
$(g_{test}/g_{ref})_{lat}$	0.9973	0.9975	0.9979	0.9986	0.9995	1.0004	1.0013	1.0020	1.0024	1.0026

1762
1763   Step 3) Determine g_{test}/g_{ref} to correct for test altitude by linear interpolation from Table A3-6:
1764
1765   Table A3-6. g_{test}/g_{ref} for altitude (altitude correction)
1766

g_{test}/g_{ref} for altitude (altitude correction)											
Reference Altitude - Test Geometric Altitude (ft)	-5000	-4000	-3000	-2000	-1000	0	1000	2000	3000	4000	5000
$(g_{test}/g_{ref})_{alt}$	0.9995	0.9996	0.9997	0.9998	0.9999	1.0000	1.0001	1.0002	1.0003	1.0004	1.0005

1767
1768   Step 4) Determine g_{test}/g_{ref} for headwind/tailwind (centrifugal correction) by linear interpolation from Table
1769   A3-7:
1770
1771
1772   **Table A3-7.**
1773
1774   **g_{test}/g_{ref} for headwind/tailwind (centrifugal correction)**
1775

g_{test}/g_{ref} for headwind/tailwind (centrifugal correction)						
TAS (kts)		200	300	400	500	600
Tailwind (kts)	300	0.9991	0.9989	0.9986	0.9983	0.9981
	200	0.9995	0.9993	0.9991	0.9990	0.9988
	100	0.9998	0.9997	0.9996	0.9995	0.9994
	0	1.0000	1.0000	1.0000	1.0000	1.0000
Headwind (kts)	-100	1.0001	1.0002	1.0003	1.0004	1.0005
	-200	1.0002	1.0003	1.0005	1.0007	1.0009
	-300	1.0001	1.0004	1.0006	1.0009	1.0011

1776
1777
1778   Step 5) Determine g_{test}/g_{ref} for track angle (Coriolis correction) by linear interpolation from Table A3-8:
1779
1780
1781
1782
1783

1784
1785
1786
1787

Table A3-8.

g~test~/g~ref~ for track angle (Coriolis correction)

g~test~/g~ref~ for track angle (Coriolis correction) for ground speeds from 200 to 400 knots												
GS (kts)	200				300				400			
Latitude (either north or south) (degrees)	0	30	60	90	0	30	60	90	0	30	60	90
True Track Angle (degrees) 0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	0.9992	0.9993	0.9996	1.0000	0.9988	0.9990	0.9994	1.0000	0.9985	0.9987	0.9992	1.0000
60	0.9987	0.9988	0.9993	1.0000	0.9980	0.9983	0.9990	1.0000	0.9973	0.9977	0.9987	1.0000
90	0.9985	0.9987	0.9992	1.0000	0.9977	0.9980	0.9988	1.0000	0.9969	0.9973	0.9985	1.0000
120	0.9987	0.9988	0.9993	1.0000	0.9980	0.9983	0.9990	1.0000	0.9973	0.9977	0.9987	1.0000
150	0.9992	0.9993	0.9996	1.0000	0.9988	0.9990	0.9994	1.0000	0.9985	0.9987	0.9992	1.0000
180	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
210	1.0008	1.0007	1.0004	1.0000	1.0012	1.0010	1.0006	1.0000	1.0015	1.0013	1.0008	1.0000
240	1.0013	1.0012	1.0007	1.0000	1.0020	1.0017	1.0010	1.0000	1.0027	1.0023	1.0013	1.0000
270	1.0015	1.0013	1.0008	1.0000	1.0023	1.0020	1.0012	1.0000	1.0031	1.0027	1.0015	1.0000
300	1.0013	1.0012	1.0007	1.0000	1.0020	1.0017	1.0010	1.0000	1.0027	1.0023	1.0013	1.0000
330	1.0008	1.0007	1.0004	1.0000	1.0012	1.0010	1.0006	1.0000	1.0015	1.0013	1.0008	1.0000

1788
1789
1790

1791
1792

Table A3-8 (continued)

g_{test}/g_{ref} for track angle (Coriolis correction) for ground speeds from 500 to 700 knots												
GS (kts)	500				600				700			
Latitude (either North or South) (degrees)	0	30	60	90	0	30	60	90	0	30	60	90
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
30	0.9981	0.9983	0.9990	1.0000	0.9977	0.9980	0.9988	1.0000	0.9973	0.9977	0.9987	1.0000
60	0.9967	0.9971	0.9983	1.0000	0.9960	0.9965	0.9980	1.0000	0.9953	0.9960	0.9977	1.0000
90	0.9961	0.9967	0.9981	1.0000	0.9954	0.9960	0.9977	1.0000	0.9946	0.9953	0.9973	1.0000
120	0.9967	0.9971	0.9983	1.0000	0.9960	0.9965	0.9980	1.0000	0.9953	0.9960	0.9977	1.0000
150	0.9981	0.9983	0.9990	1.0000	0.9977	0.9980	0.9988	1.0000	0.9973	0.9977	0.9987	1.0000
180	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
210	1.0019	1.0017	1.0010	1.0000	1.0023	1.0020	1.0012	1.0000	1.0027	1.0023	1.0013	1.0000
240	1.0033	1.0029	1.0017	1.0000	1.0040	1.0035	1.0020	1.0000	1.0047	1.0040	1.0023	1.0000
270	1.0039	1.0033	1.0019	1.0000	1.0046	1.0040	1.0023	1.0000	1.0054	1.0047	1.0027	1.0000
300	1.0033	1.0029	1.0017	1.0000	1.0040	1.0035	1.0020	1.0000	1.0047	1.0040	1.0023	1.0000
330	1.0019	1.0017	1.0010	1.0000	1.0023	1.0020	1.0012	1.0000	1.0027	1.0023	1.0013	1.0000

(Left vertical label: True Track Angle (degrees))

1793
1794
1795   Step 6) Determine Mass$_{grav}$, as defined below. Couple this mass with the tested SAR values, corrected for
1796   reference specifications from Step 7 above, in a regression model to determine the SAR values at each of
1797   the three reference masses of the FEM, and to determine the 90 percent confidence intervals.
1798
1799 $Mass_{grav} = Mass_{test} \times (g_{test}/g_{ref})_{lat} \times (g_{test}/g_{ref})_{alt} \times (g_{test}/g_{ref})_{cent} \times (g_{test}/g_{ref})_{Coriolis}$
1800
1801   where:
1802
1803   Mass$_{grav}$ is the mass at which the reference SAR value should be associated in a regression model to
1804   provide a SAR versus mass corrected for gravitational acceleration;
1805
1806   Mass$_{test}$ is the test mass, as defined in paragraph A3-1.1, in kg;
1807
1808 $(g_{test}/g_{ref})_{lat}$ is g_{test}/g_{ref} for the test latitude, from Table A3-5;
1809
1810 $(g_{test}/g_{ref})_{alt}$ is g_{test}/g_{ref} for altitude, from Table A3-6;
1811
1812 $(g_{test}/g_{ref})_{cent}$ is g_{test}/g_{ref} for headwind/tailwind (centrifugal correction) from Table A3-7; and
1813
1814 $(g_{test}/g_{ref})_{Coriolis}$ is g_{test}/g_{ref} for track angle (Coriolis correction) from Table A3-8.
1815
1816   *A3-1.3 Acceleration/deceleration (energy).* Drag determination is based on an assumption of steady,
1817   unaccelerated flight. Acceleration or deceleration relative to the ground occurring during a test condition
1818   affects the assessed drag level. The reference specification is steady, unaccelerated flight.

1819
1820   The correction for the change in drag force resulting from acceleration during the test condition can be
1821   determined from the following equation:

1822
$$\Delta D_{accel} = -Mass_{test}\left(\frac{dV_g}{dT}\right)$$

1823   where:
1824
1825 ΔD_{accel} is the drag correction in N due to acceleration occurring during the test condition;
1826
1827 $Mass_{test}$ is the average mass of the airplane during the test condition, as defined in paragraph A3-1.1 in
1828   kg; and
1829
1830 (dV_g/dT) is the change in ground speed over time during the test condition in m/s^2.
1831
1832   *A3-1.4 Reynolds number.* The RE needs to be calculated to determine its contribution to airplane drag.
1833   For a given test condition, the RE is a function of the density and viscosity of air at the test altitude and
1834   temperature. The reference RE is derived from the density and viscosity of air from the ICAO standard
1835   atmosphere at the reference altitude.
1836
1837   The value of the drag coefficient correction for RE during the test can be expressed as:
1838

1839
$$\Delta C_{D\,RE} = -B\,log\left|\frac{\frac{1}{M}\left(\frac{RE}{m}\right)_{test}}{\frac{1}{M}\left(\frac{RE}{m}\right)_{Ref}}\right|$$

1840
1841   where:
1842
1843 $\Delta C_{D\,RE}$ is the change in drag coefficient when correcting from test RE to the reference RE;
1844
1845   B is a value representing the variation of drag with RE for the specific airplane (see guidance below);
1846
1847   M is Mach number; and
1848
1849   RE/m is RE per meter.
1850
1851   One method to obtain B is to use a drag model to obtain the incremental drag variation in response to
1852   changing Mach and altitude from a reference cruise condition. The value for B is the value of a single
1853   representative slope of a plot of the drag variation, ΔDrag versus $Log_{10}\left[\frac{1}{M}\left(\frac{RE}{m}\right)x10^{-6}\right]$.
1854
1855   The term $\left[\frac{\frac{1}{M}\left(\frac{RE}{m}\right)_{test}}{\frac{1}{M}\left(\frac{RE}{m}\right)_{Ref}}\right]$ is the term $\frac{1}{M}\left(\frac{RE}{m}\right)$ determined at the temperature and altitude for the test condition,
1856   divided by the same term determined at the standard day temperature and the reference altitude for the
1857   test mass/δ using the following equation:
1858

1859
$$\frac{1}{M}\frac{RE}{m} = 4.7899\,x\,10^5\,P_S\left(\frac{T_S + 110.4}{T_S^2}\right)$$

1860
1861   where:
1862
1863   RE/m is RE per m;
1864
1865 P_S is static pressure in Pa; and
1866

1867 T_S is static temperature in K.
1868
1869   The effect on airplane drag can then be determined from $\Delta C_{D\,RE}$ and the airplane drag equation as
1870   follows:
1871
1872
$$\Delta D_{RE} = \frac{1}{2}\rho V^2 \Delta C_{D\,RE}\,A$$

1873
1874   where:
1875
1876 ΔD_{RE} is the airplane drag correction in N due to the test RE being different than the reference RE;
1877
1878 ρ is the density of air at the test altitude and test temperature in kg/m^3;
1879
1880   V is the airplane's average true airspeed during the test condition in m/s;
1881
1882   A is the airplane's reference wing area in m^2; and
1883
1884 $\Delta C_{D\,RE}$ is the change in drag coefficient due to being off the reference RE.
1885
1886   *A3-1.5 CG position.* The position of the airplane center of gravity (CG) affects the drag due to longitudinal
1887   trim.
1888
1889   The drag correction for CG position during the test is the difference between the drag at the reference CG
1890   position and the drag at the test CG position. This drag correction can be determined by adjusting the
1891   longitudinal trim drag, determined from the airplane's drag model at the reference CG, to adjust for the
1892   test CG position. For example, testing at a CG position aft of the reference CG used in the drag model
1893   would yield a positive drag correction (that is, a decrease to the test SAR).
1894
1895   A method to determine the change in longitudinal trim drag for CG position from the reference is to first
1896   determine the amount of longitudinal trim drag ($C_{D\,Trim\,Ref\,CG}$) that exists at the reference CG position as a
1897   function of Mach and C_L. This can be done using wind tunnel testing and analytical methods. The change
1898   of the longitudinal trim drag with CG, which is specific to an airplane type design, can be estimated with
1899   wind tunnel and analytical methods, and verified by flight test data. This relationship can then be used to
1900   determine the longitudinal trim drag ($C_{D\,Trim\,Test\,CG}$) at the test CG position.
1901
1902   Once the trim drag coefficients are determined from the airplane drag model, the airplane drag correction
1903   for the CG position can be determined from the drag equation:
1904
1905
$$\Delta D_{Trim\,CG} = \frac{1}{2}\rho V^2\left(C_{D\,Trim\,Ref\,CG} - C_{D\,Trim\,Test\,CG}\right)A$$

1906
1907   where:
1908
1909 $\Delta D_{Trim\,CG}$ is the airplane drag correction in N due to the test CG being different than the reference CG;
1910
1911 ρ is the density of air at the test altitude and test temperature in kg/m^3;
1912
1913   V is the airplane's average true airspeed during the test condition in m/s;
1914
1915   A is the airplane's reference wing area in m^2; and
1916
1917 $C_{D\,Trim\,Ref\,CG}$ and $C_{D\,Trim\,Test\,CG}$ are the trim drag coefficients from the airplane's drag model at the reference
1918   CG and test CG positions, respectively.
1919
1920   *A3-1.6 Aeroelastics.* Wing aeroelastics may cause a variation in drag as a function of airplane wing mass
1921   distribution. Airplane wing mass distribution will be affected by the fuel load distribution in the wings and

1922   the presence of any external fuel stores.
1923
1924   There are no simple analytical means to correct for different wing structural loading conditions. If
1925   necessary, corrections to the reference specification should be developed by flight test or a suitable
1926   analysis process, subject to the approval of the FAA.
1927
1928   The reference specification for the wing structural loading is to be selected by the applicant based on the
1929   amount of fuel and/or removable external stores to be carried by the wing, based on the airplane's
1930   payload capability and the manufacturer's standard fuel management practices. The reference to the
1931   airplane's payload capability is for establishing the zero fuel mass of the airplane, while the reference to
1932   the manufacturer's standard fuel management practices is for establishing the distribution of that fuel and
1933   how that distribution changes as fuel is burned.
1934
1935   The reference specification for the wing structural loading reference specification should be based on an
1936   operationally representative empty weight and payload which defines the zero fuel mass of the airplane.
1937   The total amount of fuel loaded for each of the three reference masses would be the reference mass
1938   minus the zero fuel mass. Standard fuel management practices will determine the amount of fuel present
1939   in each fuel tank. An example of standard fuel management practice is to load the main (wing) fuel tanks
1940   before loading the center (body) fuel tanks and to first empty fuel from the center tanks before using the
1941   fuel in the main tanks. This helps keep the CG aft and reduces trim drag.
1942
1943   Commercial freighters may be designed from scratch, but more often are derivatives of or converted from
1944   passenger model airplanes. In determining aeroelastic effects, it is reasonable to assume that the
1945   reference loading for a freighter is the same as the passenger model it was derived from. If there is no
1946   similar passenger model, the reference zero-fuel-mass of a freighter can be based on its payload design
1947   density. The payload design density is defined by the full use of the volumetric capacity of the freighter
1948   and the highest mass it is designed to carry, expressed in kg/m^3. For example, a typical payload design
1949   density for large commercial freighters is 160 kg/m^3.
1950
1951   Using a reference payload significantly lower than the passenger interior limits or structural limited
1952   payload could potentially provide a more beneficial aeroelastic effect. An applicant would need to justify
1953   the reference payload assumptions in the context of the capability of the airplane and what could be
1954   considered typical for the type design.
1955
1956   *A3-1.7 Fuel lower heating value.* The fuel lower heating value defines the energy content of the fuel. The
1957   lower heating value directly affects the fuel flow at a given test condition.
1958
1959   The fuel flow measured during the flight test is corrected to the fuel flow for the reference lower heating
1960   value as follows:
1961

1962 $$\Delta Fuel\ Flow_{Corr\ LHV} = Fuel\ Flow_{test\ LHV}\left(\frac{LHV_{test}}{LHV_{Ref}}\right) - Fuel\ Flow_{test\ LHV}$$

1963
1964   where:
1965
1966 ΔFuel Flow$_{Corr\ LHV}$ is the fuel flow correction in kilograms/hour due to the fuel lower heating value being
1967   different than the reference fuel lower heating value;
1968
1969   Fuel Flow$_{test\ LHV}$ is the measured fuel flow in kilograms/hour during the test (at the test fuel lower heating
1970   value);
1971
1972   LHV$_{test}$ is the fuel lower heating value of the fuel used for the test in MJ/kg; and
1973
1974   LHV$_{Ref}$ is the reference fuel lower heating value = 43.217 MJ/kg.
1975

1976   *A3-1.8 Altitude.* The altitude at which the airplane is flown affects the fuel flow. As noted in Table A3-1,
1977   since testing at any altitude other than the reference optimum altitude increases the FEM, this correction
1978   is considered optional. For applicants choosing to make this correction, the selection of the reference
1979   altitude depends on the method used for determining SAR for the three reference airplane masses
1980   specified in § 38.13 (b). For SAR data clustered around each of the three reference masses (see §
1981   A38.5.3.3), a reference altitude is selected by the applicant for each of the specified reference masses. If
1982   SAR data is obtained over a range of masses (see § A38.5.3.4), the applicant should select a reference
1983   altitude for each test point (since none of the test points are directly associated with any of the reference
1984   masses). For applicants using a first principle model (see paragraph 6.4.4 of this AC), the applicant
1985   should select a reference altitude for each target Weight/δ value (see Figure 6-6 of this AC).

1987   The engine model should be used to determine the fuel flow at the test altitude (Fuel Flow$_{test\ alt}$) and the
1988   fuel flow at the reference altitude (Fuel Flow$_{ref\ alt}$). The fuel flow correction for altitude is determined as
1989   follows:

1991 ΔFuel Flow$_{alt}$ = Fuel Flow$_{ref\ alt}$ – Fuel Flow$_{test\ alt}$.

1993   *A3.9 Temperature.* The ambient temperature affects the fuel flow. The reference temperature is the
1994   standard day temperature from the ICAO standard atmosphere at the reference altitude.

1996   The engine model should be used to determine the difference between the fuel flow at the test
1997   temperature (Fuel Flow$_{test\ temp}$) and the fuel flow at the reference temperature (Fuel Flow$_{ref\ temp}$). The fuel
1998   flow correction for temperature is determined as follows:

2000 ΔFuel Flow$_{temp}$ = Fuel Flow$_{ref\ temp}$ – Fuel Flow$_{test\ temp}$.

2002   *A3-1.10 Engine deterioration level.* When first used, engines undergo a rapid, initial deterioration in fuel
2003   efficiency. Thereafter, the rate of deterioration significantly decreases. Engines with less than the
2004   reference deterioration level may be used, subject to the approval of the FAA, as stated in 14 CFR part
2005   38, Appendix A, § 5.2.2.1.7.1. In such a case, the fuel flow is to be corrected to the reference engine
2006   deterioration level using an approved method. Engines with more deterioration than the reference engine
2007   deterioration level may be used. In this case, a correction to the reference specification shall not be
2008   permitted in accordance with 14 CFR part 38, Appendix A, 5.2.2.1.7.2.

2010   As stated above, a correction should generally not be made for engine deterioration level. If an applicant
2011   proposes to use an engine or engines with less than the reference deterioration level for testing, it may be
2012   possible to establish a conservative correction level to apply to the test fuel flow to represent engines at
2013   the reference deterioration level. Such a correction should be substantiated by engine fuel flow
2014   deterioration data from the same engine type or family and approved by the FAA.

2016   *A3-1.11 Electrical and mechanical power extraction and bleed flow.* Electrical and mechanical power
2017   extraction and bleed flow both affect the fuel flow.

2019   The engine model should be used to determine the difference between the fuel flow at the test power
2020   extraction (Fuel Flow$_{test\ bleed}$) and bleed flow and the fuel flow at the reference power extraction and bleed
2021   flow (Fuel Flow$_{ref\ bleed}$). The fuel flow correction for electrical and mechanical power extraction and bleed
2022   flow is determined as follows:

2024 ΔFuel Flow$_{Corr\ bleed}$ = Fuel Flow$_{ref\ bleed}$ – Fuel Flow$_{test\ bleed}$.

2026   *A3-1.12 Modifications and non-standard equipment that will not be included on the production airplane.*
2027   The test airplane may contain modifications and non-standard equipment, such as flight test
2028   instrumentation, that will not be included on the production airplane. Examples of such flight test
2029   instrumentation includes trailing cones, precision total air temperature probes, air data booms, telemetry
2030   antennas, and engine pressure rakes. Where these modifications or non-standard equipment increase
2031   drag or fuel flow, this effect may be corrected out of the tested drag and fuel flow levels used to determine

2032   the SAR used for calculating the FEM.
2033

2034
2035   **Appendix 4**: Confidence Interval Evaluation
2036
2037
2038   A4-1 Direct flight testing
2039
2040   If n measurements of SAR (y_1, y_2, …., y_n) are obtained under approximately the same conditions, and it
2041   can be assumed that they constitute a random sample from a normal population with true population
2042   mean, μ, and true standard deviation, σ, then the following statistics can be derived:
2043

2044
$$\bar{y} = estimate\ of\ the\ mean = \frac{1}{n}\left\{\sum_{i=1}^{i=n} y_{(i)}\right\}$$

2045
$$s = estimate\ of\ the\ standard\ deviation\ of\ the\ mean = \sqrt{\frac{\sum_{i=1}^{i=n}(y_i-\bar{y})^2}{n-1}}.$$

2046
2047   From these and the Student t-distribution, the confidence interval, CI, for the estimate of the mean, $\bar{y}$, can
2048   be determined as:
2049

2050
$$CI = \bar{y} \pm t_{\left(1-\frac{\alpha}{2},\zeta\right)}\frac{s}{\sqrt{n}}$$

2051
2052   where $t_{\left(1-\frac{\alpha}{2},\zeta\right)}$ denotes the $\left(1-\frac{\alpha}{2}\right)$ percentile of the single-sided Student t-test with ζ degrees freedom
2053   (for a clustered data set $\zeta = n-1$) and where α is defined such that $100(1-\alpha)$ percent is the desired
2054   confidence level for the confidence interval. In other words, it denotes the probability with which the
2055   interval will contain the unknown mean, μ. For fuel efficiency metric certification purposes, 90 percent
2056   confidence intervals are required and thus $t_{.95,\zeta}$ is used. See Table A4-1 for a listing of values of $t_{.95,\zeta}$ for
2057   different values of ζ.
2058
2059
2060   A4-2 Regression model
2061
2062   If n measurements of SAR (y_1, y_2, …., y_n) are obtained under significantly varying values of mass (x_1, x_2,
2063   …., x_n), respectively, then a polynomial can be fitted to the data by the method of least squares. For
2064   determining the mean SAR, μ, the following polynomial regression model is assumed to apply:
2065
2066 $\mu = B_0 + B_1x + B_2x^2 +…..+ B_kx^k$.
2067
2068   The estimate of the mean line through the data of the SAR is given by:
2069
2070 $y = b_0 + b_1x + b_2x^2 +…..+ b_kx^k$.
2071
2072   Each regression coefficient (B_i) is estimated by b_i from the sample data using the method of least squares
2073   in a process summarized as follows:
2074
2075   Each observation (x_i, y_i) satisfies the equations:
2076
2077 $y_i = B_0 + B_1x_i + B_2x_i^2 +…..+ B_kx_i^k + \varepsilon_i$
2078
2079 $= b_0 + b_1x_i + b_2x_i^2 +…..+ b_kx_i^k + e_i$
2080
2081   where ε_i and e_i are, respectively, the random error and residual associated with the SAR. The random
2082   error is assumed to be a random sample from a normal population with mean zero and standard deviation
2083 σ. The residual (e_i) is the difference between the measured value and the estimate of the value using the

2084 estimates of the regression coefficients and x_i. Its root mean square value (s) is the sample estimate for
2085 σ. These equations are often referred to as the normal equations.
2086
2087
2088   **Table A4-1.**
2089
2090   Student t-distribution (for 90 percent confidence) for various degrees of freedom
2091

Degrees of freedom (ζ)	$t_{.95, \zeta}$
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
12	1.782
14	1.761
16	1.746
18	1.734
20	1.725
24	1.711
30	1.697
60	1.671
>60	1.645

2092
2093
2094 The n data points of measurements (x_i,y_i) are processed as follows:
2095
2096 Each elemental vector ($\underline{x}_i$) and its transpose ($\underline{x}'_i$) are formed such that:
2097
2098 $\underline{x}_i = (1 \quad x_i \quad x_i^2 \quad . \quad . \quad x_i^k)$, a row vector; and
2099

2100 $x'_i = \begin{pmatrix} 1 \\ x_i \\ x_i^2 \\ . \\ . \\ x_i^k \end{pmatrix}$, a column vector.

2101
2102 A matrix $\underline{X}$ is formed from all the elemental vectors $\underline{x}_i$ for i = 1, ….., n. $\underline{X}'$ is the transpose of $\underline{X}$. A matrix $\underline{A}$
2103 is defined such that $\underline{A} = \underline{X}'\underline{X}$ and a matrix $\underline{A}^{-1}$ is the inverse of $\underline{A}$. In addition, $\underline{y} = (y_1 \, y_2 \dots y_n)$ and $\underline{b} = (b_0 \, b_1$

2104   ... b_2), with $\underline{b}$ determined as the solution of the normal equations:

2105

2106 $\underline{y} = \underline{Xb}$ and $\underline{X'y} = \underline{X'Xb} = \underline{Ab}$

2107

2108   to give

2109

2110 $\underline{b} = \underline{A}^{-1}\underline{X'y}$.

2111

2112   The 90 percent confidence interval CI_{90} for the mean value of the SAR estimated with the associated
2113   value of the mass x_0 is then defined as:

2114

2115 $CI_{90} = \bar{y}(x_0) \pm t_{.95,\zeta}\, s\, v(x_0)$

2116

2117   where $v(x_0) = \sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0'}}$.

2118

2119   Thus, $CI_{90} = \bar{y}(x_0) \pm t_{.95,\zeta}\, s\, \sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0'}}$,

2120

2121   where:

2122

2123 $\underline{x_0} = (1\ x_0\ x_0^2 \ldots x_0^k)$;

2124

2125 $\underline{x'}_\square$ is the transpose of $\underline{x_0}$;

2126

2127 $\bar{y}(x_0)$ is the estimate of the mean value of the SAR at the associated value of the mass x_0;

2128

2129 $t_{.95,\zeta}$ is obtained for ζ degrees of freedom. For the general case of a multiple regression analysis involving
2130 K independent variables (i.e. $K + 1$ coefficients), ζ is defined as $\zeta = n - K - 1$; and

2131

2132 $s = \sqrt{\dfrac{\sum_{i=1}^{i=n}(y_i - \bar{y}(x_i))^2}{n-K-1}}$ is the estimate of σ, the true standard deviation.

2133

2134

2135   A4-3 Worked examples of the determination of 90 percent confidence intervals

2136

2137   Direct flight testing

2138

2139   Example 1: In which the confidence interval is less than the confidence interval limit.

2140

2141   Consider the following set of 6 independent measurements of SAR obtained by flight test around one of
2142   the three reference masses of the CO_2 emissions evaluation metric. After correction to reference
2143   specifications, the following clustered data set of SAR values is obtained:

2144

2145

2146   **Table A4-2.**

2147

2148   Measurements of SAR — Example 1

2149

Measurement number	Corrected SAR (km/kg)
1	0.38152
2	0.38656
3	0.37988

Measurement number	Corrected SAR (km/kg)
4	0.38011
5	0.38567
6	0.37820

2150
2151
2152   The number of data points (n) = 6
2153
2154   The degrees of freedom (n-1) = 5
2155
2156   The Student t-distribution for 90 percent confidence and 5 degrees of freedom ($t_{(.95,5)}$) = 2.015. (See
2157   Table A4-1.)
2158
2159   Note.— 6 is the minimum number of test points required, as stated in § A38.5.3.3.
2160   Estimate of the mean SAR ($\overline{SAR}$) for the clustered data set:
2161
2162 $\overline{SAR} = \frac{1}{n} \{\sum_{i=1}^{i=n} SAR_{(i)}\} = 0.38282$ km/kg.
2163
2164   Estimate of the standard deviation(s):
2165

2166 $s = \sqrt{\frac{\sum_{i=1}^{i=n}(SAR_{(i)}-\overline{SAR})^2}{n-1}} = 0.00344$ km/kg .

2167
2168
2169   Confidence interval determination
2170
2171   The 90 percent confidence interval (CI90) is calculated as follows (see 3.3.2):
2172
2173 $CI_{90} = \overline{SAR} \pm t_{(.95,n-1)} \frac{s}{\sqrt{n}} = 0.38282 \pm 2.015 \text{ x } \frac{0.00344}{\sqrt{6}} = 0.38282 \pm 0.00283$ km/kg.
2174
2175
2176   Check of confidence interval limits
2177
2178   The confidence interval extends to ±0.00283 km/kg around the mean SAR value of the clustered data set
2179   (0.38282 km/kg). This represents ±0.74 percent of the mean SAR value, which is below the confidence
2180   interval limit of 1.5 percent, as defined in § A38.5.3.2.
2181
2182   As a result, the SAR value of 0.38282 km/kg associated to one of the reference masses of the FEM can
2183   be used for the metric determination.
2184
2185   Example 2: In which the confidence interval exceeds the confidence interval limit.
2186
2187   Consider the following set of 6 independent measurements of SAR obtained by flight test around one of
2188   the three reference masses of the FEM. After correction to reference specifications, the following
2189   clustered data set of SAR values is obtained:
2190
2191
2192
2193
2194
2195

2196   **Table A4-3.**
2197
2198   Measurements of SAR — Example 2
2199

Measurement number	Corrected SAR (km/kg)
1	0.15208
2	0.15795
3	0.15114
4	0.15225
5	0.15697
6	0.15834

2200
2201   The number of data points (n) = 6
2202
2203   The degrees of freedom (n-1) = 5
2204   The Student t-distribution for 90 percent confidence and 5 degrees of freedom $(t_{(.95,5)})$ = 2.015. (See
2205   Table A4-1)
2206
2207   Estimate of the mean SAR ($\overline{SAR}$) for the clustered data set:
2208
2209 $\overline{SAR} = \frac{1}{n}\left\{\sum_{i=1}^{i=n} SAR_{(i)}\right\} = 0.15479$ km/kg.
2210
2211   Estimate of the standard deviation(s):
2212
2213 $s = \sqrt{\frac{\sum_{i=1}^{i=n}(SAR_{(i)}-\overline{SAR})^2}{n-1}} = 0.0033$ km/kg .
2214
2215
2216   Confidence interval determination
2217
2218   The 90 percent confidence interval (CI$_{90}$) is calculated as follows (see 3.3.2):
2219
2220 $CI_{90} = \overline{SAR} \pm t_{(.95,n-1)}\frac{s}{\sqrt{n}} = 0.15479 \pm 2.015 \text{ x } \frac{0.0033}{\sqrt{6}} = 0.15479 \pm 0.00271$ km/kg.
2221
2222
2223   Check of confidence interval limits
2224
2225   The confidence interval extends to ±0.00271 km/kg around the mean SAR value of the clustered data set
2226   (0.15479 km/kg). This represents ±1.75 percent of the mean SAR value, which is above the confidence
2227   interval limit of 1.5 percent, as defined in § A38.5.3.2.
2228
2229   In such case, a penalty equal to the amount that the 90 percent confidence interval exceeds ±1.5 percent
2230   is applied to the mean SAR value, i.e. (1.75-1.50) = 0.25 percent. The mean SAR value is therefore be
2231   penalized by an amount of 0.25 percent as follows:
2232
2233 $\overline{SAR} = (1 - \frac{0.25}{100}) \text{ x } 0.15479 = 0.15440$ km/kg.
2234
2235   As a result, the SAR value of 0.15440 km/kg associated to one of the reference masses of the FEM can
2236   be used for the metric determination.

2237
2238   Regression model
2239
2240   Example 3: In which the confidence interval at each of the three reference masses of FEM is less than
2241   the confidence interval limit.
2242
2243   Consider the following set of 12 measurements of SAR obtained by flight test at optimum speed and
2244   optimum altitude as a function of the airplane gross mass. After SAR correction to reference
2245   specifications, the following data set is obtained:
2246
2247   **Table A4-4.**
2248
2249   Measurements of SAR — Example 3
2250

Measurement number and reference mass	Gross mass (m_i) (kg)	Corrected SAR (SAR_i) (km/kg)
1	17,800	0.928
Low mass [*]	17,825	
2	17,970	0.905
3	18,400	0.908
4	18,850	0.884
5	19,500	0.850
6	19,950	0.845
Mid mass [*]	19,953	
7	20,180	0.833
8	20,350	0.818
9	21,000	0.792
10	21,500	0.781
11	21,870	0.779
High mass [*]	22,080	
12	22,150	0.771

2251
2252   (*) Low, mid and high mass represent the reference masses of the FEM, as defined in §38.13(b).
2253
2254   The number of data points (n) = 12
2255
2256   Note.— 12 is the minimum number of test points requested, as stated in § A38.5.3.4.
2257
2258   A representation of the above measurement points is proposed in Figure A4-5.
2259
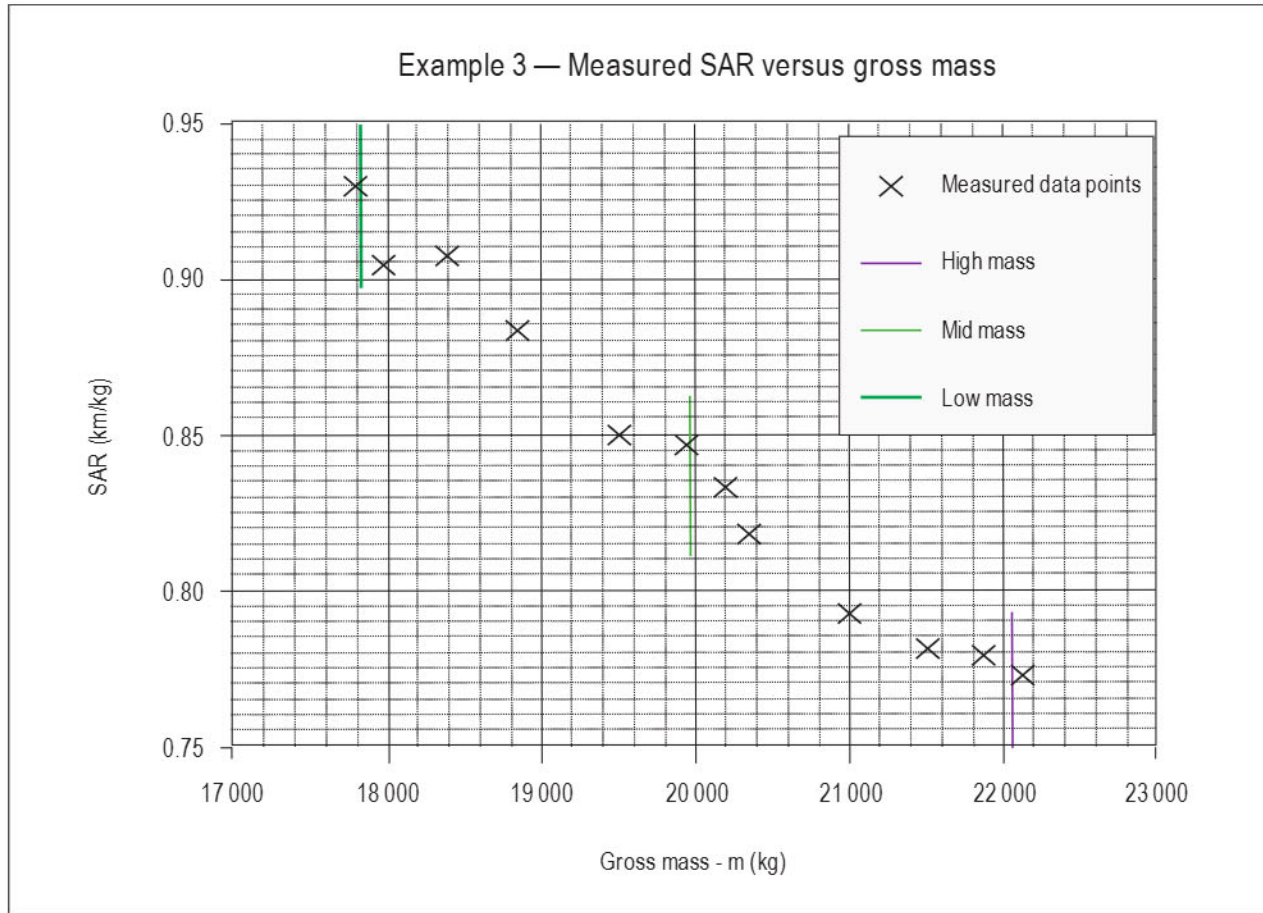
Figure A4-5.   Measured SAR versus gross mass — Example 3

Estimate of the mean SAR model by polynomial regression

In order to estimate the SAR model (SAR_{av}) as a function the airplane gross mass (m), a polynomial regression of second order is proposed so that:

$$SAR_{av} = B_0 + B_1 m + B_2 m^2$$

Each observation (m_i, SAR_i), for $I = 1, \ldots, 12$ satisfies the equation:

$$SAR_{(i)} = b_0 + b_1 m_i + b_2 m_i^2 + e_i$$

where e_i = residual error (difference between the measured SAR value and its estimate).

Under a matrix form this gives:

$$
\begin{pmatrix} SAR_1 \\ SAR_2 \\ SAR_3 \\ \vdots \\ SAR_{12} \end{pmatrix}
=
\begin{pmatrix}
1 & m_1 & m_1^2 \\
1 & m_2 & m_2^2 \\
1 & m_3 & m_3^2 \\
\vdots & \vdots & \vdots \\
1 & m_{12} \cdots & m_{12}^2
\end{pmatrix}
\begin{pmatrix} b_0 \\ b_1 \\ b_2 \end{pmatrix}
+
\begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_{12} \end{pmatrix}
$$

2281   SAR = M b + e

2282

2283   where:

2284

2285 $\underline{SAR} = \begin{pmatrix} 0.928 \\ 0.905 \\ 0.908 \\ 0.884 \\ 0.850 \\ 0.845 \\ 0.833 \\ 0.818 \\ 0.792 \\ 0.781 \\ 0.779 \\ 0.771 \end{pmatrix}$ $\underline{M} = \begin{pmatrix} 1 & 17800 & 17800^2 \\ 1 & 17970 & 17970^2 \\ 1 & 18400 & 18400^2 \\ 1 & 18850 & 18850^2 \\ 1 & 19500 & 19500^2 \\ 1 & 19950 & 19950^2 \\ 1 & 20180 & 20180^2 \\ 1 & 20350 & 20350^2 \\ 1 & 21000 & 21000^2 \\ 1 & 21500 & 21500^2 \\ 1 & 21870 & 21870^2 \\ 1 & 22150 & 22150^2 \end{pmatrix}$ $\underline{b} = \begin{pmatrix} b_0 \\ b_1 \\ b_2 \end{pmatrix}$ $\underline{e} = \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_n \end{pmatrix}$.

2286

2287   The least square principle consists in looking for the parameter values of vector B, minimizing the sum of

2288   the squares of residuals, i.e.:

2289

2290 $\text{Min} \sum_{i=1}^{i=12} e_i^2 = \text{min} \sum_{i=1}^{i=12} (SAR_{(i)} - b_0 - b_1\, m_i - b_2\, m_i^2)^2.$

2291

2292   It is equivalent to look for the solutions of $\frac{\partial(\sum e_i^2)}{\partial b_j} = 0$ for j = (0, 1, 2).

2293

2294   The solution $\underline{B} = \begin{pmatrix} B_0 \\ B_1 \\ B_2 \end{pmatrix}$ is given by:

2295

2296 $\underline{A}^{-1}\,\underline{M}'\,\underline{SAR}$ (see **A4-2**)

2297

2298   where:

2299

2300 $\underline{M}'$ = transpose of $\underline{M}$; and

2301

2302 $\underline{A}^{-1} = (\underline{M}'\,\underline{M})^{-1}$ = inverse of $(\underline{M}'\,\underline{M})$.

2303

2304   Finally, $\underline{B} = \begin{pmatrix} 2.402921963 \\ -0.000120515 \\ 2.10695\ x10^{-09} \end{pmatrix}$; and
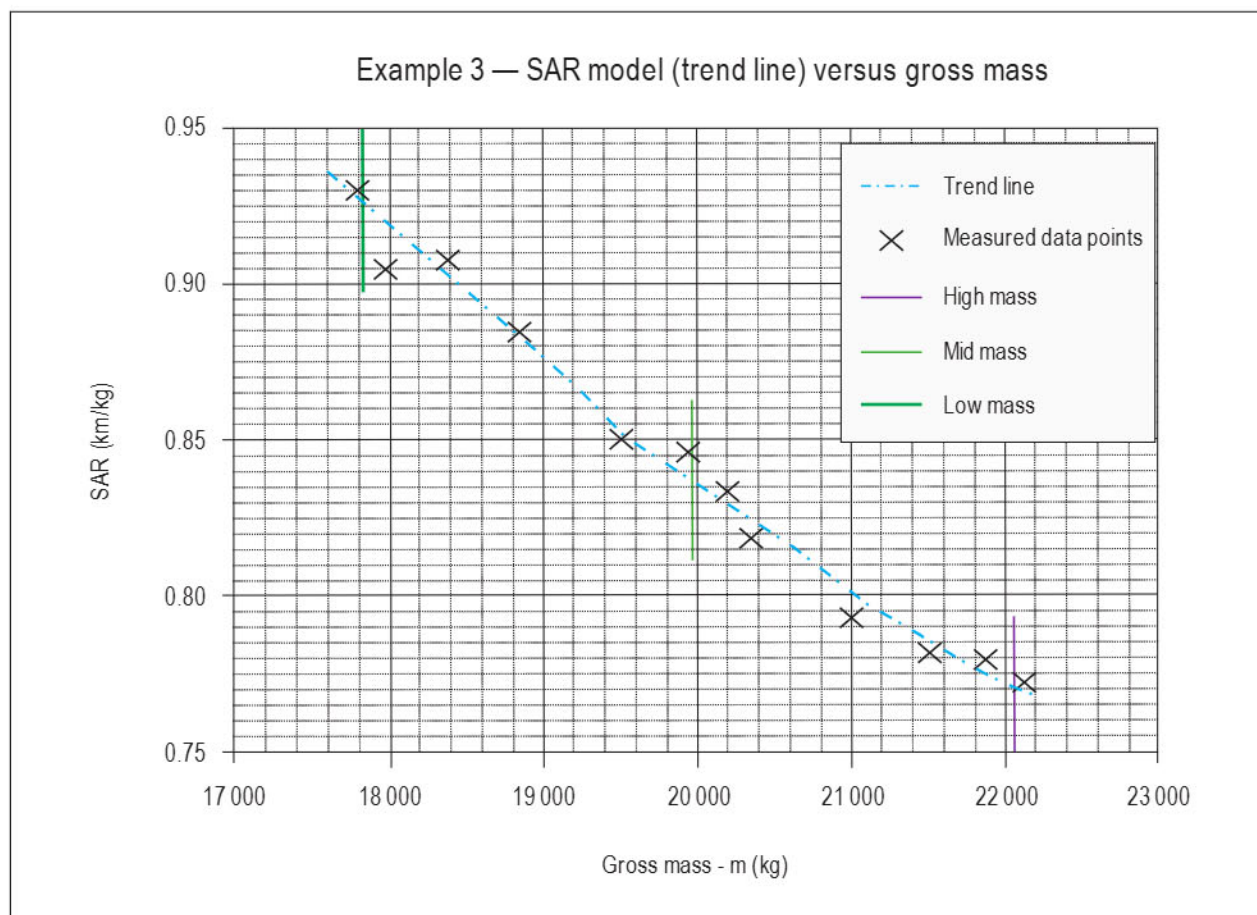
2305

2306 $SAR_{av} = 2.402921963 - 0.000120515\ m + 2.10695.10^{-9}\ m^2.$

2307

2308   Figure A4-6 provides a representation of the mean SAR model as a function of the airplane gross mass.

2309

Figure A4-6.   SAR model (trend line) versus gross mass — Example 3

The mean SAR values at each of the three reference gross masses of the FEM are as follows:

Table A4-7.

Mean SAR values — Example 3

Reference mass	Mass value (kg)	Mean SAR value (km/kg)
Low mass	17,825	0.92418
Mid mass	19,953	0.83710
High mass	22,080	0.76914

Estimate of the standard deviation(s):

$$s = \sqrt{\frac{\sum_{i=1}^{i=n}(SAR_i - SAR_{av(i)})^2}{n-K-1}} = 0.00765 \text{ km/kg}$$

2325   where:
2326
2327   the number of data points (n) = 12;
2328
2329   K = 2 for a second order polynomial regression (see **A4-2**); and
2330
2331   the degrees of freedom (n-K-1) = 9.
2332
2333
2334   Confidence interval determination
2335
2336   The 90 percent confidence interval (CI_{90}) at an airplane gross mass m_0 is calculated as follows (see **A4-**
2337   **2**):
2338

$$CI_{90} = SAR_{av}(m_0) \pm t_{(.95, n-K-1)}\, s\, \sqrt{m_0\, \underline{A}^{-1}\, m_0'}$$

2340
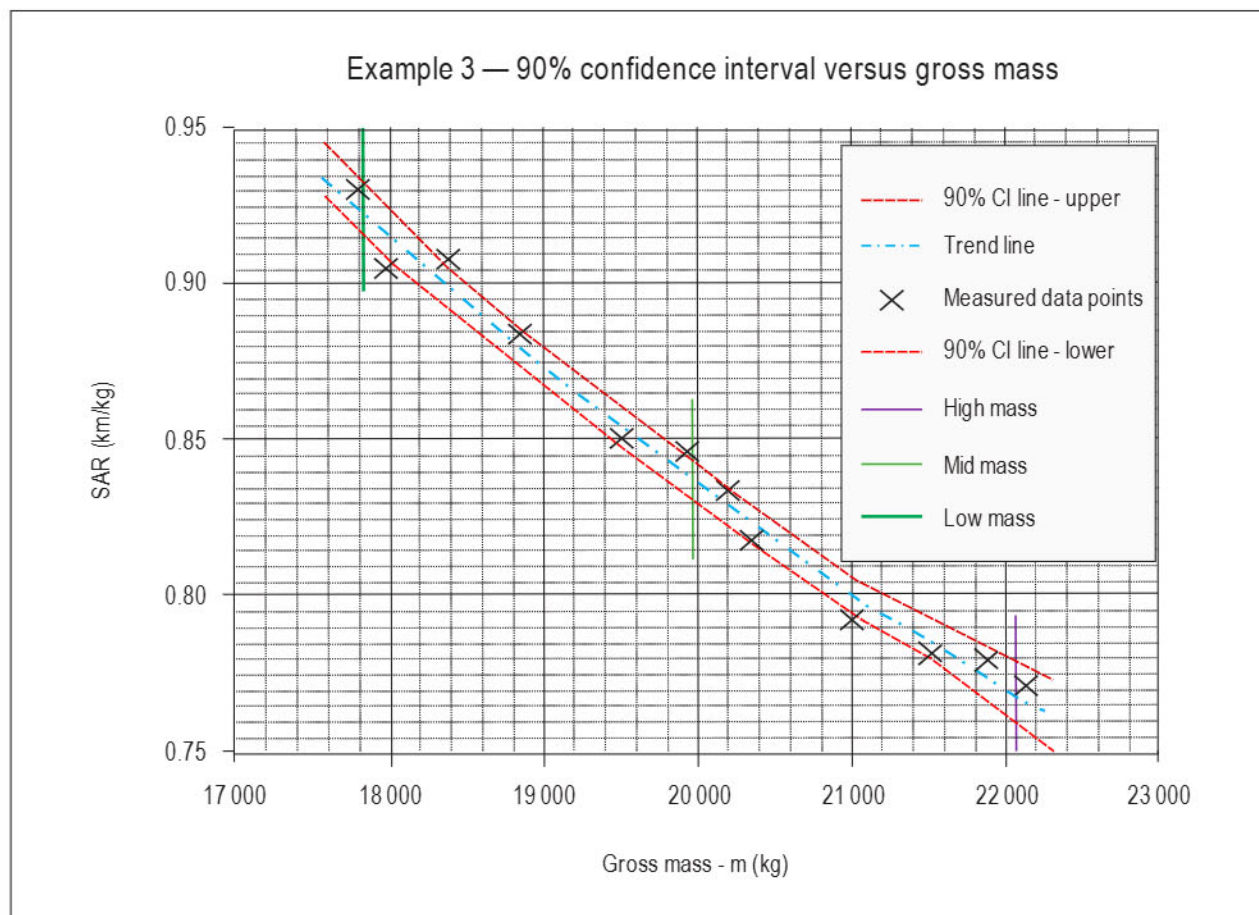2341   where:
2342
2343   the Student t-distribution for 90 percent confidence and 9 degrees of freedom $t_{(.95, 9)}$ = 1.833. (See Table
2344   A4-1);
2345

2346 $m_0 = (1\ m_0\ m_0^2)$ and $m_0' = \begin{pmatrix} 1 \\ m_0 \\ m_0^2 \end{pmatrix}$; and

2347
2348 $A^{-1} = (M'\ M)^{-1}$ = inverse of $(M'\ M)$.
2349
2350   Figure A4-8 provides a representation of the 90 percent confidence interval as a function of airplane
2351   gross mass.
2352
2353

Figure A4-8. 90 percent confidence interval versus gross mass — Example 3

The 90 percent confidence intervals at each of the three reference gross masses of the FEM are as follows:

Table A4-9.

Confidence intervals — Example 3

Reference mass	Mass value (kg)	90% confidence interval (kg/km)
Low mass	17 825	$CI_{90} = 0.92418 \pm 0.00915$
Mid mass	19 953	$CI_{90} = 0.83710 \pm 0.00619$
High mass	22 080	$CI_{90} = 0.76914 \pm 0.00925$

Check of confidence interval limits

For each of the three reference gross masses of the FEM, the confidence interval extends around the mean SAR value by a percentage, as shown in Table A4-10.

2370
2371   **Table A4-10.**
2372
2373   Check of confidence intervals — Example 3
2374

Reference mass	Mass value (kg)	90% confidence interval (percentage of mean SAR)
Low mass	17,825	(0.00915/0.92418) x 100 = 0.99%
Mid mass	19,953	(0.00619/0.83710) x 100 = 0.74%
High mass	22,080	(0.00925/0.76914) x 100 = 1.2%

2375
2376
2377   The 90 percent confidence intervals at each of the three reference gross masses of the FEM are all below
2378   the confidence interval limit of 1.5 percent, as defined in § A38.5.3.2.
2379
2380   As a result, the following mean SAR values associated to each of the three reference masses of the FEM
2381   can be used for the metric determination:
2382
2383   **Table A4-11.**
2384
2385   Mean SAR values — Example 3
2386

Reference mass	Mass value (kg)	Mean SAR value (km/kg)
Low mass	17,825	0.92418
Mid mass	19,953	0.83710
High mass	22,080	0.76914

2387
2388
2389   Example 4: In which the confidence interval of at least one of the three reference masses of the FEM
2390   exceeds the confidence interval limit.
2391
2392   Consider the following set of 12 measurements of SAR obtained by flight test at optimum speed and
2393   optimum altitude as a function of the airplane gross mass. After SAR correction to reference
2394   specifications, the following data set is obtained:
2395
2396

2397
2398
2399
2400

Table A4-12.

Measurements of SAR — Example 4

Measurement number and reference mass	Gross mass (m_i) (kg)	Corrected SAR (SAR_i) (km/kg)
1	17,800	0.932
Low mass (*)	17,825	
2	18,200	0.925
3	18,620	0.913
4	18,890	0.889
5	19,350	0.868
6	19,610	0.848
Mid mass (*)	19,953	
7	19,920	0.838
8	20,510	0.830
9	20,790	0.806
10	21,220	0.815
11	21,480	0.779
High mass (*)	22,080	
12	22,100	0.788

2401
2402   (*) Low, mid and high mass represent the reference masses of the CO_2 emissions evaluation metric, as
2403   defined in §38.13(b).
2404
2405   The number of data points (n) = 12 (minimum required, as stated in § A38.5.3.4).
2406
2407   A representation of the above measurement points is proposed in Figure A4-13.
2408
2409
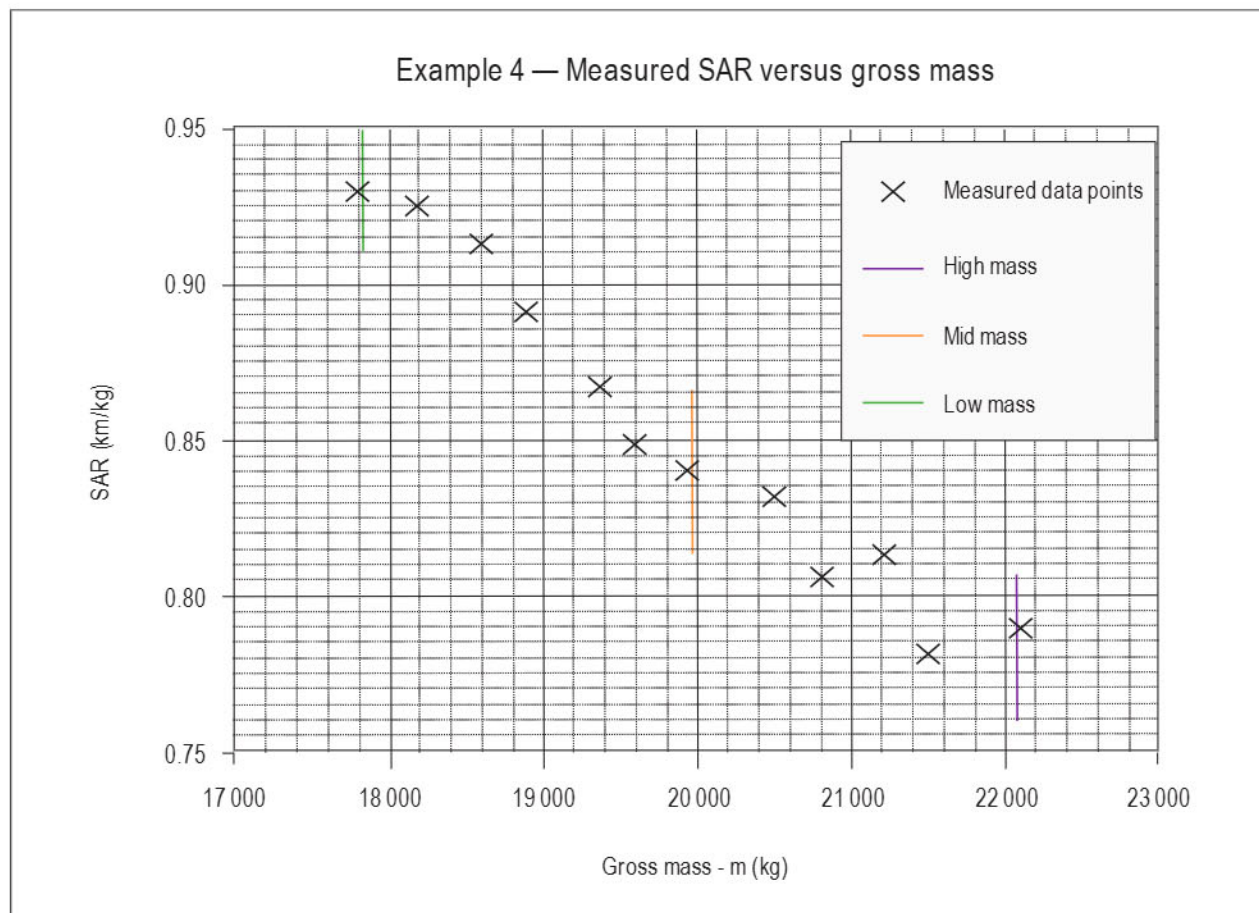
Figure A4-13.   Measured SAR versus gross mass — Example 4

Estimate of the mean SAR model by polynomial regression

In order to estimate the SAR model (SAR_{av}) as a function the airplane gross mass (m), a polynomial regression of second order is proposed, so that:

$$SAR_{av} = B_0 + B_1 m + B_2 m^2.$$

Each observation (m_i, SAR_i), for i = 1, …, 12 satisfies the equation:

$$SAR_{(i)} = b_0 + b_1 m_i + b_2 m_i^2 + e_i$$

with e_i = residual error (difference between the measured SAR value and its estimate).

2426   Under a matrix form this gives:
2427

2428
$$\begin{pmatrix} SAR_1 \\ SAR_2 \\ SAR_3 \\ \vdots \\ SAR_{12} \end{pmatrix} = \begin{pmatrix} 1 & m_1 & m_1^2 \\ 1 & m_2 & m_2^2 \\ 1 & m_3 & m_3^2 \\ \vdots & \vdots & \vdots \\ 1 & m_{12}\cdots & m_{12}^2 \end{pmatrix} \begin{pmatrix} b_0 \\ b_1 \\ b_2 \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_{12} \end{pmatrix}$$

2429
2430 $\underline{SAR} = \underline{M}\ \underline{b} + \underline{e}$
2431
2432   where:
2433

2434 $SAR = \begin{pmatrix} 0.932 \\ 0.925 \\ 0.913 \\ 0.889 \\ 0.868 \\ 0.848 \\ 0.838 \\ 0.830 \\ 0.806 \\ 0.815 \\ 0.779 \\ 0.788 \end{pmatrix}$ $M = \begin{pmatrix} 1 & 17800 & 17800^2 \\ 1 & 18200 & 18200^2 \\ 1 & 18620 & 18620^2 \\ 1 & 18890 & 18890^2 \\ 1 & 19350 & 19350^2 \\ 1 & 19610 & 19610^2 \\ 1 & 19920 & 19920^2 \\ 1 & 20510 & 20510^2 \\ 1 & 20790 & 20790^2 \\ 1 & 21220 & 21220^2 \\ 1 & 21480 & 21480^2 \\ 1 & 22100 & 22100^2 \end{pmatrix}$ $b = \begin{pmatrix} b_0 \\ b_1 \\ b_2 \end{pmatrix}$ $e = \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_n \end{pmatrix}$.

2435
2436   The least square principle consists in looking for the parameter values of vector B, minimizing the sum of
2437   the squares of residuals, i.e.:
2438
2439 $\text{Min } \sum_{i=1}^{i=12} e_i^2 = \min \sum_{i=1}^{i=12}(SAR_{(i)} - b_0 - b_1\ m_i - b_2\ m_i^2)^2.$
2440
2441   It is equivalent to look for the solutions of $\frac{\partial(\sum e_i^2)}{\partial b_j} = 0$ for j = (0, 1, 2).
2442

2443   The solution B = $\begin{pmatrix} B_0 \\ B_1 \\ B_2 \end{pmatrix}$ is given by:
2444 $A^{-1}\ M'\ SAR$ (see **A4-2**)
2445
2446   where:
2447
2448   M' = transpose of M; and
2449
2450 $A^{-1} = (M'\ M)^{-1}$ = inverse of (M' M).
2451

2452   Finally, B = $\begin{pmatrix} 3.26727172 \\ -0.000205692 \\ 4.21798\ x10^{-09} \end{pmatrix}$; and
2453
2454 $SAR_{av} = 3.26727172 - 0.000205692\ m + 4.21798.10^{-9}\ m^2.$
2455
2456   Figure A4-14 provides a representation of the mean SAR model as a function of the airplane gross mass.
2457
2458
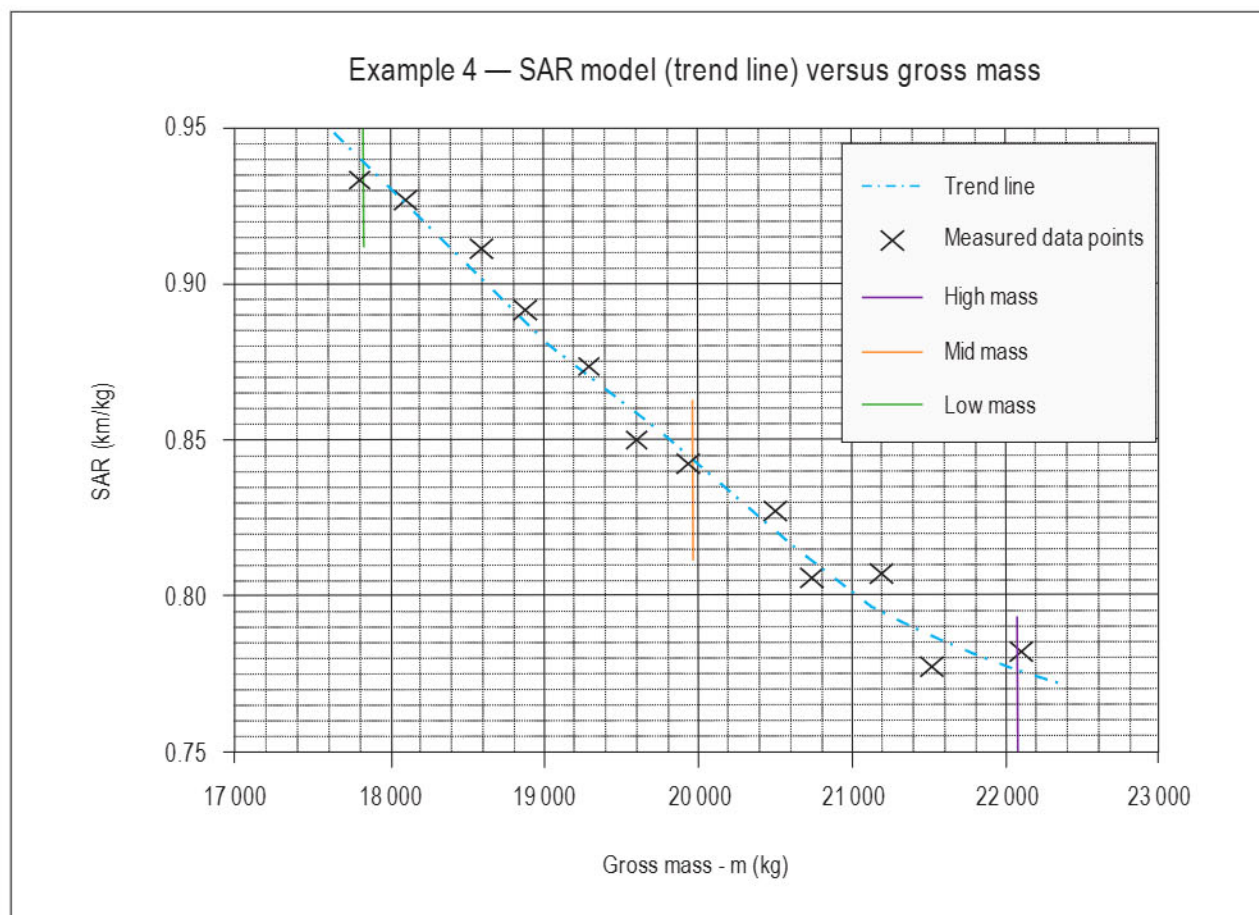
Figure A4-14.   SAR model (trend line) versus gross mass — Example 4

The mean SAR values at each of the three reference gross masses of the FEM are as follows:

Table A4-15.

Mean SAR value — Example 4

Reference mass	Mass value (kg)	Mean SAR value (km/kg)
Low mass	17,825	0.94100
Mid mass	19,953	0.84238
High mass	22,080	0.78198

Estimate of the standard deviation(s):

$$s = \sqrt{\frac{\sum_{i=1}^{i=n}(SAR_i - SAR_{av(i)})^2}{n-K-1}} = 0.01050 \text{ km/kg}$$

2474   where:
2475
2476   the number of data points (n) = 12;
2477
2478   K = 2 for a second order polynomial regression (see **A4-2**); and
2479
2480   the degrees of freedom (n-K-1) = 9.
2481
2482
2483   Confidence interval determination
2484
2485   The 90 percent confidence interval (CI_{90}) at an airplane gross mass m_0 is calculated as follows (see **A4-**
2486   **2**):
2487

$$CI_{90} = SAR_{av}(m_0) \pm t_{(.95,\,n-K-1)}\, s\, \sqrt{\underline{m_0}\, \underline{A^{-1}}\, \underline{m_0'}}$$
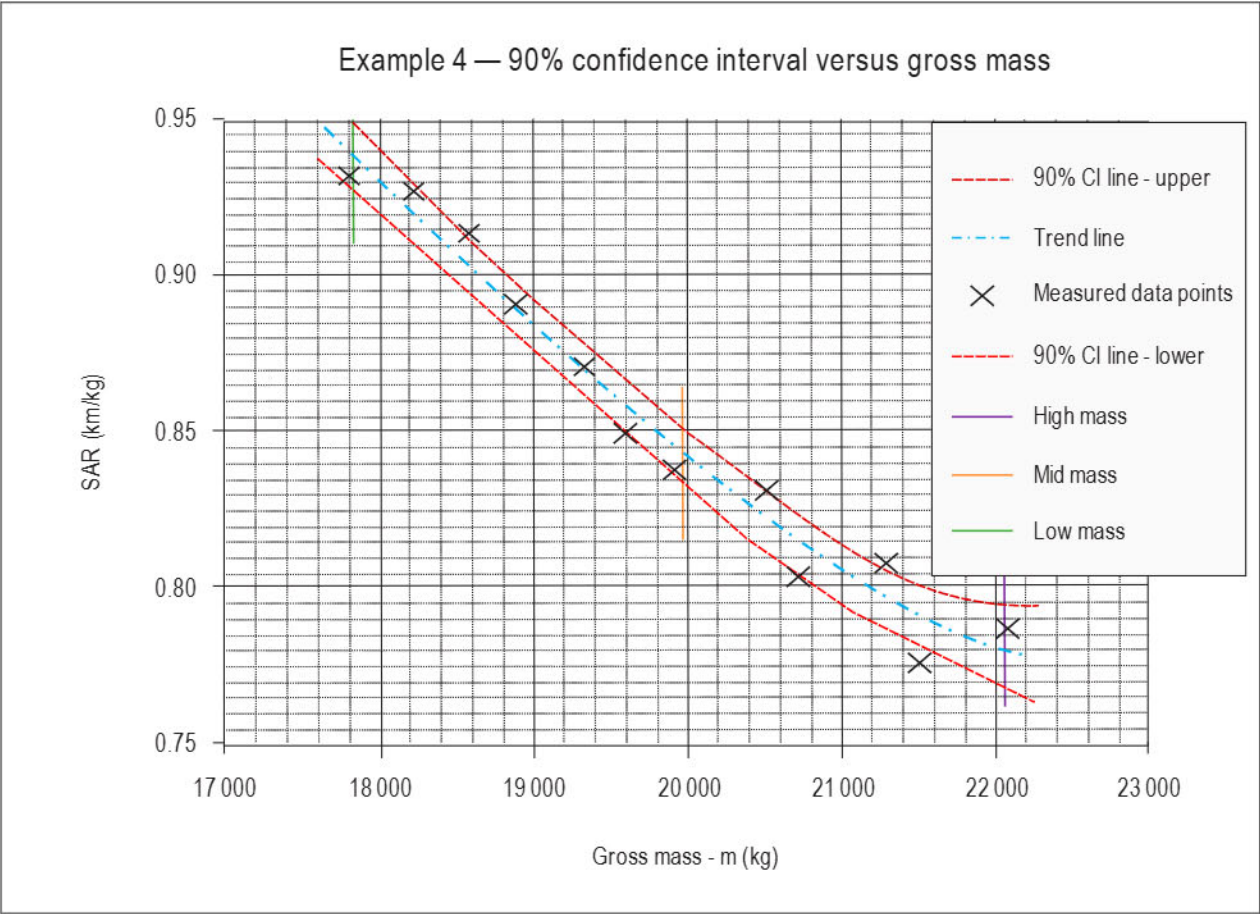
2489
2490   where:
2491
2492   the Student t-distribution for 90 percent confidence and 9 degrees of freedom $t_{(.95,\,9)} = 1.833$ (See Table
2493   A4-1);
2494

2495 $m_0 = (1\ m_0\ m_0^2)$ and $m_0' = \begin{pmatrix} 1 \\ m_0 \\ m_0^2 \end{pmatrix}$; and

2496
2497 $A^{-1} = (M'\, M)^{-1}$ = inverse of (M' M).
2498
2499   Figure A4-16 provides a representation of the 90 percent confidence interval as a function of airplane
2500   gross mass.
2501

Figure A4-16. 90 percent confidence interval versus gross mass — Example 4

The 90 percent confidence intervals at each of the three reference gross masses of the CO_2 emissions evaluation metric are as follows:

Table A4-17.

Confidence intervals — Example 4

Reference mass	Mass value (kg)	90% confidence interval (kg/km)
Low mass	17,825	$CI_{90} = 0.94100 \pm 0.01399$
Mid mass	19,953	$CI_{90} = 0.84238 \pm 0.00823$
High mass	22,080	$CI_{90} = 0.78198 \pm 0.01505$

Check of confidence interval limits

For each of the three reference gross masses of the FEM, the confidence interval extends around the mean SAR value by an amount provided in Table A4-18.

2518
2519 **Table A4-18.**
2520
2521 Check of confidence intervals — Example 4
2522

Reference mass	Mass value (kg)	90% confidence interval (percentage of mean SAR)
Low mass	17,825	(0.01399/0.94100) x 100 = 1.52%
Mid mass	19,953	(0.00823/0.84238) x 100 = 0.98%
High mass	22,080	(0.01505/0.78198) x 100 = 1.93%

2523
2524 The 90 percent confidence intervals at the low and high reference gross masses of the FEM are above
2525 the confidence interval limit of 1.5 percent, as defined in § A38.5.3.4.
2526
2527 In such case, a penalty equal to the amount that the 90 percent confidence interval exceeds ±1.5 percent
2528 is applied to the mean SAR values as follows:
2529
2530
2531 **Table A4-19.**
2532
2533 Corrected SAR values — Example 4
2534

Reference mass	Mass value (kg)	Corrected SAR value (km/kg)
Low mass	17,825	0.94100 x [1 - (1.52-1.5)/100] = 0.94081
High mass	22,080	0.78198 x [1 - (1.93-1.5)/100] = 0.77862

2535
2536
2537 As a result, the following mean SAR values associated to each of the three reference masses of the FEM
2538 can be used for the metric determination.
2539
2540 **Table A4-20.**
2541
2542 Mean SAR values — Example 4
2543

Reference mass	Mass value (kg)	Mean SAR value (km/kg)
Low mass	17,825	0.94081
Mid mass	19,953	0.84238
High mass	22,080	0.77862

2544
2545

Appendix 5: References

2546
2547
2548
2549
2550   1.   International Standards and Recommended Practices, Annex 16 to the Convention
2551   on International Civil Aviation, Environmental Protection, Volume III – Aeroplane CO2
2552   Emissions, First Edition, July 2017, Applicable 1 January 2018, Including Amendment
2553   1 of January 1, 2021
2554
2555   2.   International Standards and Recommended Practices, Annex 16 to the Convention
2556   on International Civil Aviation, Environmental Protection, Doc 9501 Environmental
2557   Technical Volume III, Procedures for the CO2 Emissions Certification of Aeroplanes,
2558   First Edition, 2018
2559
2560   3.   ASTM International D1655-15 entitled "*Standard Specification for Aviation Turbine
2561   Fuels*". This ASTM International publication may be obtained from the ASTM
2562   International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA,
2563   19428-2959 USA, www.astm.org.
2564
2565   4.   UK MOD DEF-STAN 91-91, Issue 7, Amendment 3, entitled "*Turbine Fuel, Kerosene
2566   Type, Jet A-1*". This United Kingdom Ministry of Defence Standard may be obtained
2567   from Defence Equipment and Support, UK Defence Standardization, Kentigern
2568   House, 65 Brown Street, Glasgow G2 8EX, UK.
2569
2570   5.   ASTM International D4809-13 entitled "*Standard Test Method for Heat of Combustion
2571   of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)*". This ASTM
2572   International publication may be obtained from the ASTM International, 100 Barr
2573   Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA,
2574   www.astm.org.
2575
2576   6.   ASTM International D4052-11 entitled "*Standard Test Method for Density and
2577   Relative Density and API Gravity of Liquids by Digital Density Meter*". This ASTM
2578   International publication may be obtained from the ASTM International, 100 Barr
2579   Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA,
2580   www.astm.org.
2581
2582   7.   ASTM International D445-15 entitled "*Standard Test Method for Kinematic Viscosity
2583   of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)*". This
2584   ASTM International publication may be obtained from the ASTM International, 100
2585   Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA,
2586   www.astm.org.
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