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Guidelines for *In Situ* Eddy Dissipation Rate (EDR) Algorithm Performance

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FOREWORD

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- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of Minimum Operational Performance Standards for electronic systems and equipment that support aviation; and
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PREFACE

In 1963, in a document titled, *Standardization of Gustiness Values from Aircraft*, Paul B. MacCready, Jr. opened his work with "Turbulence refers to motions at various intensities and scales in three dimensions and so a complete statistical description of it would be expected to be complex" [MacCready, 1964]. It is with this timeless complexity in mind that we address the development of performance requirements for *in situ* Eddy Dissipation Rate (EDR) algorithms. The concept of EDR, measured as $\varepsilon_{\omega}^{1/3} m^{2/3}\, s^{-1}$, is a specific measure of the energy state of the atmosphere. This measure has been correlated to subjective interpretations of turbulence that have been referenced by pilots in the long-standing Pilot Report system. The generational leap taken by EDR, however, is in its ability to be computed and reported by thousands of aircraft already operating in the United States today. The operationally comparable output of this data, despite the complexities in its creation, can be used by a myriad of end users.

Turbulence encounters have always been of particular concern to all operators. Forecast areas of turbulence were broad and only sparsely populated with a handful of reports. In the late 1990s, advances in end-user display technology, as well as advances in devices on-board the aircraft used to interface with aircraft sensors allowed for initial implementations of software-based *in situ* EDR computation. Results from these initial studies led to improved forecast resolution of hazardous turbulence areas and more optimal avoidance routing. EDR algorithm calculations, in part due to their complex nature, remained experimental up until only recently, but operational testing has demonstrated the product as a valuable tool for enhancing safety.

With a growing body of research to demonstrate the value of *in situ* EDR reports, and as implementers enter the marketplace, the need to set objective performance requirements for these outputs is critically important. End users must be able to receive operationally comparable *in situ* EDR reports from any authorized source.

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1 PURPOSE AND SCOPE

1.1 Introduction

This document defines the minimum user performance requirements applicable to *in situ* Eddy Dissipation Rate (EDR) turbulence computational algorithms (hereafter referred to as "the EDR algorithm"). *In situ*, as used herein, refers to calculations that use aircraft-derived observations, obtained through direct contact with the atmosphere or aircraft, as input (as opposed to remote sensing observations, such as RAdio Detection And Ranging (RADAR) or LIght Detection And Ranging (LIDAR)).

Initially, this Special Committee (SC) set forth to develop a Minimum Operational Performance Standards (MOPS) document to formalize these algorithm performance requirements. However, as the research into defining these performance requirements progressed, it became apparent to the RTCA SC-206 that the issue was much more complex than anticipated. There are several different methods of EDR calculation in the marketplace at this time, and none is preferential over the others; that is, there is no "Gold Standard" method of calculating EDR. Each method has benefits and drawbacks unique to that developer's algorithm. In addition, there are various methods of physically implementing the calculations both on-board aircraft systems or in ground processing systems, each unique to the individual algorithms. This presented the RTCA SC-206 with challenges in utilizing the RTCA MOPS Drafting Guidelines, which are designed primarily for use in defining hardware performance requirements, which can be well established within airframe construct. This is not possible for EDR calculations. In the end, the RTCA SC-206 made the decision to develop a guidelines document instead of a MOPS. The scope of the document is extremely narrow – because of the differences in calculation methods, only the performance of the algorithms in a strictly defined testing environment is considered within scope. This requires developers to adhere to strictly defined testing procedures. Hence, while this is a "Guidelines" document, there are contained within "requirements" for developers to follow when testing their algorithms against the performance requirements provided in this document. These "requirements" set the necessary statistical boundaries for test outputs to ensure operational algorithms will generate operationally comparable reports to be used by a variety of end users.

The requirements of this document apply to developers of EDR algorithms. These requirements specify algorithm output characteristics that should be beneficial to manufacturers, implementers, and other users of the EDR reports, such as flight crews, dispatchers, wake vortex models, meteorological forecasters, and forecast models. Collectively, these output characteristics define a set of requirements that apply to a universal set of EDR algorithms.

Compliance with these requirements is the means of assuring that the EDR algorithm output for a given aircraft will be comparable with that of other aircraft, within a range of accepted uncertainty, for the same turbulence conditions encountered in routine

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aeronautical operation. Any regulatory application of this document is the sole responsibility of appropriate governmental agencies.

Section 1 of this document provides information needed to understand the rationale for the EDR algorithm output characteristics and requirements stated in the remaining sections. It describes typical EDR algorithm functionality, as envisioned by the members of RTCA SC-206, *Aeronautical Information Services and Meteorological Data Link Services*, and establishes the basis for the requirements and recommendations stated in Sections 2, 3, and 4. Definitions and assumptions essential to proper understanding of this document are also provided in this section.

Section 2 contains the EDR algorithm performance requirements for performance in a standardized test environment. Also included are the required bench-test procedures necessary to demonstrate EDR algorithm compliance with the performance requirements. These requirements apply to the developers of EDR algorithms, not to operators or manufacturers that implement the algorithm, nor to users of the algorithm output.

Section 3 describes considerations for EDR algorithm implementations for use by aircraft manufacturers and algorithm developers.

Section 4 describes considerations for EDR algorithm implementations for use by operators and algorithm developers.

Section 5 contains recommendations for entities that invoke the recommendations in this document.

Section 6 contains a listing of RTCA SC-206 membership.

Appendix A contains a listing of all acronyms contained within the document and explanations for each. [informative]

Appendix B contains the *FAA EDR Standards Project Report, Version 1.0, August 31, 2014*. [normative]

Appendix C contains the *FAA EDR Algorithm Standards Validation Plan, Version 1.1, July 31, 2017*. [normative]

Appendix D contains the *FAA EDR Algorithm Standards Analysis Project Report, Version 1.1, June 30, 2017*. [normative]

Appendix E contains the *EDR Algorithm Input Dataset Descriptions*. [normative]

Appendix F lists all documents referenced or applicable to this document. [informative]

Appendix G contains the FAA Documents in EDR Guidelines 6-15-2017. [normative]

This guidelines document applies to a specific defined function (the calculation of EDR). The EDR algorithm may have additional features related to that function for which there are no specified minimum performance requirements. For example, the algorithm may

include a means to output the data, but that means is independent of the actual EDR calculation.

1.2 EDR Algorithm Overview

The turbulence metric EDR is not directly measured, but rather calculated (i.e., estimated) using a variety of computational algorithms and on-board sensor data from aircraft avionics. The term EDR in this guidelines document refers to $\varepsilon^{1/3}$ with units of meters$^{2/3}$/second ($m^{2/3}s^{-1}$) [Sharman, et al., 2014], where ε is referred to as Energy Dissipation Rate or EDR. Take careful note that even though the acronym, EDR, is derived from the terms, Energy Dissipation Rate or Eddy Dissipation Rate (denoted symbolically as ε), the term EDR, in this document, refers to $\varepsilon^{1/3}$ (i.e., the cube root of Eddy/Energy Dissipation Rate). This is consistent with the common usage of this term in the commercial aviation industry.

As depicted in Figure 1-1 below, an EDR algorithm refers only to the algorithm (series of calculations/steps) and parameter settings (including, but not limited to, data sampling frequency, window lengths, filter settings, window functions, turbulence models, etc.) used to calculate EDR.

The EDR algorithm, as defined in this context, does not include the physical systems with which it interacts operationally on-board the aircraft or ground-based processing systems. Calculations may be done on-board the aircraft prior to downlink, or on ground-based processing systems, or a combination of both; this is left to the discretion of the individual developer. The EDR algorithm does not include the input data used by the EDR algorithm, nor does it include the method whereby the calculated EDR data, or data used for the EDR calculation if the calculation is performed on the ground, is transmitted to the ground processor, as this is dependent upon the aircraft, operators, and communications provider. In addition, definition of different downlink rates, data formats, and "bundling" of reports to conserve communications costs are not within the defined processor system, as each operator will have unique requirements.

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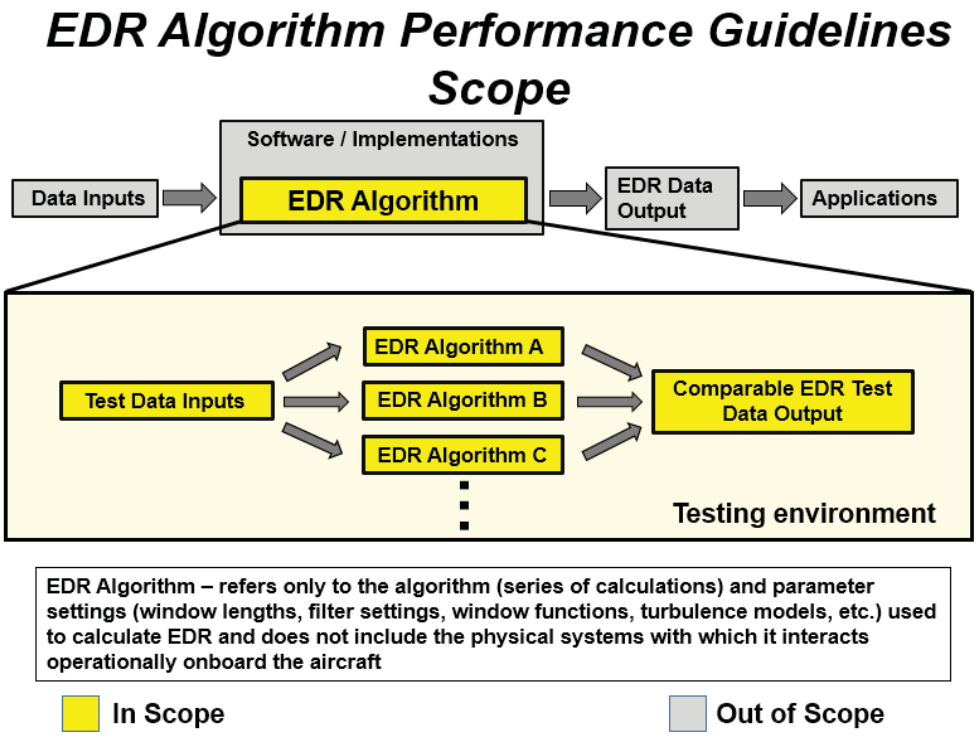


Figure 1-1: EDR Algorithm Performance Guidelines Scope

1.2.1 Supporting Documents

The industry recommendations that prompted this research project were provided by the Aviation Rulemaking Committee (ARC) and RTCA for Automatic Dependent Surveillance – Broadcast (ADS-B) In.

1. ADS-B In ARC

ADS-B In is defined as the reception by aircraft of Flight Information Service – Broadcast and Traffic Information Service – Broadcast data, as well as other data such as that from direct communication from nearby aircraft. The Federal Aviation Administration (FAA) chartered the ADS-B In ARC on June 30, 2010 to provide a forum for the United States' aviation community to define a strategy for incorporating ADS-B In technologies into the National Airspace System. The ARC was tasked to provide recommendations that clearly define how the community should proceed with ADS-B In, while ensuring compatibility with ADS-B Out avionics standards. In their September 30, 2011 report to the FAA, the ARC recommended (FAA Reference #34) to "establish performance standards for EDR computational approaches."

2. RTCA

RTCA SC-186, *Automatic Dependent Surveillance – Broadcast (ADS-B)* was established in February 1995 to develop operational requirements and minimum performance standards for airborne and ground-user applications of ADS-B. The documentation developed by the committee details safety, performance, and interoperability requirements

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