11.3 *In Situ* Performance Standard for Eddy Dissipation Rate

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1. INTRODUCTION

The Federal Aviation Administration (FAA) has assembled a team of subject matter experts from relevant domains to develop *in situ* Eddy Dissipation Rate (EDR) performance standards. The term, *in situ* EDR, refers to the calculation of turbulence values by aircraft in-flight. The turbulence metric EDR, is an aircraft-independent, universal measure of turbulence based on the rate at which energy dissipates in the atmosphere.

The team is collaborating with both domestic and international stakeholders to bring together a diverse and comprehensive community of interest to participate in this research project. The specific work elements of the FAA EDR Standards project (herein referred to as "the project") include: establishing the process by which the EDR performance standard will be defined, identifying the associated performance artifacts (i.e. algorithm input data, "EDR Truth" values, EDR tolerance thresholds), and specifying EDR value and data label definitions. The end product of the project will be a report that will include the research and analysis required for the FAA to define performance standards for *in situ* EDR.

To initiate this project, a comprehensive literature search has been conducted to draw EDR information from scores of articles, briefings, and reports. This paper provides a high-level summary of the EDR literature search findings including: background material, *in situ* EDR calculation methods and operational implementations, algorithm aircraft sensor and input requirements, EDR data applications, and *in situ* EDR reporting methods.

This paper also provides an overview of the project's approach to develop *in Situ* EDR standard recommendations, including a description of the standardization process that will be used to develop EDR performance artifacts. Additionally, it describes the potential methods being researched to calculate "EDR Truth", which for this project is defined as the best representation of calculating EDR in nature, independent of the operational environment. The project will use "EDR Truth" as a baseline from which to compare existing or potential *in situ* EDR algorithms and subsequently to develop performance standards.

2. BACKGROUND

Since the turbulence metric EDR is an aircraft-independent calculation, a single engine Cessna 152 and a Boeing 747 should determine the same EDR value when flying through the same atmosphere at the same time. It is important to note, EDR is not directly measured, but calculated using a variety of data from aircraft avionics and computational algorithms employing alternative techniques with dissimilar inputs and assumptions to calculate EDR. A standard against which to measure EDR reports is therefore necessary so that the differences in algorithmic approaches and operational inputs do not lead to unacceptable deviations in the resulting EDR values.

The study of atmospheric turbulence, leading up to the development of *in situ* EDR algorithms, has a history dating back to the early 1940's. Significant EDR milestones relevant to the project are depicted in Figure 1.

Turbulence research was initiated in 1941 by Andrey Nikolaevich Kolmogorov's theory on turbulent kinetic energy in the inertial subrange[102]. In 1948, Theodore Von Karman went on to develop an empirical formula that describes the energy spectrum for scales in the inertial subrange and larger[103]. In 1962, Paul B. MacCready Jr. utilizing the theory developed by Kolmogorov, illustrated the utility of using EDR as a quantitative metric of turbulence intensity[104 105 106]. In 1995, Larry Cornman and colleagues from the National Center for Atmospheric Research (NCAR), published a paper that describes an *in situ* EDR algorithm based on MacCready's 1964 paper[110]. A key reason that EDR is a suitable metric for turbulence intensity follows from the inertial subrange concept first developed by Kolmogorov in 1941[102]. Kolmogorov showed that for fully-developed turbulence, and for spatial scales well-separated from the large scale energy production range, and small scale viscous dissipation range, the turbulence kinetic energy is only a function of EDR. The inertial subrange in the free atmosphere typically encompasses millimeter to a few kilometer scales, as denoted in Figure 2 as the lower and upper inertial subrange frequency boundaries. In turn, these are the scales which produce most of the acceleration response of aircraft.

In 2001, *in situ* EDR was adopted as the International Civil Aviation Organization (ICAO) standard for automated reporting of turbulence from commercial aircraft. Then in 2011, the Automatic Dependent Surveillance-Broadcast-In (ADS-B-In) Aviation Rulemaking Committee (ARC) provided two EDR recommendations to the FAA. The first recommendation called for the establishment of performance standards for EDR computational approaches. The second recommendation called to initiate necessary activities to, through appropriate standards bodies, standardize EDR data value encoding and label definitions[90]. Today there are multiple operational algorithms that compute *in situ* EDR, but no standard defining the performance requirements of the resulting data. Additionally, no standard encoding and label definitions exist for EDR.

The RTCA Special Committee (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[119]. The documentation being developed by the committee will detail safety, performance and interoperability requirements for specific ADS-B applications[119].

The RTCA SC-206 Aeronautical Information Services (AIS) Data Link was created in February, 2005 and is working under the auspices of RTCA SC-186 to identify AIS and Flight Information Services (FIS) data link services that are envisaged to be implemented with the next decade[120]. The committee is developing Minimum Aviation System Performance Standards (MASPS) and Minimum Operations Performance Standards (MOPS)[120]. In 2012, the committee developed an Operational Services and Environmental Definition (OSED) entitled, "Aircraft Derived Meteorological Data via ADS-B Data Link for Wake Vortex, Air Traffic Management and Weather Applications."[20] The OSED identified the necessity for an international effort to develop performance standards for aircraft EDR values, independent of computation approach, to set Minimum Operational Performance Standards (MOPS)[20]. Also identified in the OSED, is the equally essential need for the standardization of aircraft EDR data bus labels and encoding of EDR parameter values[20]. The recommendations outlined in the OSED have lead the FAA to initiate the project to perform the research required to recommend *in situ* EDR performance standards along with EDR encoding and label definitions.

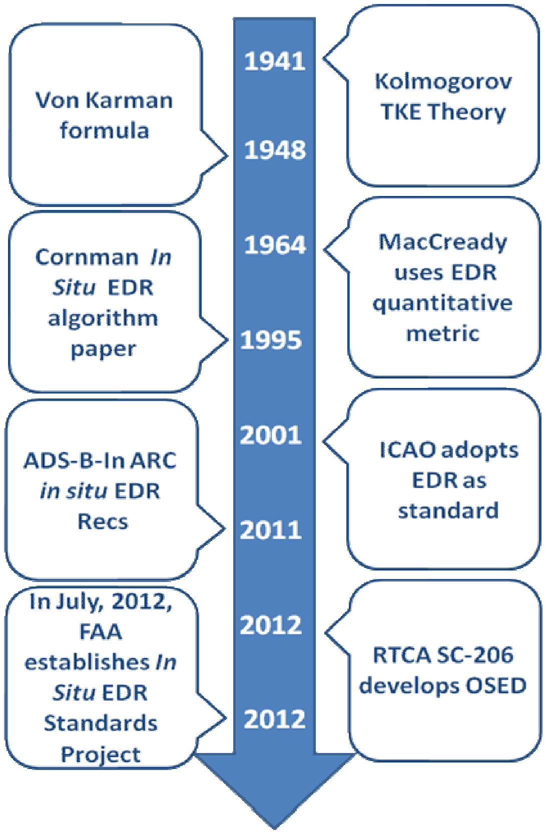


Figure 1: Timeline of Significant EDR Milestones

3. EDR LITERATURE SEARCH FINDINGS

The project conducted an EDR literature search studying scores of articles, presentations, papers, etc. from several relevant domain areas. The high-level details of each piece of literature was then recorded in a spreadsheet that is intended to be shared as a public reference of existing EDR literature (instructions to access spreadsheet are included at end of this paper). The EDR literature was then reviewed, and pertinent information was extracted and incorporated into an EDR Literature Search Findings briefing. The information learned will be included in the project's final report, as well as leveraged throughout the project. This section provides of overview on some of the key information gathered.

3.1 *In situ* EDR Calculation Methods and Implementations

There are currently three operational algorithms for calculating *in situ* EDR, one using aircraft accelerometer data and two using a more direct calculation involving wind data[19]. The accelerometer method provides an indirect calculation, which depends on certain assumptions regarding the behavior of the aircraft under various circumstances[19]. This method is considered indirect because the turbulence level is inferred from the aircraft response to turbulence, rather than a direct measure of the atmosphere. Of the wind methods, one uses vertical wind data, as well as other aircraft parameters. A second wind method has been developed for the Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Program, which utilizes an estimate of the longitudinal wind via the true airspeed[19,68].

The operational EDR algorithms each use a unique set of inputs from various aircraft sensors. The sensor and input requirements for each operational algorithm are provided in Table 1 and Table 2 respectively. Note the TAMDAR algorithm has the ability to receive the longitudinal winds via the TAMDAR sensor and/or aircraft bus data. The TAMDAR input and sensor requirements vary based on what method the longitudinal winds are received.

Table 1: EDR Algorithm Sensor Requirements

Algorithm	Required Sensors					
ATR Algorithm Accelerometer-based	Body-Axis Vertical Accelerometer					
NCAR Algorithm Vertical acceleration-based	Body-Axis Vertical Accelerometer	Static Pressure	Dynamic Pressure	Outside Temperature	Flap Position	
NCAR Algorithm Vertical wind-based	Attitude and Attitude Rate Ratios	Static Pressure	Dynamic Pressure	Outside Temperature	Accelero meter	AoA Vanes
TAMDAR Algorithm Longitudinal wind-based using TAMDAR sensor	TAMDAR dynamic pressure (10.67 Hz)		TAMDAR Static Pressure or bus data	TAMDAR outside air temperature or bus temperature	TAMDAR roll calculated from GPS track, TAS and ext. bus heading	
TAMDAR Algorithm Longitudinal wind-based using aircraft bus data	Bus TAS (based on aircraft static and dynamic pressure, and temperature)		TAMDAR roll calculated from GPS track, TAS and ext. bus heading.			

Table 2: EDR Algorithm Input Requirements

Algorithm	Required Inputs				
ATR Algorithm Accelerometer-based	TAS	Altitude	Vertical Acceleration	Weight	Freq. Response
NCAR Algorithm Vertical acceleration-based	TAS	Altitude	Vertical Acceleration	Weight	Freq. Response
	Mach	Flap Angle	Autopilot Status	Parameters for Quality Control Algorithms	
NCAR Algorithm Vertical wind-based	TAS	Altitude	Inertial Vertical Velocity	Body Axis AoA	Pitch Rate
	Pitch	Roll Angle	Quality Control	Filter Parameters	
TAMDAR Algorithm Longitudinal wind-based using TAMDAR Sensor	TAMDAR TAS		Roll Angle for quality control (TAMDAR calculated)	TAMDAR Icing for quality control	
TAMDAR Algorithm Longitudinal wind-based using aircraft bus data	Bus TAS		Roll Angle for quality control (TAMDAR calculated)		

Summarized in Table 3 are the various EDR algorithms, and the airlines and airframes on which they are implemented. The NCAR vertical acceleration-based algorithm has been implemented on United Airlines Boeing 737 and Boeing 757 aircraft. The NCAR vertical wind-based algorithm has been implemented on Delta Airlines and Southwest Airlines Boeing 737 aircraft as well as Delta Airlines Boeing 767 aircraft[36,68,22].

American Airlines calculates *in situ* EDR using the AeroTech Research (ATR) accelerometer based algorithm. Their *in situ* EDR calculations are included in the Turbulence Auto-PIREP (Pilot Report) System (TAPS) data stream[41]. TAPS was developed in the National Aviation and Space Administration's (NASA) Aviation Safety Program and has been implemented on over 180 commercial aircraft[41].

Multiple regional airlines including; Mesaba, AeroMexico, and Chautauqua calculate *in situ* EDR via the TAMDAR program. The TAMDAR *in situ* EDR algorithm utilizes an estimate of the longitudinal wind via true airspeed to calculate EDR.

Although the literature search did not identify any current international *in situ* EDR operational implementations, AirDat representatives in a recent collaboration meeting have confirmed the implementation of the TAMDAR EDR Algorithm on the first aircraft outside of the United States. The TAMDAR algorithm has been implemented by AirDat on a Flybe Airlines Embraer ERJ-195. Flybe is a regional airline, based out of the United Kingdom, and Flybe has plans to implement the TAMDAR algorithm on additional aircraft.

Table 3: Airline Implemented EDR Algorithms

Airline	Algorithm Implemented	Aircraft
American Airlines	ATR accelerometer-based	B737-800 B767-300ER B767-400ER A318 A319
Delta Airlines	NCAR vertical wind-based	B737NG B767
Southwest Airlines	NCAR vertical wind-based	B737-700 B737NG
United Airlines	NCAR vertical acceleration-based	B737 B757
TAMDAR Regional Airlines	Longitudinal wind-based via true airspeed	SAAB 340 ERJ-145 / 195

3.2 Dissemination

In situ EDR data is disseminated to public users and subscribers through multiple sources, dependent on user privileges. Access to *in situ* EDR data can be obtained through the web-based Experimental Aviation Digital Data Service (ADDS) maintained at NCAR[69] available at http://weather.aero. Although the real-time data available through ADDS is restricted to reporting airlines and government users, the data becomes publically available 48 hours after being reported. ATR TAPS provides subscribers with aircraft automated pilot reports of all significant encounters with turbulence, including *in situ* EDR[48]. The international Aircraft Meteorological Data Relay (AMDAR) Program provides quality controlled *in situ* EDR data displayed on Earth Systems Research Laboratory (ESRL) Global Systems Division (GSD) AMDAR Display[71,69,31]. The display has restricted access to National Oceanic and Atmospheric Administration (NOAA), research institutions, select foreign weather services, and airlines that provide AMDAR data[71]. In addition, TAMDAR has developed a network with regional airlines, which transmit *in situ* EDR data, using a self-contained sensor and computational device mounted on the aircraft. TAMDAR uses the aircraft's ARINC-429 data bus to interface with the aircraft's avionics system, allowing the aircraft true airspeed to be used to calculate *in situ* EDR. Access to the resulting EDR data is restricted to participating regional airlines[3].

3.3 Applications for EDR Data

There are multiple applications that currently incorporate EDR, and others that could be enhanced by incorporating standardized *in situ* EDR data. *In situ* EDR provides benefits to turbulence detection and prediction through increases in the fidelity, accuracy, and verification. It is used as input to a variety of meteorological applications including wake decay, Graphical Turbulence Guidance (GTG) Forecast, NCAR Turbulence Detection Algorithm (NTDA) – operational Next-generation Radar (NEXRAD) turbulence detection, diagnosis of convectively induced turbulence (D-CIT), Significant Meteorological Information (SIGMET), and PIREPs. *In situ* EDR data facilitates greater real time turbulence situational awareness and drives enhancements in safety, capacity, and operational efficiencies[29].

The improved situational awareness provided by EDR, allows pilots the ability to make tactical decisions when flying near or through turbulence such as requesting an altitude change, reroute planning, or anticipating situations that would require activating the fasten seatbelt sign.

Flight dispatchers and meteorologists in Airline Operations Centers (AOCs) use *in situ* EDR reports to verify turbulence forecasts, perform proactive flight planning, and allow for improved tactical traffic operations management.

Currently most airlines maintenance facilities complete severe load inspections on their aircraft based on the pilot's interpretation of turbulence levels encountered. This approach can lead to both performing a severe load inspection when possibly not required and perhaps failing to perform one when an encounter may have warranted such an inspection. *In situ* EDR data provides greater accuracy and reliability in determining when an aircraft has encountered a turbulent event that necessitates preventative/corrective actions to maintain airworthiness.

Aviation forecasters benefit from *in situ* EDR data by timely ingesting the data into forecast models, thus improving forecast accuracy[101]. *In situ* EDR data is being used as input to the NCAR GTG product. Future versions of GTG are expected to incorporate more *in situ* EDR data and provide enhanced turbulence forecasting capability at improved altitude ranges and temporal resolution[2].

In the future, a wake vortex mitigation system will likely incorporate *in situ* EDR data since the level of atmospheric turbulence directly impacts the rate at which a wake vortex decays. *In situ* EDR values will also provide real-time awareness of wake vortex locations that have been encountered by the reporting aircraft, alerting aircraft in the vicinity to take appropriate precautions.

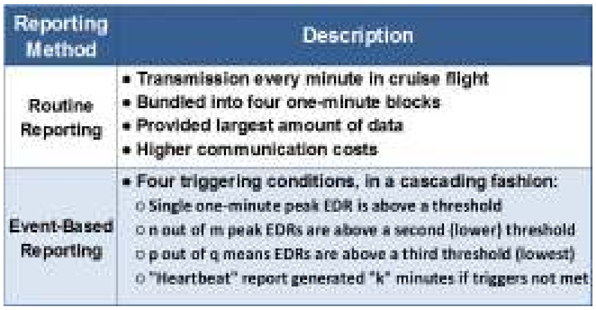
3.4 Reporting Methods

There are two different reporting mechanisms of *in situ* EDR data, summarized in Table 4, routine reporting and event-based reporting. Routine reporting was the initial method implemented, but has been largely replaced with the more cost efficient event-based method[68].

Routine reporting consists of aircraft transmitting *in situ* EDR values every minute while in the cruise phase of flight. The transmissions are typically bundled into four one-minute blocks before being transmitted. Routine reporting transmits EDR values regardless of EDR intensity levels, e.g., "nil". This information is useful in the context of turbulence forecasting, as well as indicating airspace that is free from significant turbulence. While this method provides more comprehensive spatial coverage, it is less cost efficient due to downlink communication costs[68].

The event-based reporting method has been developed as an alternative that supplies valuable *in situ* EDR data, while also being more cost efficient. The event-based reporting method transmits *in situ* EDR data based on four triggering conditions, in a cascading fashion[68]. The first trigger being a single one-minute peak *in situ* EDR value being above a threshold. Second, n out of m *in situ* EDR values are above a second (and lower) threshold. Third, p out of q mean *in situ* EDR values are above a third threshold (lower than the first two). Fourth, a "heartbeat" report that is generated every k minutes – if none of the other three triggering conditions have been met since the last report was sent[68].

Table 4: EDR Dissemination Methods



Reporting Method	Description
Routine Reporting	▪ Transmission every minute in cruise flight ▪ Bundled into four one-minute blocks ▪ Provided largest amount of data ▪ Higher communication costs
Event-Based Reporting	▪ Four triggering conditions, in a cascading fashion: ○ Single one-minute peak EDR is above a threshold ○ n out of m peak EDRs are above a second (lower) threshold ○ p out of q means EDRs are above a third threshold (lowest) ○ "Heartbeat" report generated "k" minutes if triggers not met

3.5. Inertial Subrange

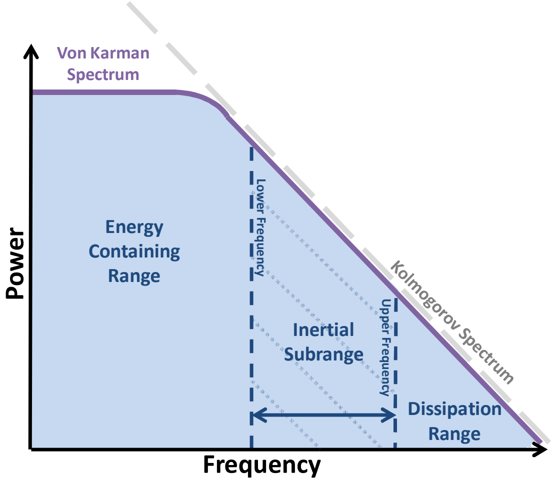


Figure 2: Inertial Subrange

In situ EDR estimation algorithms, although using different processing techniques, all rely on the spectral representations of turbulence. In this approach[110] two forms of spectra are equated as shown in Figure 2: the Von Karman spectrum (purple solid line) and the Kolmogorov spectrum (grey dotted line).

The frequency range in which these spectral forms coincide is termed the “Inertial Subrange”. There are no set values for the upper and lower frequencies of the inertial subrange (shown at the blue vertical dotted lines in Figure 2), and the frequency range may vary in different atmospheric conditions and at different altitudes. Often a turbulence length scale of 500 meters is assumed in establishing these frequency limits.

Based on these assumptions, the EDR algorithms must filter vertical winds, vertical accelerations, or longitudinal winds (depending on the algorithm applied) to include data only in frequencies in the inertial subrange between the upper and lower frequencies.

4. FAA *IN SITU* EDR STANDARDS PROJECT

The FAA, based on industry recommendations, has embarked on a research project that will lead to *in situ* EDR performance standards. With these standards, techniques that calculate and report *in situ* EDR can be certified for implementation and adoption for various functions. The project intends to establish performance standards independent of *in situ* EDR computational approaches.

The scope of the project is strictly focused on recommending performance standards and label and encoding values for *in situ* EDR. The project will maintain an awareness of alternative *in situ* turbulence measurements (e.g. Derived Equivalent Vertical Gusts) and calculations as well as ground-based EDR calculation methods. However, recommending performance standards for these types of calculations falls outside the projects scope. There is also research being conducted to investigate the feasibility of calculating EDR from Global Positioning Satellites (GPS). This research, while valuable, also falls outside the scope of the project.

The project will analyze various operational implementations of *in situ* EDR algorithms to develop recommendations for performance standards. The project will not score algorithms nor will it suggest changes to algorithms, avionics, quality control, etc. The research and recommendations included in the project’s final report will be utilized by industry groups and the FAA to ultimately define EDR performance standards.

The diverse stakeholder team assembled by the FAA represented in Figure 3 includes algorithm developers, avionics manufacturers, airlines, and data users. This team will provide valuable input into the development of the recommended *in situ* EDR performance standards and value and label definitions that will be included in the project’s final report. The report will then be leveraged by certification entities to develop official *in situ* EDR performance standards. Note the project anticipates the development of multiple performance standards for different applications (e.g. wake vortex decay programs will likely have a different performance standard for EDR than turbulence forecast verification).

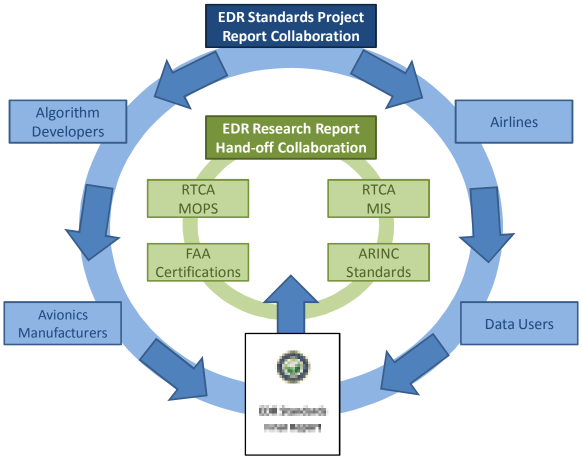


Figure 3: Project Collaborative Team

The project consists of work elements that will provide the necessary information for certification entities (e.g. RTCA, FAA Certification Office) to develop official *in situ* EDR performance standards. The principal work elements of the project, shown in Figure 4, include collaboration, standardization process development, performance artifact development, and EDR value and label definitions. The standardization process provides the approach by which recommendations for *in situ* EDR performance standards will be realized. This process will enable the development of EDR performance artifacts including, a sanctioned volume of algorithm input data sets such as horizontal and/or vertical wind fields, objective EDR values or “EDR Truth”(i.e., resulting EDR value the algorithms are expected to return), and error tolerances thresholds (i.e., allowable deviation from objective EDR values). In a separate, but parallel effort, data value encoding and data bus labeling definitions for EDR will be proposed.

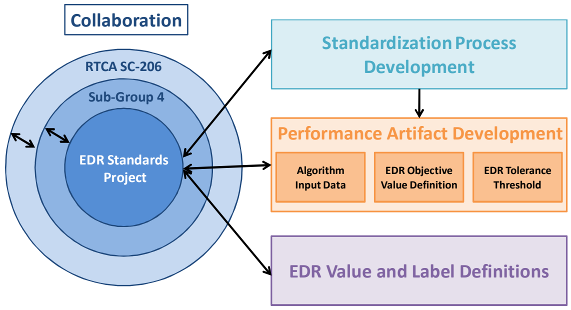


Figure 4: Project work elements including collaboration, process development, performance aritifact development, and value and label encoding definitions

The project’s final report is scheduled to be published in June, 2014. Sensitive information related to individual algorithm performance will be obscured from the project’s final report and project team members.

5. Standardization Process

The project has developed a preliminary high-level standardization process (Figure 5). An initial trial of this process will be used to more completely define and validate the process. The initial trial will also help to identify algorithm input data, *in situ* algorithm EDR outputs, "EDR truth", and methods to statistically evaluate the standardization process results. After finalizing the standardization process, pseudo-operational implementations of *in situ* EDR will be simulated and processed to support the development of the project's recommendations. The standardization process, as represented in Figure 5, consists of the following 15 steps to develop an *in situ* EDR performance standard:

Step 1: Define algorithm input data that will include developing a wind field simulation that incorporates parameters to reflect multiple types of turbulence (e.g. convection, mountain wave) to develop an input wind dataset with known EDR values.

Step 2: The input wind dataset will then be run through aircraft simulators to translate to simulated aircraft response. This step is required since operational aircraft calculate, rather than measure vertical wind. The calculation requires a variety of aircraft state variables, such as pitch, angle of attack, etc. Also, the vertical accelerometer-based algorithms require an aircraft response parameter. The Step 1 input wind data is run through a simulator to produce the input data needed by the operational algorithms.

Step 3-5: The properties of real world aircraft sensors, databus and avionics will then be incorporated to improve the realism of the algorithm input data.

Step 6: The input dataset will then be run through an *in situ* EDR algorithm to perform a simulated operational algorithm run and calculate EDR values.

Step 7: The EDR algorithm output will then be simulated for downlink data communication characteristics of an aircraft.

Step 8: The down linked EDR will then go through any appropriate ground processing. One of the existing in situ EDR implementations performs some of its calculations on the ground.

Step 9-10: The results of the simulated operational *in situ* EDR resultant values will then be compared with "EDR Truth" values derived directly from the input winds.

Step 11: A statistical analysis will be performed on the difference between *in situ* EDR resultant values and "EDR Truth" to determine current *in situ* EDR system performance.

Step 12-13: Collaboration with the user community will be ongoing throughout the project to determine the user's EDR performance needs and establish the appropriate EDR application error thresholds.

Step 14: The development of EDR data label and encoding definitions will be done in parallel with the preceding steps.

Step 15: The EDR Standards Project will then provide recommended EDR performance standards for certification entities to leverage.

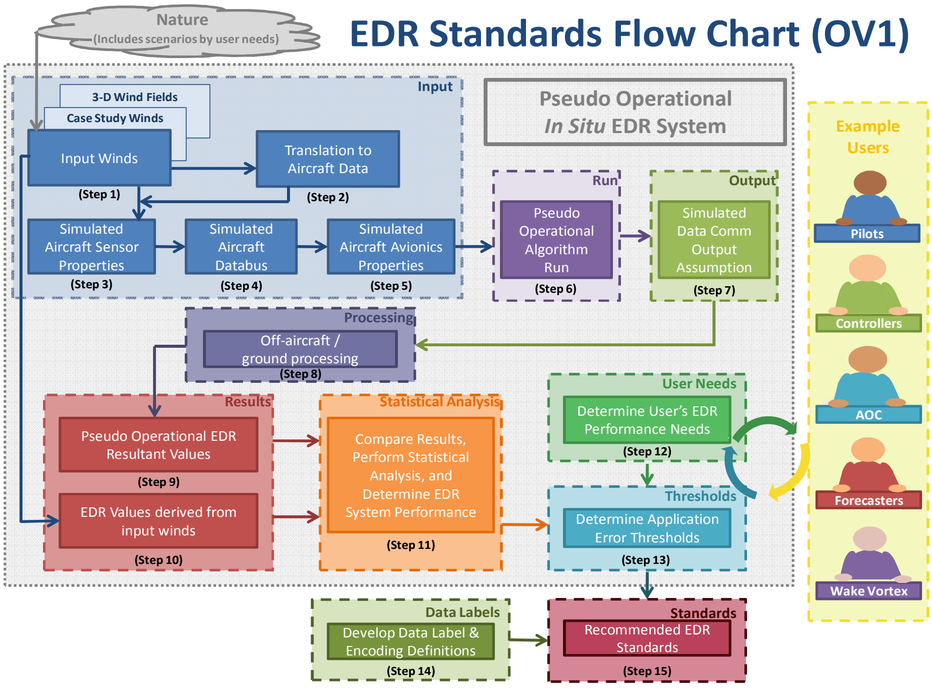


Figure 5: Preliminary Standardization Process

6. Approaches to "Truth EDR" Calculation

A method for calculating "EDR Truth" is required to support the statistical analyses to be used in developing EDR performance standards. Truth EDR in the context of this project means: the best practical calculation of EDR, which is as independent from operational algorithms as feasible. For this project, truth EDRs are used as a baseline from which to compare existing or potential *in situ* EDR algorithms and subsequently to develop performance standards for said algorithms. Given these considerations, there are several approaches to defining "truth" under consideration for the project.

The definition of the EDR comes directly from the Navier-Stokes (N-S) turbulent kinetic energy (TKE) equation. This definition is fundamental in that it requires no assumptions as to homogeneity or isotropy (although typically it assumes incompressibility), nor any physical model; it merely describes the rate of mechanical energy dissipated due to viscous forces. In its general form, the defining EDR equation is not suitable for the analysis of flight data. This is because it requires derivatives of the velocity field for all components (u,v,w) in all directions (x,y,z). Going from the inhomogeneous case to the homogeneous case does not change these considerations. It is not until we make the assumption of isotropy that one can deal solely with a single component in a single direction, either the derivatives of the transverse velocity in the longitudinal direction or those for the longitudinal velocity in the longitudinal direction. If we use a 3-d, 3-component velocity simulation, then in theory one could calculate EDR from the basic definition. Unfortunately, the simulation produces a gridded field, and so the derivatives must be approximated by finite differences, which in turn act like filters on the underlying turbulent field. This is a standard problem in large eddy simulations (LES), and so one approach is to use an eddy viscosity-type method.

Apart from the Navier-Stokes method, a useful technique for EDR estimation is maximum likelihood (ML). For this method, one develops a model function, calculates the so-called likelihood function, L, (which is predicated on the probability distribution of the field, the model function, and the data), and then finds the model parameters that minimize the likelihood function. For example, if the model function is chosen to be the power spectrum of the turbulent velocity field, the probability distribution will be exponential, and then one solves the simultaneous sets of equations,

$$\frac{\partial L(\alpha_1,...,\alpha_n)}{\partial \alpha_j} = 0,\ j = 1,...,n$$

to estimate the parameters $\alpha_j, j = 1,...,n$, where one of the parameters is the EDR. For the truth EDR estimation with simulated data, the model function and the parameter values input to the simulation would be known, so one could develop an ML-based algorithm that took advantage of these aspects.

The most severe real world turbulence encounters are of the inhomogeneous type, e.g., flight over building convection or through breaking mountain waves. That is, the turbulent energy is confined to a very small spatial region, with minimal turbulence levels surrounding the turbulent "burst." Therefore, to develop EDR performance standards that make sense for these severe encounter scenarios, we must be able to determine EDR truth-values from inhomogeneous turbulence. One potential method to handle inhomogeneous data is use the so-called "arc-sine law." This method is based on the assumption that the random data can be described via a so-called product model or *uniformly modulated* inhomogeneous field, $w(x) = \alpha(x)\mu(x)$. Where *w* is the measured inhomogeneous data, $\alpha(x) > 0$ is a deterministic modulation function, and μ is a realization of a unit variance homogeneous random field. Under certain conditions, the correlation function of w can be written as $R_w(x,\rho) = \alpha^2(x)R_\mu(\rho)$. The arc-sine law then allows for $R_\mu(\rho)$ to be calculated from $R_w(x,\rho)$, which in turn allows for an estimation of $\alpha(x)$; and hence EDR, given a turbulence model for $R_\mu(\rho)$. Other, more sophisticated approaches may be required if the data cannot be expressed via the simple uniformly modulated model. These methods include non-uniformly modulated models (e.g., the sum of uniformly modulated ones) or wavelet methods.

Clearly, there is some applied R&D required to determine the most appropriate method for calculating EDR truth-values from real or simulated turbulence data. We have outlined a few basic approaches and indicated the areas for which further development is required.

7. Conclusion

The EDR Standards Project has been initiated by the FAA to perform the research required to develop performance standard recommendations for *in situ* EDR. Equally essential will be the project's recommendations for *in situ* EDR data encoding and label definitions.

The project is leveraging information learned through the EDR literature search and collaboration outreach with key stakeholders. The knowledge gained will assist the team in development of a standardization process, which provides the artifacts required to support recommendations for *in situ* EDR performance standards.

The standardization of *in situ* EDR will support the greater aviation community through the increase in fidelity and accuracy of *in situ* turbulence information. EDR performance standards will facilitate greater real time turbulence situational awareness and drive enhancements in safety, capacity, and operational efficiencies.

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Note the FAA EDR Standards Project has developed a publically available spreadsheet that includes reference data for all of the literature located during the project’s EDR literature search. The reference data included in the spreadsheet is intended to allow an individual to perform a basic internet search and locate the literature desired. The spreadsheet can be obtained by contacting Sal Catapano at salvatore.catapano@exelisinc.com