

Abstract

Where Can We Justify Safe Autonomous Operation? Formalizing and Validating ODD Boundaries in Aviation

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An autonomous system cannot be considered safe independently of the conditions in which it operates. Instead, its safety and performance claims are conditional on an explicitly defined operational context. The Operational Domain (OD) describes the operating conditions relevant to the system, while the Operational Design Domain (ODD) refines these conditions for the autonomous or AI-based constituent. The ODD therefore establishes the boundary within which the constituent is designed to provide its intended behavior and performance. Recent EASA guidance recognizes the ODD as an important link between system requirements and AI constituent behavior, as well as guidelines for managing data, scenarios, knowledge, and operational monitoring [1].

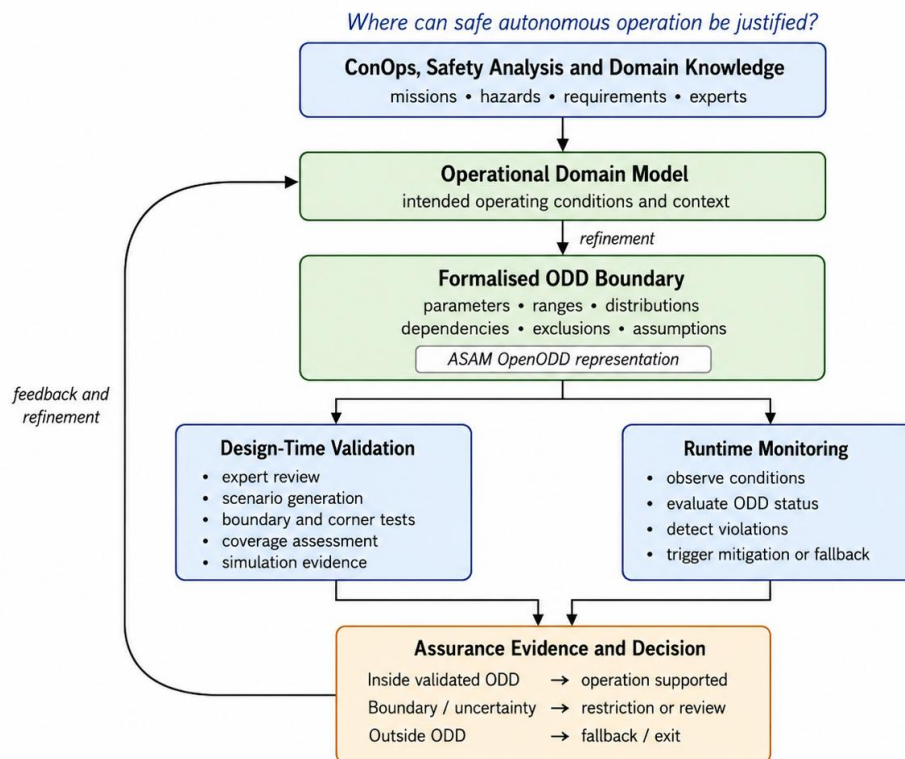


Figure 1: From operating assumptions to validated ODD boundaries.

However, defining an ODD does not by itself demonstrate that autonomous operation is safe. The boundary may omit relevant operating conditions, contain inappropriate parameter ranges, neglect dependencies between parameters, or include conditions for

which sufficient performance evidence is unavailable. The central assurance questions are therefore: How can the boundary of intended operation be formalized? How can its correctness and adequacy be evaluated? What evidence is required to justify operation within that boundary and manage operation outside it?

This work introduces a model-based framework addressing these questions through three connected activities: ODD formalization, design-time validation, and runtime monitoring. Domain knowledge, operational scenarios, and system requirements are first represented in a structured domain model. From this model, an ODD is derived in terms of operating parameters, ranges, distributions, dependencies, constraints, and exclusions. A machine-readable representation based on ASAM OpenODD® supports consistent exchange with scenario-generation, simulation, and monitoring components [4]. Although developed for automated road vehicles, ISO 34503 provides a complementary reference for the structured specification of ODD attributes and boundaries [5].

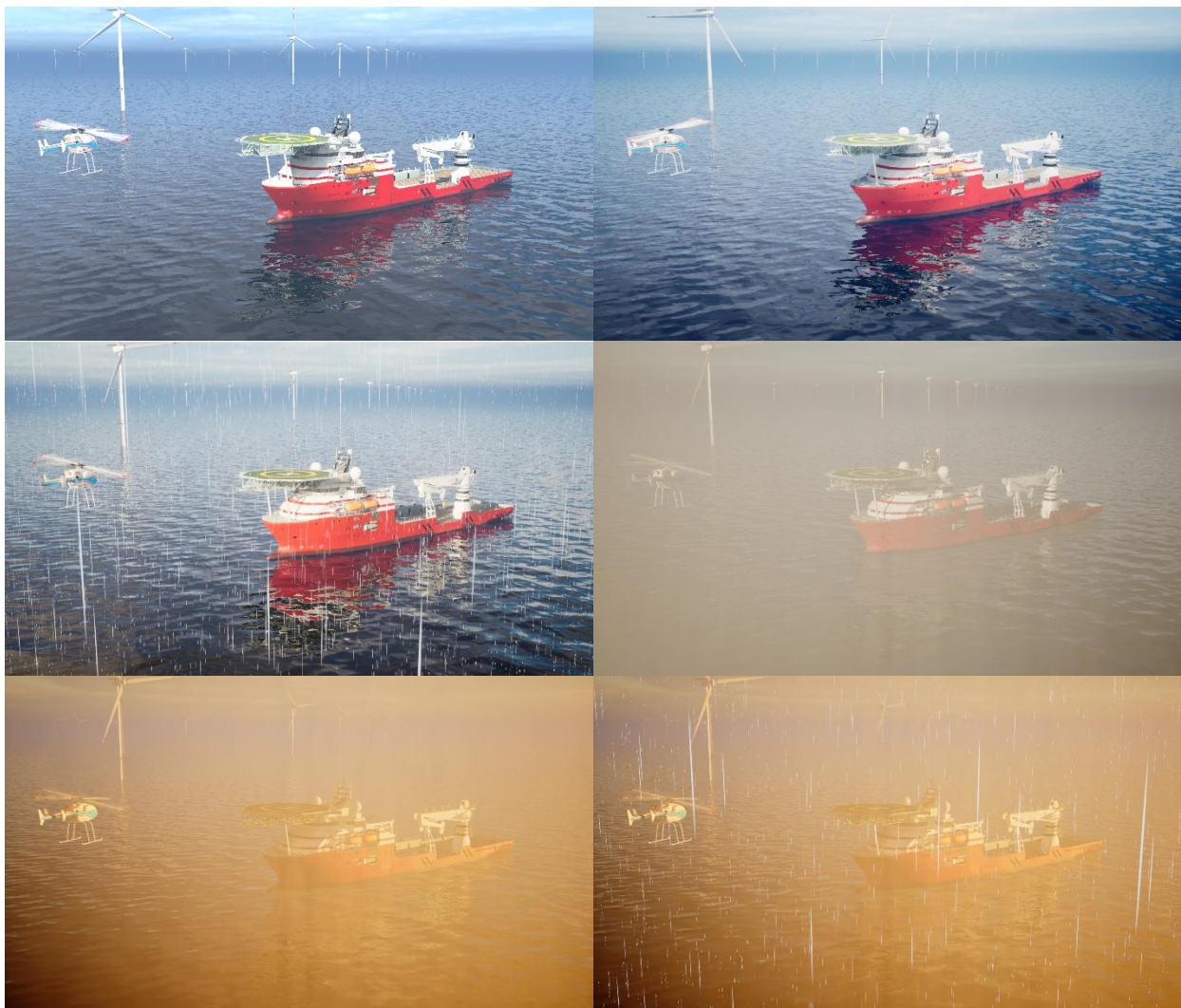


Figure 2: SenSim2 simulations of selected ODD conditions, including rain, snow, fog and daylight.

ODD validation is considered from two complementary perspectives. First, conceptual validation examines whether the selected parameters, boundaries, and dependencies are

correct, sufficiently complete, and consistent with the intended operation and system requirements. Second, evidence-based validation uses systematically generated nominal, boundary, edge, corner, and out-of-ODD scenarios to evaluate coverage and system performance. As illustrated in Figure 2, the SenSim2 simulation environment is used to vary operational conditions such as weather, visibility, and daylight and to examine system behavior close to the proposed boundaries. Previous work on scenario-based data generation and executable ODD monitoring provides the foundation for this integrated framework [2,3].

The resulting approach treats the ODD not as a static declaration of a "safe region", but as a testable and revisable assurance artifact. Simulation results, coverage gaps, and detected ODD violations provide feedback for refining the domain model, operational assumptions, and ODD boundaries. The presentation discusses how this continuous relationship between formal modeling, validation evidence, and runtime monitoring can contribute to a safe autonomous operation and future certification activities.

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- [4] ASAM e.V. ASAM OpenODD®, Version 1.0.0. April 2025.
- [5] ISO. ISO 34503:2023, Road vehicles - Test scenarios for automated driving systems - Specification for operational design domain. International Organization for Standardization, 2023.

Biography

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Christoph Torens is a researcher at the DLR Institute of Flight Systems, Department Unmanned Aircraft, Safe Autonomy Group. His research focuses on the connection of software standards, software certification, and the safe operation of autonomous unmanned aircraft systems.

Siddhartha Gupta



He is a researcher at the German Aerospace Center (DLR) and at TU Clausthal. He is working on the best practices for safety verification and validation practices to certify AI systems in aviation, focusing on modelling scenarios and operational design domain for such systems. He has demonstrated his modelling approach in many EU and German national projects.