

## Interface Requirements for Drone-Agnostic Ground Infrastructure

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Ground infrastructure for unmanned aerial vehicles (UAVs) in delivery service is being built without a common interface to the UAVs it serves. Design guidance is available for the crewed aircraft vertiport scale [1], and airworthiness standards exist for the UAVs themselves, but do not declare the properties on which a small UAV and the node handling it must agree. Automated drone logistics requires ground handling without personnel. A UAV must be received, positioned, secured, charged, protected and released with no human present for safety and efficiency reasons. Deriving the ground functions following from this is straightforward. Deciding how to realize them is harder, and the difficulty does not come from a shortage of technical options. Several implementable solutions exist for nearly every sub-function of a small automated ground node. What separates them is how much each of them presupposes: any solution can be designed only once a particular set of UAV properties is known and fixed, and those sets differ widely. A node able to handle whichever UAV arrives, that is, a drone-agnostic node, is an obviously desirable property. Given how many different UAVs are in service, and how widely their relevant properties differ, it is also a utopian one. Every node is agnostic only within some envelope, and flexible interoperability between node and UAV is achievable only with a degree of standardization.

The purpose of this contribution follows from that gap: to determine which interface properties must be declared in common for such an envelope to be defined at all, and how far existing specifications already go toward declaring them. To that end the drone-depot interface is examined systematically rather than case by case, by enumerating the full solution space for each ground function in a morphological analysis instead of committing to one design; that is what makes visible what each candidate silently presupposes about the UAV. The starting point of the analysis is the design of a micro-depot for an urban regulatory sandbox within the project “U-Space-Berlin” [2] serving two operationally contrasting logistics use cases. Resulting from the initial specific project task and a systematic empirical overview of existing interface solutions, the generic research gap addressed in this contribution was identified. Requirements are elicited from both operators and consolidated into a traceable database. The ground system is then decomposed into main and sub-functions, and for each sub-function the space of implementable solutions is enumerated and assessed in a structured weighted evaluation.

To the conventional morphological matrix the analysis adds a second dimension. Each alternative is also classified by three strategies according to how the undefined interface is resolved: it is absorbed by the node, or it is removed by declaring a property the UAV already possesses, or it is removed by adding a capability to the UAV. The distinction between the latter two matters, because a declared constraint costs a UAV that already satisfies it nothing at all, whereas an added capability costs mass, power and

qualification effort. Determining the relative pose of a landed UAV, correcting its lateral offset, establishing a charging contact, and providing weather protection can all be realized in any of the three ways. The alternatives differ far more along this dimension than in technical difficulty.

These three strategies are not equivalent in cost, and the asymmetry between them is structural rather than technical. Ground-side absorption is available immediately and demands nothing of the UAV. It pays in ground-side mass, volume, actuation and tolerance-chain complexity, and it pays once per node. A vehicle-side capability is paid once per UAV and yields the simplest possible node. A declared constraint costs neither mass nor hardware; what it costs is agreement. Because a fleet visits many nodes, the economics of a distributed network favor the second and third strategies, while a single installation will rationally select the first. This accounts for the convergence of early ground systems on compensation, and for why that convergence does not scale. The three strategies also indicate where compensation cannot be avoided. Where nothing is declared, ground-side absorption is the only strategy left. Its effort is set by the range of values a node must accommodate, and in the limiting case a node would have to interpret arbitrary and previously unknown mechanics autonomously. Such a node cannot be specified, let alone verified.

On this reading, drone-agnosticism is no longer a binary property of a ground system. Agnosticism is purchased with ground-side complexity, and it remains bounded. The design question is therefore not whether a depot is type-open, but which minimal set of declared parameters allows a node to serve any UAV within a class. Which strategy is practicable depends on the mass class. Where maximum take-off mass and payload budget are generous, a requirement can be met by adding a capability to the UAV, and existing ground-handling conventions assume as much; the most specific publicly referenceable one presumes a net payload of at least 2.5 kg [2]. Where the payload budget is on the order of a kilogram, the same capability competes directly with the cargo the flight exists to carry, and adding it may not be feasible at all. For the smaller class the declared-constraint strategy is therefore often the only practicable one, which raises the value of declaring properties a UAV already possesses. Two such properties stand out: the geometric reference including static ground attitude, that is, the orientation in which a UAV comes to rest relative to the landing surface, and the mechanical quantities a node designer needs, namely admissible actuation forces and positional tolerance windows. Wherever a parameter is declared instead of compensated, complexity is removed from every node built thereafter, at no mass cost to any UAV.

The work sets out the morphological treatment of the interface, which is derived from requirements rather than from an existing product, and the three strategies that make the trade between ground and UAV explicit. It closes with a discussion of which parameters would most usefully be standardized next, and with the engineering steps required to close the gap: agreeing on the minimal parameter set, specifying tolerance and force envelopes alongside the geometry already covered, and defining verification

procedures so that conformity can be demonstrated rather than asserted. The findings stem from an ongoing implementation project.

[1] EASA, "Prototype Technical Specifications for the Design of Vertiports," European Union Aviation Safety Agency, 2022.

[2] U-Space Berlin, "Urban Drone Delivery in Berlin," Reallabor U-Space Berlin, 2026.

[Online]. Available: <https://u-space.berlin/>

[3] DORAI - Drone Operator Requirements Aero Initiative, "Joint UA Operator Statement, UAV Specifications," Release v03, May 2025.

## **Biography**

**Ramón Beck**



Ramon Beck studied aerospace engineering at Technische Universität Berlin, where he is a research associate. He is responsible for system architecture and development within the U-Space Berlin testbed, and his work focuses on automated ground infrastructure for unmanned delivery aircraft and the interface between UAV and ground node.