

Three Steps (and nine milestones) to Commercial Reality in Quantum Computing

A vendor-neutral, modality-agnostic checklist of achievements toward large-scale, fault-tolerant quantum computing (FTQC)

The path to commercial-scale quantum computing is both technically complex and strategically important. Yet, progress in the field is often described in aspirational, abstract or inconsistent terms — making it difficult for decision-makers, policymakers, and innovators to evaluate where we are and what remains to be done.

This framework lays out three major states, each broken into three concrete milestones, that any quantum vendor, regardless of modality or approach, should achieve on the road to fault-tolerant quantum computing. It is not a prediction of *when* each milestone will be reached, nor a claim about which platform will succeed first. Instead, it provides a structured, technology-agnostic punch list to track progress and foster clarity in a field where hype and genuine breakthroughs are often hard to separate.

To make this journey more tangible, it helps to draw a parallel with one of the most transformative technological revolutions of the last century: aviation.

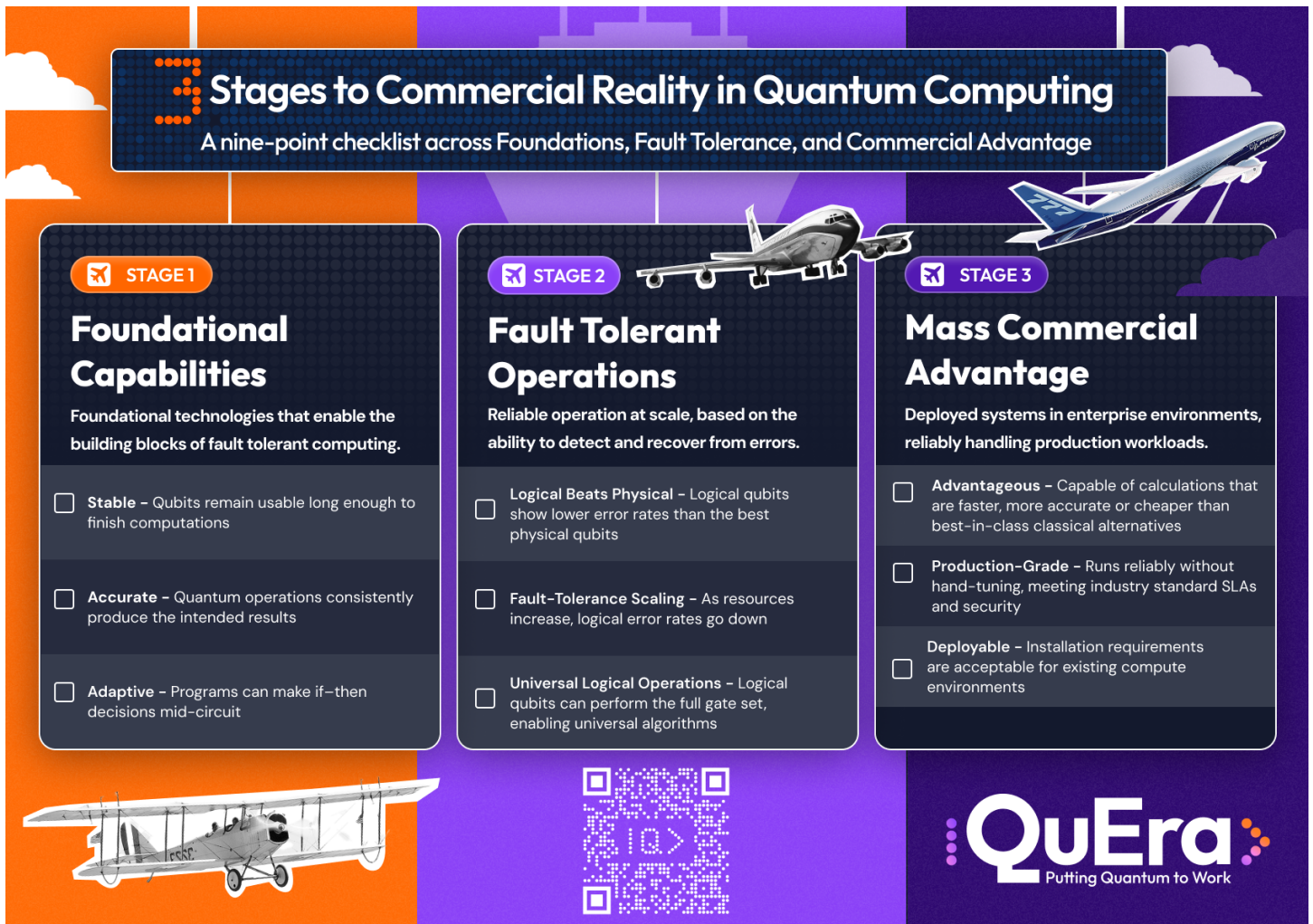
Just as aviation transformed from the Wright Brothers' 12-second flight to today's global airline industry, quantum computing is progressing through critical milestones toward commercial viability. This aviation analogy helps illustrate where we are in quantum's journey:

- **Early aviation (1900s-1920s)** struggled with basic reliability, short flight times, and frequent crashes — like today's quantum computers with high error rates. This corresponds to Stage 1 of the framework: *Foundational Capabilities*.
- **The breakthrough era (1930s-1950s)** introduced pressurized cabins, reliable navigation, and safety systems that made commercial flight possible. This parallels quantum's current push toward error correction and scalable architectures. This aligns with Stage 2: *Fault-Tolerant Operations*.
- **Modern aviation (1960s-present)** achieved the safety, scale, and integration needed for business-critical operations — the destination for quantum computing. This reflects Stage 3: *Mass Commercial Advantage*.

Three Stages and Nine Milestones to Commercial Reality in Quantum Computing

Stage	Milestone	What it shows in practice	Why it matters	Airline analogy
1. Foundational capabilities	Stable - Qubits remain usable long enough to finish computations	Mostly automatic calibration/health monitoring; minimal manual tuning.	Transitions from ‘works in the lab’ to ‘reliable service’.	Autopilot & standardized procedures.
	Accurate - Quantum operations consistently produce the intended results	One- and two-qubit gates at target error rates; coherence long enough for useful circuits.	Proof that basic operations are trustworthy; without accuracy and coherence, nothing else works.	Reliable engines & flight controls + extending flight range beyond short hops.
	Adaptive - Programs can make if-then decisions mid-circuit	Mid-circuit measurement with low-latency feed-forward; conditional branching; qubit reset & reuse; controller fast enough to act during execution.	Foundation for error-handling and efficient circuits, enabling programs to adapt in real time.	In-flight navigation & course correction.
2. Quantum Error Correction	Logical beats physical - Logical qubits show lower error rates than the best physical qubits	Demonstrate a protected logical qubit and show it outperforms the best unprotected qubit.	Proof that protecting information yields practical gains, establishing the foundation for fault-tolerant computing.	First pressurized cabin and first flight safer than driving.
	Fault-tolerance scaling - As resources increase, logical error rates go down	Multiple logical operations can be executed; increasing logical qubit code distance improves performance.	Proof that reliability improves as systems grow, enabling large-scale computation.	Coordinated fleet operations meeting commercial safety standards.
	Universal logical operations - Logical qubits can perform the full gate set, enabling universal algorithms	Resource generation and verification enabling a universal non-Clifford logical gate set (e.g., via magic-state distillation).	Creation of special “magical” resources that unlock the full power of quantum computing.	Refine crude oil into high-octane jet fuel.

Stage	Milestone	What it shows in practice	Why it matters	Airline analogy
3. Commercial reality	Advantageous - Capable of calculations that are faster, more accurate or cheaper than best-in-class classical alternatives	Solve a relevant problem faster than top supercomputers with credible benchmarking.	The commercial tipping point.	First transcontinental route beating trains.
	Production-grade - Runs reliably without hand-tuning, meeting industry standard SLAs and security	Runs reliably without hand-tuning, with automated calibration and monitoring; meets industry-standard SLAs, uptime, and security requirements.	Proof that quantum systems can operate like enterprise infrastructure—predictable, stable, and trusted.	Scheduled commercial flights that depart and arrive on time with predictable reliability.
	Deployable - Installation requirements are acceptable for existing compute environments	Installation requirements align with existing HPC environments. Systems fit into standard infrastructure (power, cooling, space), with APIs compatible with customer workflows.	Confirmation that systems integrate without requiring custom facilities.	Airports are standardized so fleets can operate anywhere—planes don't need bespoke runways or special procedures.



These nine milestones provide a vendor-neutral framework for assessing progress toward fault-tolerant quantum computing. While different approaches will advance along this path at varying speeds, each step represents a critical achievement on the journey from experimental prototypes to commercial reality. By focusing on these concrete markers, decision-makers can distinguish meaningful advances from hype and track how the field is evolving. To see how QuEra is advancing against these milestones, visit www.quera.com