Recommendations on Quantum Computing from GIFAS Report on quantum technologies for Aerospace-Defense applications

Frédéric BARBARESCO

THALES Quantum Algorithm & Computing Segment Leader

Member of GIFAS-R&D Commission

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The French Aerospace and Defence Industry

A **dual industry** (69% Civil / 31% Defence) covering every field: aircraft, helicopters, engines, equipment, missiles, UAVs/UGVs, space launchers, satellites and defence systems.

- **469 members:** prime contractors, systems manufacturers, SMEs and startups.
- **€62.7 bn** of revenue (2022)
- **€65.8 bn** of orders (2022)
- **83%** of revenue **from exports**
- **France's biggest trade surplus** (2022)
- **Major investments in France**: R&D = 10,6% of revenue
- **195,000 direct jobs** in France; **18,000 new hires** in 2022

An integrated supply chain

- An industrial fabric of 211 Equipment Suppliers and 224 SMEs, forming the industry's entire supply chain
- This supply chain grew considerably until 2019 in line with prime contractors' growth, but has been significantly impacted by crises (Covid, inflation, material, geopolitical…)

- A supply chain open to foreign markets
- Technological excellence
- GIFAS Improvement Programmes are recognised for industrial performance, transformation and support (equipment, SMEs), etc.

- GIFAS regional footprint: 13 representatives that are GIFAS member industrialists from the regions of mainland France, ensuring a strong regional presence. Key role: interface between GIFAS and regional executive authorities as well as related departments

GIFAS: Role and Actions

Permanent, Long-Term Role

Shaping the future…

- **GIFAS defends** the interests of the profession and member companies.
- **GIFAS represents** the profession in national, European and international organisations.
- **GIFAS coordinates** research and training and harmonises technical, economic, commercial and normative procedures with the aim of continuously improving the industry in order to meet future challenges (competition, environment, etc.).
- **GIFAS promotes** the sector in France and abroad.

Role in Times of Crisis

… in response to the crisis

- **GIFAS takes action** to assist its members (support, task force, code of conduct, monitoring, etc.).
- **GIFAS defends and contributes to safeguarding** the aviation industry by helping it **move forward** and **evolve** in response to the crisis (interfacing with public authorities, negotiating support plans and associated measures, etc.).
- **GIFAS implements** new actions with a view to the **end of the crisis** and **business recovery**.

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de Paris-Le Bourget
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Save the date
16 to 22 June 2025

GIFAS WORKING GROUP ON QUANTUM TECHNOLOGIES

Contributors

Report available in French at : https://www.gifas.fr/brochures

R&D commission 20th march 2024

GIFAS

Quantum Technologies Working Group
Sub-WG Quantum Computing


COMMISSION R&D

Rapport sur les technologies quantiques pour les applications Aéronautique-Spatial-Défense

Groupe de Travail Technologies Quantiques

Ref : GIFAS/R&D/5004/2024

GROUPE DE TRAVAIL
TECHNOLOGIES QUANTIQUES
RAPPORT 2024
GIFAS

INNOVATION

Rapport 2024 sur les technologies quantiques

Le groupe de travail dédié aux Technologies Quantiques au sein de la Commission R&D du GIFAS vous propose son rapport 2024 sur les technologies quantiques pour les applications Aéronautique-Spatial-Défense, présentant leurs apports majeurs, les applications ciblées et les horizons calendaires associés. Il met en avant 3 piliers des technologies quantiques que sont le calcul, les capteurs et les communications.

TÉLÉCHARGER https://res.cloudinary.com/gifas/image/upload/Documents/Rapport_Technologies_Quantiques-GIFAS_mai_2024.pdf

GIFAS R&D Commission, March 20th 2024

WG from February 2021 to March 2024

WG Coordinator: Sylvain Schwartz (ONERA)

Quantum Computing Sub-group:

Coordinators: Alain Refloch (ONERA) & Frédéric Barbaresco (Thales)

Contributors: Robert Wang, Olivier Hess et Philippe Duluc (Eviden/Atos), Denys Quesneau (Ariane Group), Edouard Debry et Leo Dumas (MBDA), Gilles Zalamansky (Dassault Aviation), Marc Contat (ADS)

GIFAS Quantum WG Objective 2023

Define the major contributions for the quantum technology sector, the targeted applications and the associated calendar horizons as well as possible recommendations for the sector and for the national coordinator for the quantum strategy. The Quantum Technologies subgroup led by Onera and bringing together a dozen GIFAS companies will be asked to carry out these discussions in coordination with the R&D Commission.

Methodology & calendar

- Launch of work on February 10, 2023 at ONERA
- Operation in sub-working groups: quantum sensors, quantum communications, quantum computing and enabling technologies (plus a training component)
- Establishment of a common analysis grid to identify the technologies and applications envisaged, then choose (for sensors) the most promising in the short term
- Plenary meetings (10 since February 2023) and work in subgroups
- Common reflections on enabling technologies (transversal theme)
- Taking into account reports already published on the subject (Quantum computing progress and prospects NAP 2019, CGARM 2023, Quantum 2042...)
- Interview with external actors (Pasqal, Exail, Quobly, INRIA, ENSTA,…) but above all a lot of resources within the group
- Closing of work and submission of report March 20, 2024

Calendar Horizon

In the short term: quantum sensors

- gravimeters, gradiometers and cold atom inertial units for inertial navigation
- compact atomic clocks for GNSS-free synchronization
- magnetic sensors (SQUIDS, gas cells, NVs) for magnetic anomaly detection and/or navigation
- RF sensors (Rydbergs, NVs, SQUIDS, rare earth ions) for electronic warfare

In the medium term: quantum communications networks

- share confidential key
- transmit quantum states

In the longer term: quantum computation

- partial differential equations (fluid mechanics, electromagnetism)
- combustion simulation
- optimization problems...

Quantum Computing Recommandations

- **R1:** Encourage the development of research on quantum algorithms and associated ASD use cases (for example by supporting projects involving GIFAS manufacturers and academic players in the field). This action, consistent with current actions including the PROQCIMA project recently launched by the French MoD DGA, will be able to rely on the existing BACQ project.
- **R2:** Facilitate access for GIFAS manufacturers to quantum computers already available with the right level of security: in the short term by subsidizing computing hours to be able to test elementary algorithms (not necessarily limiting ourselves to French machines initially time), and in the long term by supporting the technological maturation of a quantum information network to enable sensitive or confidential algorithms to be run securely via the cloud (and also to interconnect quantum computers).
- **R3:** Encourage GIFAS manufacturers to adopt and develop the benchmarks proposed by the BACQ project and to publish the measured values in order to share a common evaluation tool to quantitatively monitor the progress of available quantum computers.
- **R4:** Encourage the development of trusted software stacks (compiler, library, programming/software engineering tools), to go from high-level language to quantum circuit level. In this context, we will take care to promote the links between classical HPC and quantum computing, because it is clear that the latter will only find applications in addition to existing classical computing means.
- **R5:** Consolidate/ensure that we are able to guarantee a European industrial sector to ultimately guarantee access to quantum computers and a viable economic model for French QPU manufacturers.

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GIFAS Quantum Computing Use-Cases

Capacity	Use Cases
Differential equation, solving linear systems	Electromagnetic simulations, fluid mechanics, structural mechanics, pyrotechnics, combustion, climate, etc.
Monte Carlo simulation, very high-dimensional probabilistic simulation, particle filtering, extreme value analysis, statistical tests	IVVQ (Integration, Verification, Validation, Qualification) configuration, influence, etc.
Design of molecules, design of materials, understanding of chemical reactions	Prediction and generation of new polymers, energetic materials, biofuels, pyrotechnic powders, etc.
Risk study, anomaly detection	Cyber Security
Combinatorial optimization, scheduling, operational research, resource allocation, logistics, shortest path	• Optimization of sensor design (radar, etc.) • Assistance with deployment and reconfiguration • Mission and traffic management (planes, drones, satellites, etc.)
AI-Machine Learning, Reinforcement Learning and Generative AI.	• Recommendation system • Image recognition • Sensor and Weapon Resource Allocation • Generation of more realistic simulated data, …
Decision-making support, mission planning	Rover, resource allocation, mission reconfiguration, etc.
Robotics	Diagnosis, perception, …
Cryptography	Crypt-Analysis, code attack

FTQC Roadmap

Faced with uncertainties, a certain number of milestones can be put in place to monitor and develop the quantum computing roadmap, according to the following list:

- The availability of the 1st logical qubit, followed by the availability of 50 logical qubits (equal to the power of a supercomputer in the top 500). The availability of 60 qubits is a leap in computing power of a factor of 1000 compared to 50 qubits ($2^{60}=2^{10}x2^{50}=1024x2^{50}$).
- The provision of a QC allowing the demonstration of quantum supremacy: solving a simple and useful problem that we know today is out of reach by classical calculation. The technologies being different, it is necessary to separate the analog approach from the digital approach (gate-based), the first being the one which should allow a quantum advantage more quickly, but which remains less universal.
- The provision of a QC allowing the demonstration of energy supremacy at equal power with a classic calculator.
- The commercial development of a "useful" gate-based QC: capable of solving problems of practical interest on a very limited number of applications.
- The development of a QC displaying 100 logical qubits and higher fidelity (50 logical qubits being considered as the current power of a large HPC system)
- The development of a QC displaying more than 1000 logical qubits.
- The development of a fault-tolerant QC coupling several QCs.

FTQC Technological Barriers

The challenges to be met are significant:

- Increase the fidelity of qubits,
- Error correction (including quantum feedback)
- The interconnection between QPUs (especially for architectures where the number of qubits per QPU is limited)
- Enabling technologies (wiring, cryogenics, ultra-high vacuum, etc.)
- Energy consumption
- Inputs/outputs because the bandwidth of quantum machines, expressed in GigaBytes per second, is very low
- Quantum memories (for coupling between quantum accelerators)
- The diffusion of quantum computing which will reduce the selling price of machines
- The lack of algorithms on industrial topics of interest
- The availability of full-stack (compilation, library, language, etc.),
- The integration of quantum computers into the classical ecosystem (HPC, Cloud), with a direct interconnection between different qubit technologies and a protected network interconnection between users and production sites
- Integration in the HPC world. Quantum computing needs HPC (validation of algorithms up to 40 qubits, debugging, optimization of circuits, preparation of input data, processing of output data, error correction).

Quantum Algorithms

Challenges on Algorithms

- The quantum plan mainly directed funding towards the development of startups producing QPUs. However, there will be no quantum advantage without a quantum algorithm. It is therefore important to encourage and support the development of quantum algorithms.
- The number of quantum algorithms remains very limited, therefore, it is difficult to claim a competitive gain by remaining a simple user of solutions proposed by the QPU manufacturer, an algorithmic investment is therefore necessary at the level of the 'industry
- We must at the same time support French laboratories working on fundamental sciences linked to algorithms, in order to ensure that France remains at the forefront in these areas

QPU & Benchmark

- We must continue to support start-ups producing computers, interconnections of multi-modality quantum computers (e.g. Welinq techno use), and enabling technologies, and everything that is linked (hardware and software) with the error correction codes: surface code, LDPC codes, bosonic codes (Cat Qubit, GKP Qubit, etc.) with quantum feedback.
- Concerning Benchmarks actions for quantum computers, there are actions abroad on the subject (QED-C, DARPA/Raytheon, etc.), the BACQ project meets this need for France. It seems relevant to extend this Benchmark action to the European level (with TU Delft/TNO in the Netherlands, Fraunhofer Institute IKS in Germany, etc.) to promote a European reference benchmark.
- The BACQ project aims to provide a benchmark for the LNE. There is an interest in extending BACQ for a benchmark oriented towards vertical market segment applications (example: optimized calculation of aircraft shape, swarm flight, etc.) in line with the needs of GIFAS in coordination with LNE and THALES
- There is a set of tools/environments for programming (Microsoft #Q, Rigetti Forest, IBM QX [OpenQASM], QISKIT, SilQ, CIRQ, Quipper, QFC, QPL, Atos QLM), an effort to avoid being dispersed by factoring developments around common trust tools would be profitable (see what was done for AI with Scikit-learn).

Benchmarking

- **Expand the activities of the BACQ project**. The benchmarking theme is oriented towards generic problems (physical simulation, optimization, resolution of linear systems and factorization), a **benchmark more oriented towards industrial verticals** would be profitable. Benchmark on the environment and use cases. It would make it possible to establish and best follow a roadmap which today is subject to too many uncertainties depending on the application cases, qubit technology, and the availability of algorithms. **This action must be coordinated with LNE and THALES to extend BACQ's activities for the needs of GIFAS**. The benchmarks of the four generic problems could be extended for GIFAS use cases:
- **Physical simulation:**
  - Study of materials for stealth (radome, UCAV, etc.)
  - Study of propellant and explosive powders (munitions, rocket powder booster, etc.)
  - Oxidation study
- **Optimization**
  - Optimization of the design of on-board equipment and their carriage (Radar/GE/COM antennas on-board airborne or satellites)
  - Assistance with deployment and mission preparation
  - Reconfiguration of complex systems in the event of breakdowns or mission changes
  - Optimization of the trajectory of drones or remote-carriers in swarms
- **Solving linear systems**
  - Electromagnetic simulation
  - Structural mechanics simulation
  - Fluid mechanics simulation
- **Factorization**
  - Cyber security of platforms
  - Hardening of post-quantum codes

Full Stack (1/2)

- It is necessary to have efficient compilers, with the development of HW-Agnostic (and HW-Dependent) compilers exists outside of France (example: Classiq in Israel www.clas-siq.io)
- There is a need to develop and maintain 'high level' libraries of trust with academic laboratories and French start-ups: alternative library to Qiskit from IBM, CIRQ from GOOGLE, etc. Generally, there is no source funding to bring tools from the world of research to life (let's cite a counter-example of a 'success story' in the field of learning machines, the 'Inria foundation' makes it possible to bring tools to life outside of research, this is the case for Scikit-learn which will follow with the development of the SNRIA P16 infrastructure for the extension of this tool).
- We must encourage the development of trusted software stacks. For example, China is working in this direction (China's announcement in February 2021 by Origin Quantum Computing Technology (Origin Tech http://www.originqc.com.cn/) of the first Chinese operating system (OS) for quantum computers called Origin Pilot, which should allow the parallel execution of several quantum computing tasks, the automatic qubit calibration and unified management of quantum computing resources. Use with Origin Quantum Cloud should make it possible to control multi-core quantum computers.
- There is also a need for profiling and optimization tools for gated circuits which must be taken into account.

Full Stack (2/2)

- Show a concerted effort on the development of trusted (maintained) software stacks. It is a global subject which brings together a very large number of technical points (compiler, language, OS, integration in computing centers, Cloud access, etc.). However, quantum hardware technologies are very different (e.g. atomic vs photonic), evolve quickly and are proprietary, so developing a universal software stack in an environment that is not yet mature remains a challenge (and could present the risk of inducing hardware stiffening). A software stack developed for a NISQ accelerator will have to be rewritten to take into account the processing of error corrections.
- Promote the development of quantum algorithms oriented towards industrial needs and the study of new breakthrough algorithms to regain leadership.
- Promote the introduction of quantum computing in companies (accelerate continuing training)
- In addition to manufacturer-oriented strategies (France quantum plan), it is also crucial to ensure users continuous access to the various quantum computer technologies already available, outside France, both for reasons of continuing education , which is currently largely self-taught by experimenting with different technologies, and for benchmarking reasons, it is essential for a Defense industry to estimate which technology is most suited to its use and how compare its quantum solutions to those of its competitors outside Europe. This facilitation of access to computing hours quantum machines for GIFAS members, must be done with sensitivity levels adapted that can be raised.
- Develop a solution for secure access to quantum computers, either via computing protocols encapsulated for protection (but risk of excessive qubit overheads) or via protocols without overhead but requiring a quantum communication link

Access for QPU

- Support for French start-ups to facilitate sovereign access for GIFAS members to French (or even European) quantum computers
- Need to industrialize cloud solutions and optimize simulators (simulation time still too long) among French qubit providers.
- Current cloud solutions for access to quantum computers are not compatible with the security constraints of GIFAS manufacturers. We must develop a cyber-secure cloud allowing access to machines with high levels of sensitivity. The pooling of a set of machines in a dedicated center is to be studied according to economic models (depreciation time of machines, in HPC the average maintenance time is 5 years, in the case of quantum the progress of hardware being fast, a machine will very quickly be outdated). The cost of one hour of calculation in QCaaS (Quantum Computing as a Service) mode would be between $1k and $5k. Due to the price of machines and their rapid developments, very few users will opt for a local solution and the demand will focus on outsourced and shared solutions.
- Ultimately what will be sought, for sensitive applications, is a global quantum solution which involves having an end-to-end protected network between users and production machines.
- The financing of a national network involves an economic model different from that of financing quantum accelerator start-up providers, and must be taken into account now due to the costs and deployment time.

Enabling Technologies

- lasers, integrated photonics, single photon sources and detectors
- materials: superconductors, diamonds, nonlinear crystals
- cryogenics (2-4K but also 40-80K) and associated techniques (electronics <4.5K, microwave cables, etc.)
- vacuum technologies
- constituents specific to quantum networks and computers

Strong synergies between sensors, communications and quantum computing.

Investing in quantum sensors could benefit quantum networks and computers (and the converse is also true)

Build or be able to guarantee a sustainable acquisition strategy for each of the key enabling technologies above, relying on the synergies between sensors, communications and quantum computing.

Some priorities: cryocoolers, integrated photonics

Training

- Encourage the development, in addition to university training, of a significant range of training for Industry employees in the field of quantum technologies for technicians and engineers intended to work in the field. A difficulty may appear linked to the mathematical foundations of quantum theory, which will undoubtedly require setting up several levels in the provision of training in quantum technologies for industry employees.

- A good knowledge of classical algorithms being necessary to understand the challenges of quantum calculation, it would also be relevant to develop such training within the framework of the national quantum plan.

International Competition

- **Standardization and standardization actions on quantum computing: there are initiatives abroad (CEN/CENELEC, ISO, IEEE Quantum Computing Benchmark, etc.). The BACQ project now meets this need**
- **Establish a technological watch on the sources of international competition in connection with industrial competitors of GIFAS in the world**
- **Need for an international conference (IEEE Quantum Week type) oriented towards engineering via the SEE to display France's position in the field and to have a place for technical exchanges between academics and industrialists. Q2B type events are sometimes considered too 'commercial' due to the lack of academic presentations.**

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GIFAS

Conclusion: GIFAS WG next step

Forces:

- **Rich and varied experiences and skills within the group**
- **Strong motivation despite busy schedules**
- **A subject of major interest for the sector**

Proposition:

- **Continue work at a rate of one to two meetings per year to promote the report and monitor the application of its recommendations, continue to share information in a rapidly evolving field and be in a position to act based on opportunities.**
- **ex: representation of GIFAS at the QUEST-IS conference in 2025**

GIFAS