

QuaSAR

Quantum Sensing Aerial Reporting

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Presentation Agenda



Situation Assessment



Proposed Solution



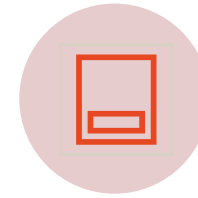
Concept of Operations



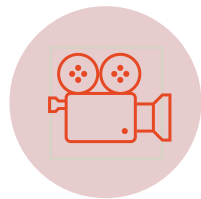
Path to Deployment



Conclusions and Findings



References



Operation Video



Q&A



Situation Assessment

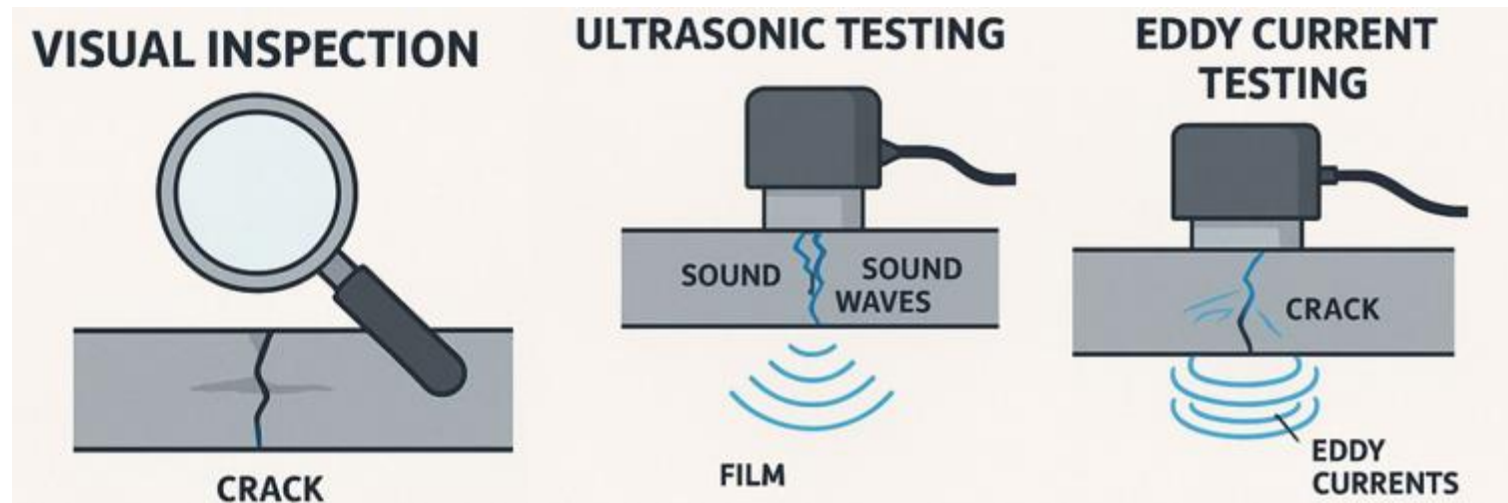


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Situation Assessment

Non-Destructive Testing (NDT)

- Visual Inspection: physically examining airframe surfaces and accessible internal structure for cracks, corrosion, or deformation.
- Eddy Current Testing: uses electromagnetic induction to identify surface and near-surface discontinuities in conductive materials.
- Ultrasonic Testing: extends detection into the internal structure of the material but similarly requires surface contact with a coupling medium and is relatively slow.



Situation Assessment

Limitations of Current Approaches

- Reactive: identifies damage that has already formed instead of the preceding material conditions
- Labor Intensive: c-check on a commercial aircraft can require up to 6000 hours of labor and 1-4 weeks
- Fixed Intervals: inspections performed on a schedule or by flight hours may not accurately reflect the actual physical conditions of the aircraft



Situation Assessment

Demand Gap

- Increasing Fleet Size: projected to require more than 40,000 new commercial aircraft by 2040 → enormous MRO expansion.
- Projected Workforce Shortfall: retirements outpacing new entries into the field and reducing the pool of skilled technicians.
- Industry Response: FPV drones, digital twins, predictive maintenance platforms.



Situation Assessment

Key Issues

1. Growing Fleet
2. Shrinking Workforce
3. Fixed-Interval Inspection

Determination: Incremental refinements to current NDT methods are unlikely to resolve key issues.



Proposed Solution



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Overview: QuaSAR

Purpose

- The autonomous detection of early-stage structural fatigue.
- Operates during scheduled and unscheduled maintenance events.
- Identifies regions of elevated stress accumulation.

System

- Operating as a drone-mounted autonomous inspection device, QuaSAR can sense defects on an airframe before crack nucleation.
- The system includes a specialized probe head, avionics module, and power distribution unit.



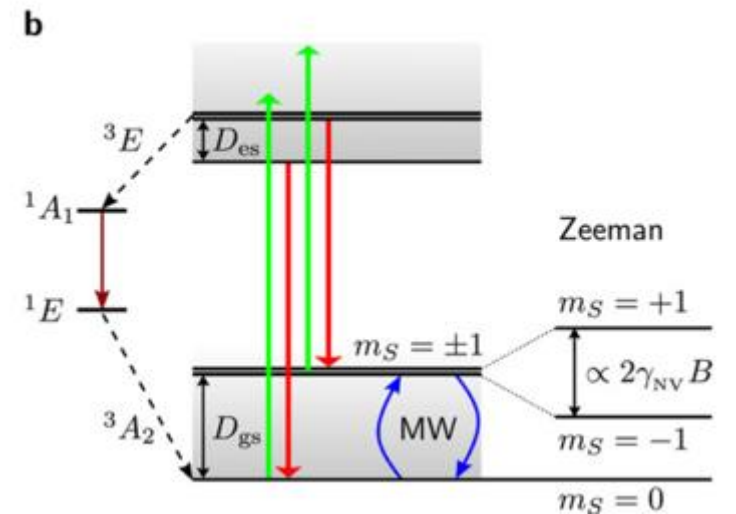
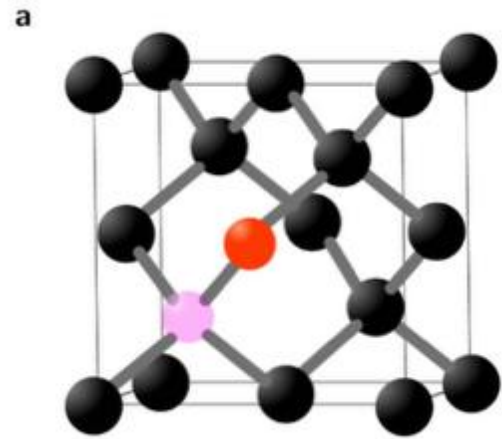
Nitrogen-Vacancy (NV) Sensing

Technology

- Process: NV defects are doped into diamond crystal lattice structure in an HPHT environment.
- Sensing: Optically Detected Magnetic Resonance (ODMR).

Sensing

- When NV centers are illuminated, they emit fluorescence proportional to their spin state.
- An applied microwave field near the NV resonance frequency ($\sim 2.87\text{GHz}$) produces a dip in fluorescence.
- The frequency of this dip shifts in the presence of a magnetic field.
- The strength of the magnetic field can be determined by the simplified equation $B = (f_+ - f_-) / 2\gamma_e$.



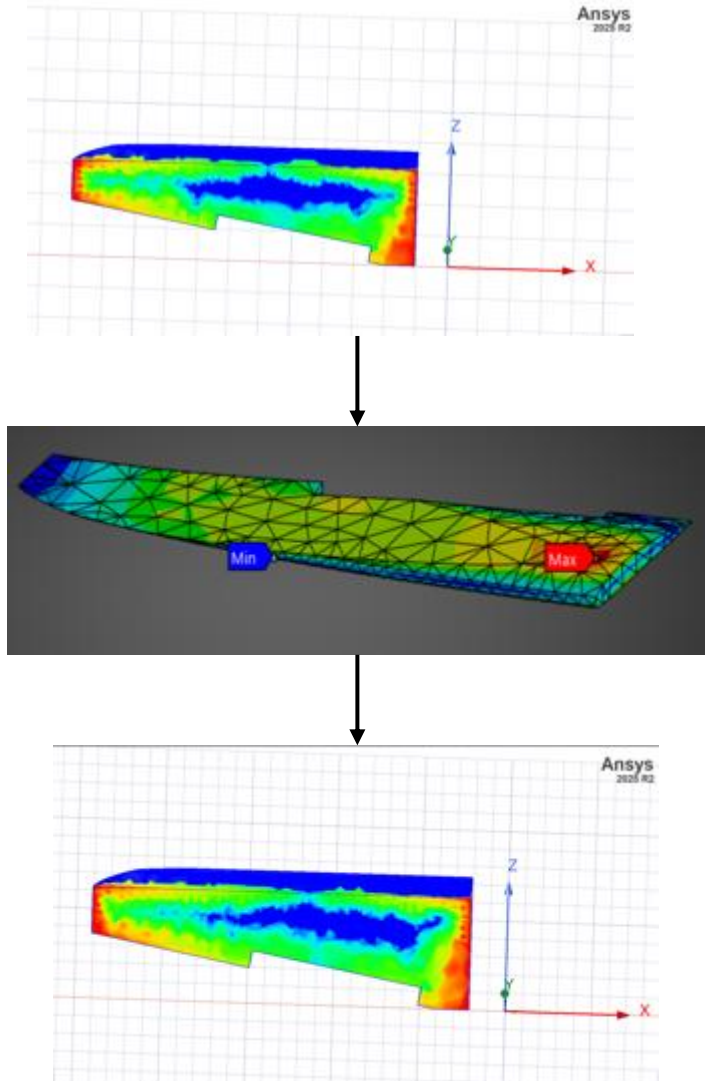
Nitrogen-Vacancy (NV) Sensing

Process

- Structural fatigue in aluminum alloys alters the local magnetic susceptibility at the crystal lattice level.
- Deformed crystal lattice structures provide reduced electrical conductivity.
- Changes in magnetic field strength are observed.

QuaSAR

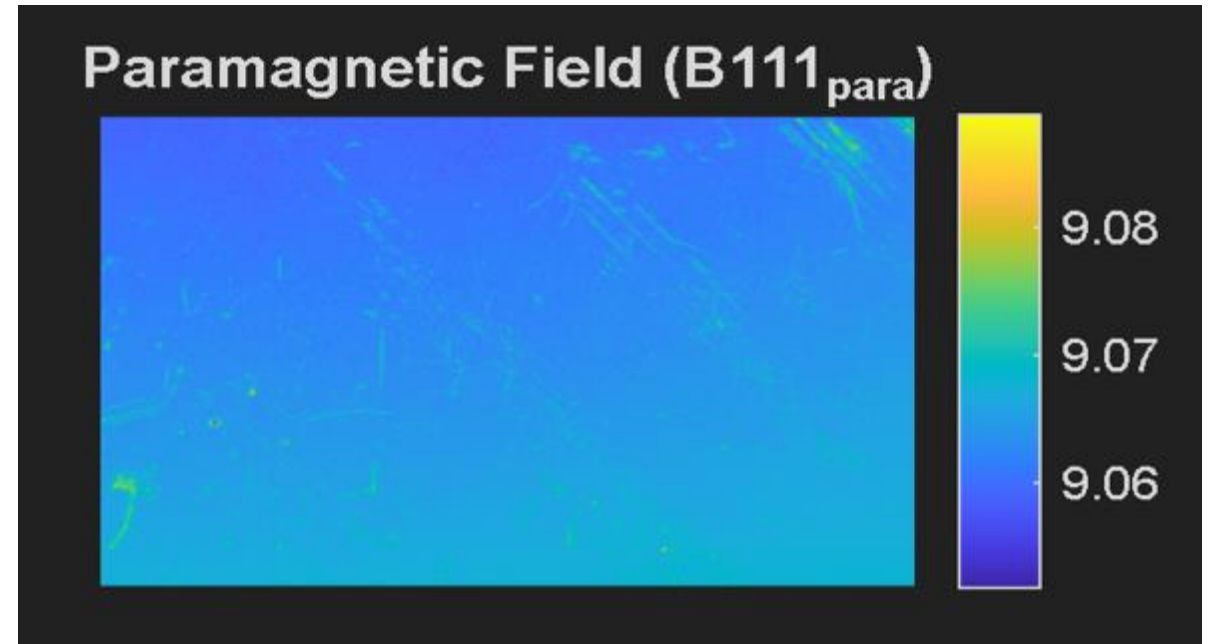
- Mapping the magnetic field heatmaps at multiple instances will show the internal stress accumulation of materials over time.
- Will identify regions of pre-nucleation fatigue and provide predictive maintenance based on the actual condition of the airframe.



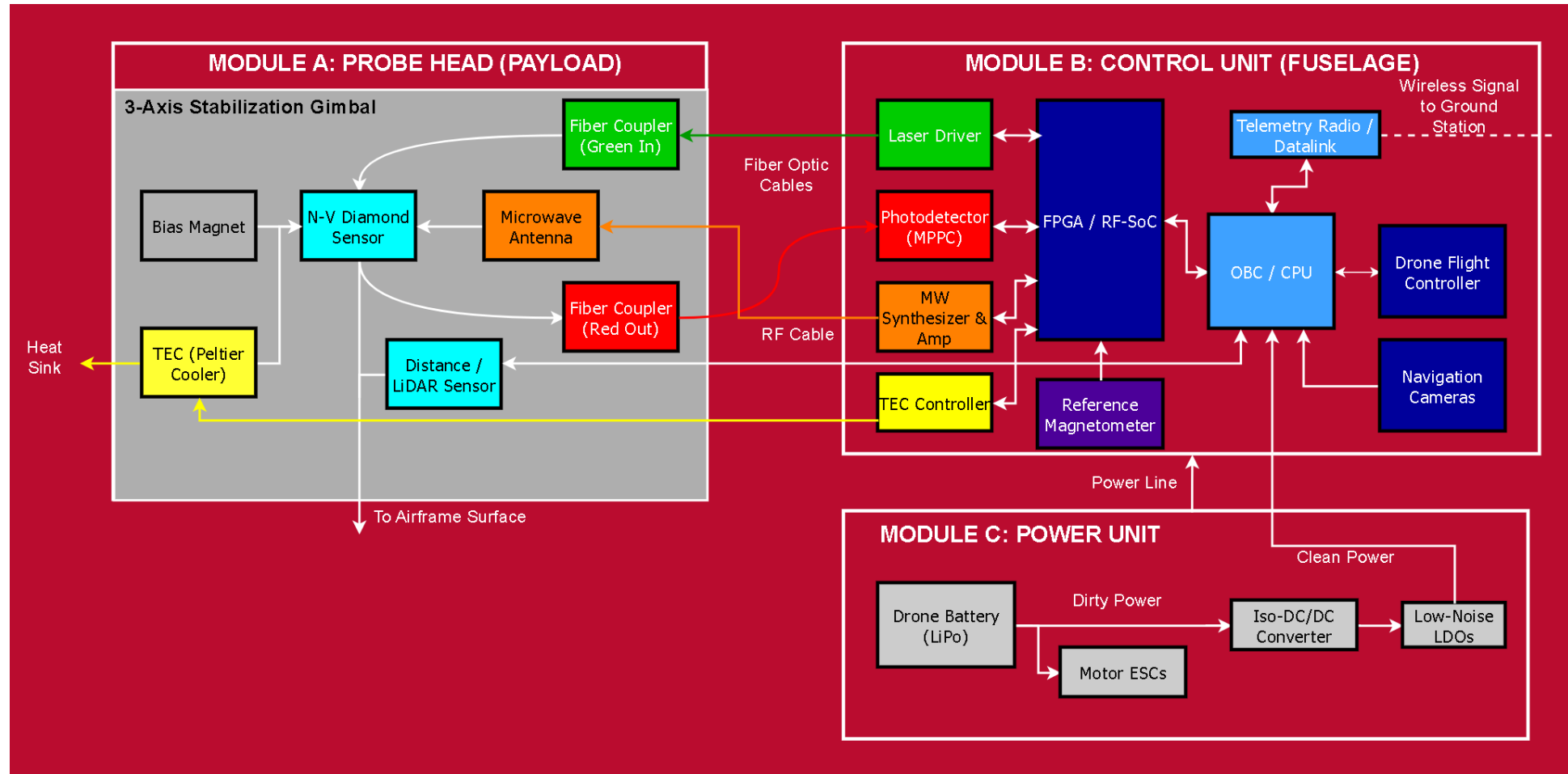
Nitrogen-Vacancy (NV) Sensing

Proof of Concept

- Real paramagnetic field data captured with a Quantum Diamond Microscope (QDM) and processed using Harvard's QDMLabs MATLAB tool.
- Variation in B111 field strength varies across scan surface, reflecting local changes in magnetic susceptibility to physical flaws.
- Produces spatially resolved, quantitative field maps capable of distinguishing structural anomalies.



Preliminary System Design



Conceptual Design CAD



Practical Advantages Over Conventional NDT

Advantages: Sensitivity and Early Detection, Non-Contact Operation, Automation and Reduced Labor, Predictive Maintenance Enablement

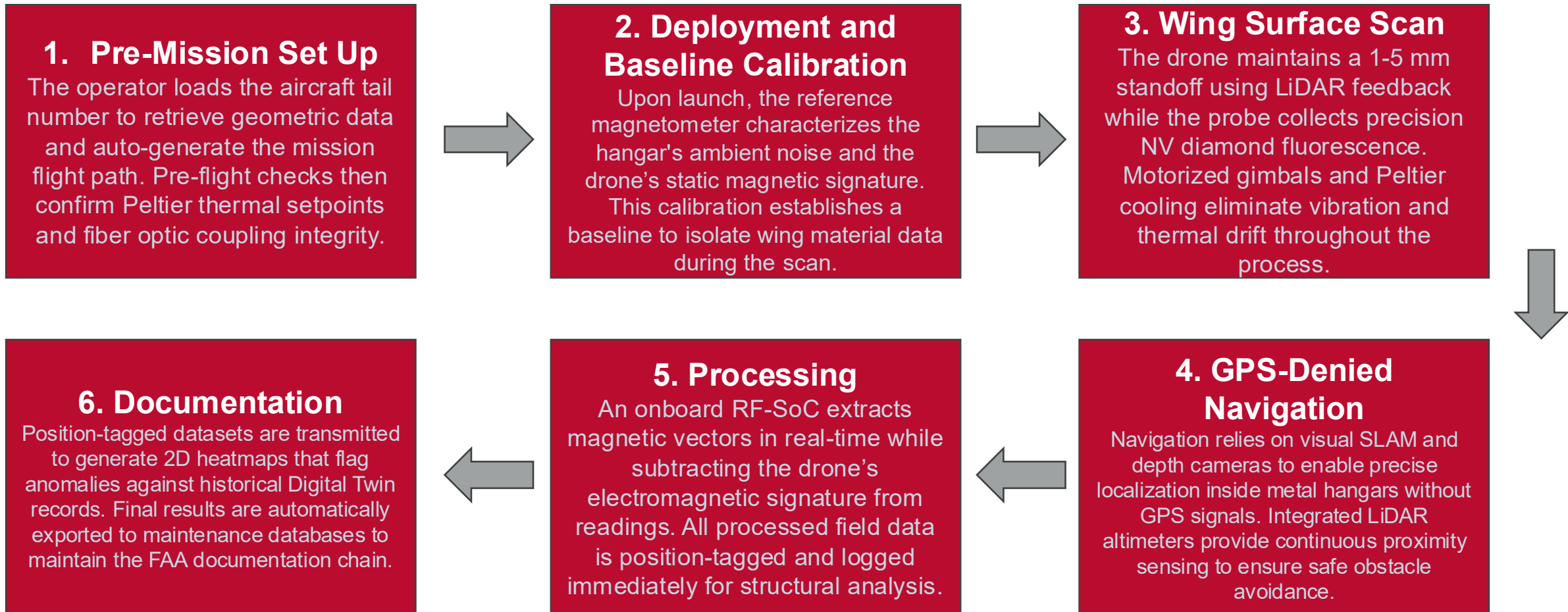
| Attribute | Visual Inspection | Eddy Current | Ultrasonic Testing | QuaSAR |
|------------------------|--------------------------|-----------------------|----------------------------|---|
| Detection Threshold | ~1 mm crack visible | ~0.1–1 mm crack | ~0.1 mm internal flaw | Pre-crack stress accumulation (picoTesla sensitivity) |
| Surface Contact | Not required (visual) | Required | Required (coupling medium) | Not required (1–5 mm standoff) |
| Operator Certification | Certified A&P technician | Specialized NDT cert. | Specialized NDT cert. | 14 CFR Part 107 + supplemental module |
| Wing Scan Time | 4–12 hrs per wing | Hours per area | Hours per area | ~30–45 min per wing (estimated) |
| Operation Mode | Manual | Manual | Manual | Autonomous |
| Detection Timing | Reactive | Reactive | Reactive | Predictive (pre-crack) |

Concept of Operations



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Operational Sequence and Data Flow



Interoperability and Operation Constraints

Complementary Tool

- Anomalies flagged by the QuaSAR system require eddy current, visual, or ultrasonic inspection to characterize the defects.
- Maintains the regulatory chain of inspection authority.
- The magnetic heatmap is structured for integration with digital twin platforms and infrastructure, lowering the adoption barrier by fitting into existing workflows.
- Support infrastructure includes a standard GS laptop.

Environmental Challenges

- Vibration and Movement: fiber-coupled optics and LiDAR sensor.
- Temperature: active Peltier TEC.
- Electromagnetic Interference: gradiometric configuration.



Path to Deployment



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Current TRL Conditions

NV Sensor Subsystem: Demonstrated under controlled laboratory conditions with published results confirming the ability to detect magnetic and strain fields at the sensitivity levels claimed.

Drone Platform: OBC, flight controller, navigation cameras, ground station laptop, motors battery charging infrastructure, and other drone hardware are COTS at TRL 9.

Integrated QuaSAR System: Mounting the payload to the carrier is not flight-tested, placing the configuration at TRL 4



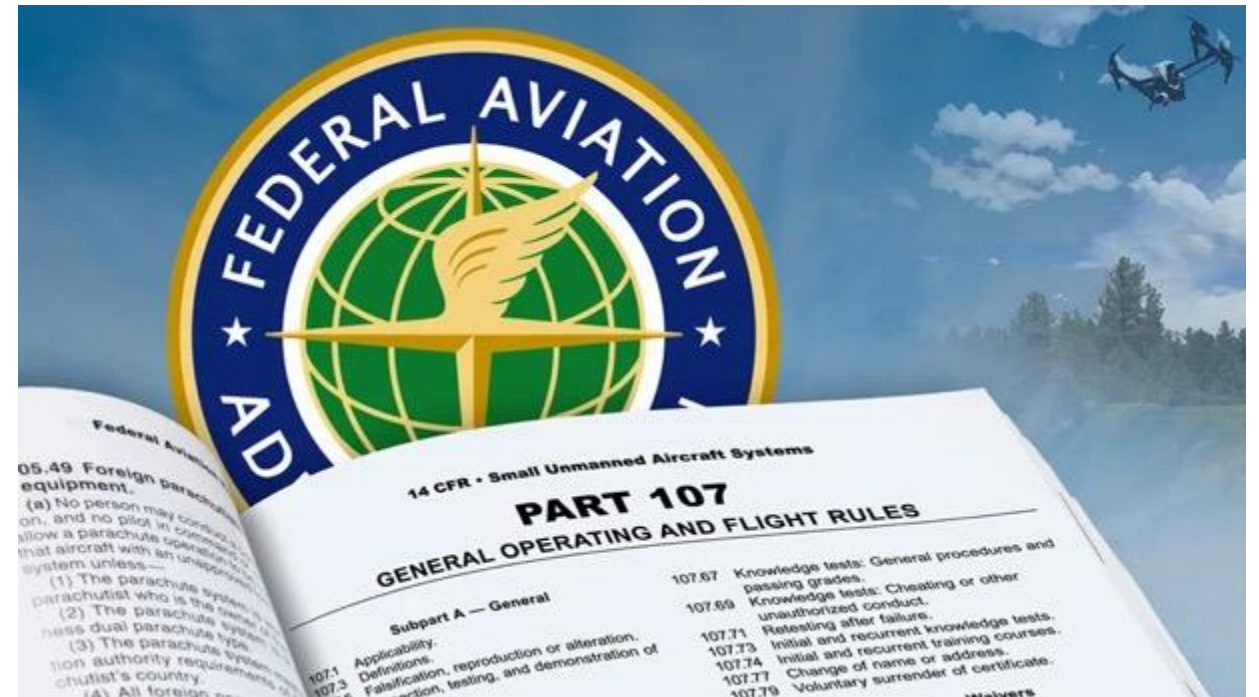
TRL Development Roadmap

| Phase | Timeline | TRL | Key Milestones | Completion Criteria |
|----------------------------|-----------|-------|--|---|
| Integration Testing | 2026–2027 | 4 → 5 | Vibration simulation testing (10–500 Hz, 5g peak) of fiber-coupled optical path; gradiometric noise cancellation algorithm characterization; Peltier temperature control validation (10–40°C ambient cycling) | Optical coupling loss <3 dB under vibration; noise floor <1 nT/√Hz; temperature stability within ±0.5°C |
| Ground Demonstration | 2027–2028 | 5 → 6 | First integrated system scan of 7075-T6 aluminum specimens with manufactured defects of known geometry and fatigue severity; direct comparison against eddy current and ultrasonic findings; MRO industry partner engagement | Quantitative sensitivity benchmark established; minimum detectable anomaly characterized and documented |
| Relevant Environment Demo | 2028–2029 | 6 → 7 | Prototype demonstration on retired aircraft wing inside commercial maintenance hangar; FAA engineering briefing under SAIT or equivalent framework; operator training protocols and safety procedures formalized; GCS software refined with user input | Regulatory dialogue initiated; operator training curriculum validated; no GPS dependency confirmed operationally |
| Operational Prototype | 2029–2031 | 7 → 8 | Refined prototype deployed at MRO facility under FAA-certified inspector supervision; QuaSAR scan data systematically correlated with conventional NDT findings; real-world labor savings quantified; regulatory submission data generated | Detection accuracy validated against certified NDT; statistical performance baseline established for certification submission |
| Certification & Deployment | 2031–2035 | 8 → 9 | FAA certification as supplemental inspection tool; commercial licensing launched 2033 under service-based deployment model; full commercial availability targeted 2035 | FAA approval obtained; first commercial operators contracted; conventional NDT retained as dispositioning authority |



Training Requirements

- Operator certification for the QuaSAR system requires 14 CFR Part 107 licensure for small UAS operations.
- QuaSAR would provide a supplemental module covering NV center operating principles, alignment re-calibration, and payload mounting.
- Supplemental training estimated at approximately 40 hours, a fraction of the multi-year certification path for FAA-authorized NDT inspectors.



Return on Investment (ROI)

Reducing AOG Costs

- Aircraft-on-ground costs for commercial narrow-body aircraft can reach tens of thousands of dollars per hour in lost revenue, crew accommodation, and operational disruption.
- Unscheduled AOG events are the most costly, requiring additional documentation and inspection,
- Predictive capabilities (detecting fatigue accumulation before crack nucleation) allow for targeted interventions during scheduled downtime.

Reducing Labor Costs

- Shifting from 200-400 hours certified NDT technician hours to a single ~45-minute scan, requiring a single operator and several certified inspectors to confirm anomalies.
- The estimated production system cost for a QuaSAR unit, including the drone platform, NV center payload, and GCS software, is projected at \$150,000–\$250,000.
- Given the labor savings per inspection cycle and the AOG avoidance benefit, the system is projected to achieve payback within the first year of operational use at an active MRO facility.



Conclusions and Findings



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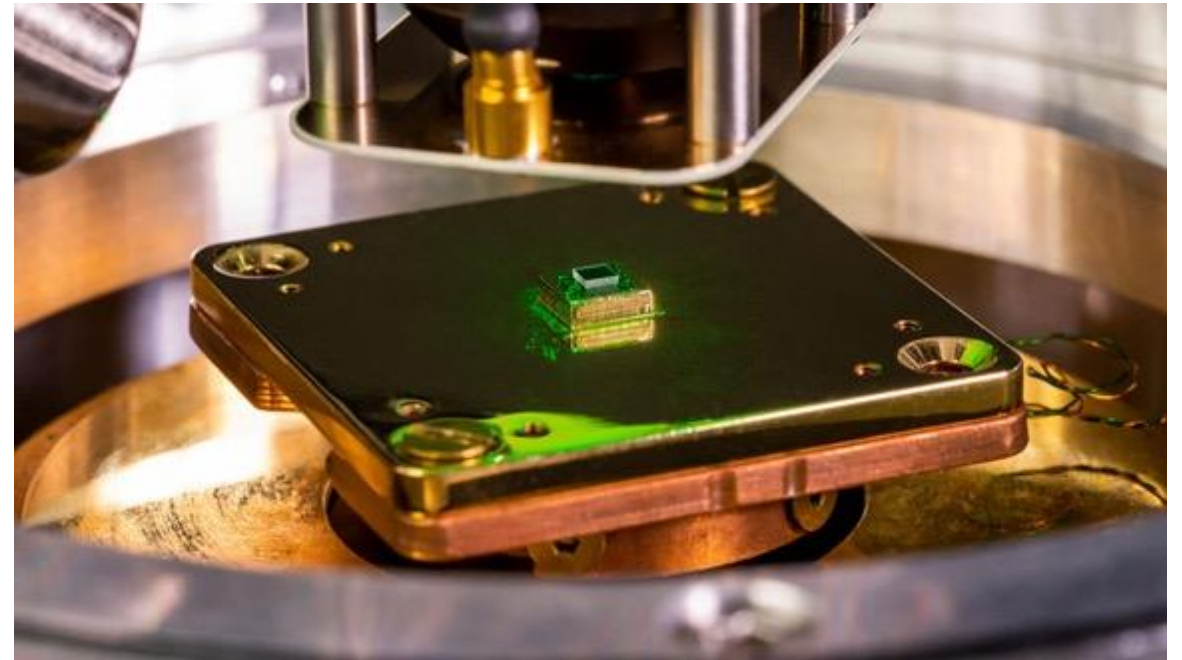
The QuaSAR System

The Future of NDT

- Technically grounded and operationally viable
- NV center, deployed on an autonomous drone platform

Key System Design Characteristics

- Vibration immunity.
- Gradiometric noise cancellation
- GPS-independent navigation enables reliable operation.
- Operational sequence integrates naturally into existing workflows.
- Low training requirement broadens the operating capabilities



Benefits to Adoption

ROI

- AOG avoidance savings and the labor reduction from automated scanning.
- Economic analysis demonstrates a compelling return on investment for airlines and MRO operators.
- Projecting a payback period well within the first year of operational use at an active facility.

Deployment Roadmap

- Advances the TRL 4 configuration to commercial viability by 2035.
- FAA regulatory engagement built into the plan from TRL 6 onward.

Safety

- Identify structural problems before they become failures.
- Advances sensing capability to the atomic level, before crack nucleation.

Technical Feasibility

- Published research confirms NV Sensing capabilities
- Preliminary Design seeks to transform laboratory research into a dynamic aerial platform
- R&D required to create a functional and fully operational prototype



Operation Video



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THANK YOU

Any Questions?

Q&A

