

Air Mobility in the Offshore Environment: Lessons Learned from the Use of Cargo RPA on Oil Rigs in Sergipe Basin, Aracaju

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ABSTRACT

This study presents lessons learned from a proof of concept evaluating the feasibility of using remotely piloted aircraft (RPA) for small cargo transport in offshore oil and gas operations in the Sergipe Basin, Brazil. Conducted by Petrobras in partnership with Speedbird Aero, the proof of concept involved 27 missions across 12 platforms and the Inácio Barbosa Maritime Terminal port, achieving up to 36% reduction in logistical service time and CO₂ emissions. The analysis employed the Bowtie methodology in conjunction with the specific operational risk assessment (SORA) framework to evaluate operational risks. National Aeronautics and Space Administration (NASA) expertise over lessons learned and the Project Management Institute oriented framework for lessons learned were used to identifying critical factors such as environmental monitoring, airspace integration, electromagnetic interference, and contingency coordination with aeromedical flights. Technical insights include the use of portable anemometers, geofencing strategies, and moving baseline global positioning system (GPS) technology to mitigate navigation challenges. Operational recommendations emphasize improved information management, horizontal signage, and periodic team training. Results confirm the technical and economic viability of RPAs in offshore environments and highlight their potential contribution to advanced air mobility ecosystems like the research (safety assurance and integrity level II). These findings support the development of regulatory frameworks and integration protocols, reinforcing RPAs as a safe and scalable solution for logistics scenarios.

Keywords: Bowtie; Lessons learned; O&G Basin; remotely piloted aircraft proof of concept; Specific operational risk assessment; Safety assurance and integrity level.

INTRODUCTION

The global oil and gas industry invests in research, development and continuous improvement of its processes, seeking to reduce costs and increase operational safety. Among the innovative technologies, the use of remotely piloted aircraft (RPA), with a maximum takeoff weight (MTOW) of 25 kg, for transporting cargo in offshore operation, was envisioned. Regarding the challenges for making the services feasible, the following stand out: shared airspace with manned aircraft; regulatory issues, especially the restriction of flights with a maximum limit of 12 nautical miles from the Brazilian coast; and technical and operational aspects, such as energy consumption, communication and control (C2 link), detect and avoid capability, safety logics for various failure and contingency scenarios.

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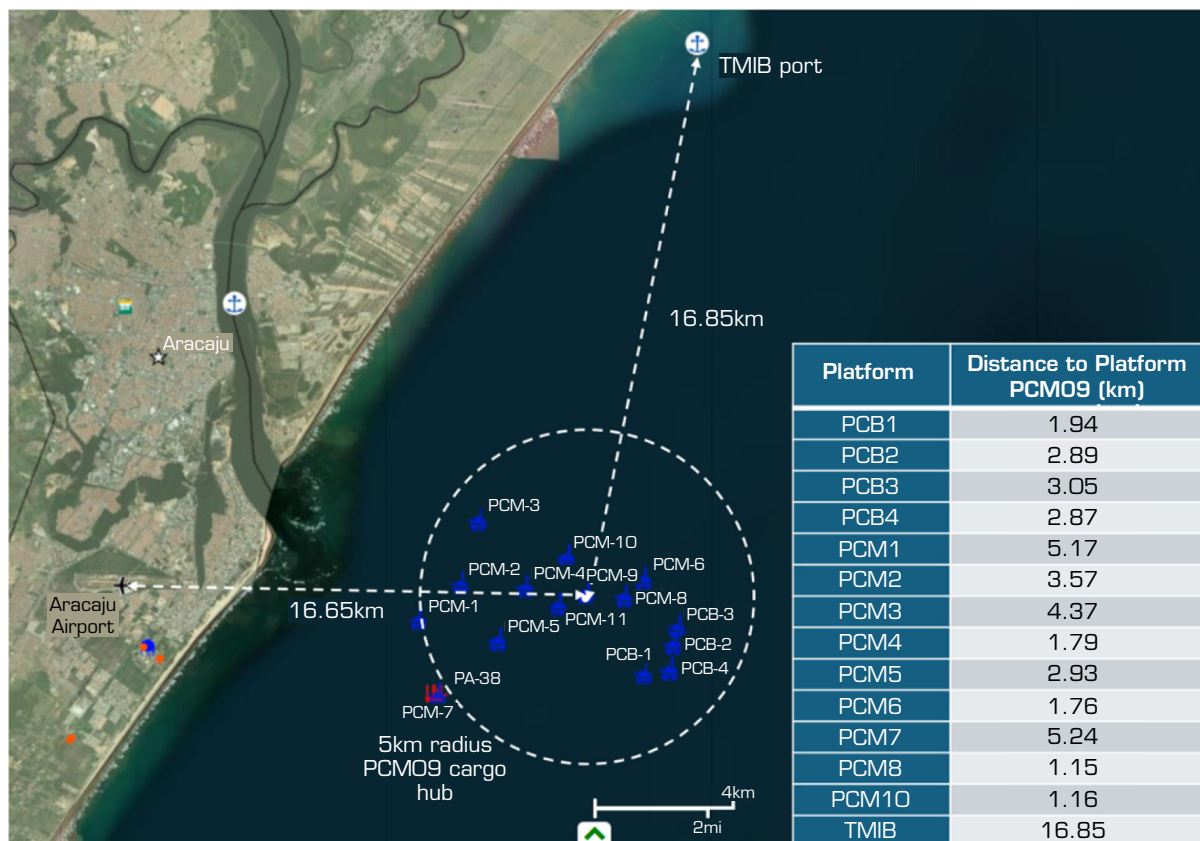
This article is an extended version of one of best papers presented at the XXII SITRAER – Simpósio de Transporte Aéreo.



Considering the challenges listed, Petrobras developed a RPA's offshore cargo transport proof of concept (PoC) in Sergipe, one of the 27 Brazilian states, in the cluster of oil platforms operated by Petrobras, composed of 15 units, where only one of the platforms has a helideck (PCM09). The PoC was conducted in partnership with a Brazilian company specializing in RPA logistics, Speedbird Aero, with the purpose to evaluate the technical and economic feasibility of using RPA in missions beyond the visual line of sight (BVLOS), for the transport of small loads on two predefined routes:

- Between the Camorim oil rig (PCM09) and the Inácio Barbosa Maritime Terminal (TMIB);
- Between PCM09 and 12 other platforms surrounding it.

Figure 1 shows the PoC's region and related distances.



Source: Elaborated by authors.

Figure 1. Cluster and distances of platforms in the Sergipe–Alagoas Basin, Brazil, considered during the proof of concept.

The PoC operation considered 27 flights conducted by the RPA model DVL-2 SN 0004, in 20 consecutive days, from November 29th until December 18th, 2024. During the testing period, average wind speeds of 16 kt were recorded, with some gusts reaching 22 kt, below the RPA wind flight restriction (Speedbird, 2024).

The RPA had three hours and two minutes total flight time. The RPA payload weight varied between 1.5 and 3.5 kg, but the model was able to achieve a MTOW of 25 kg.

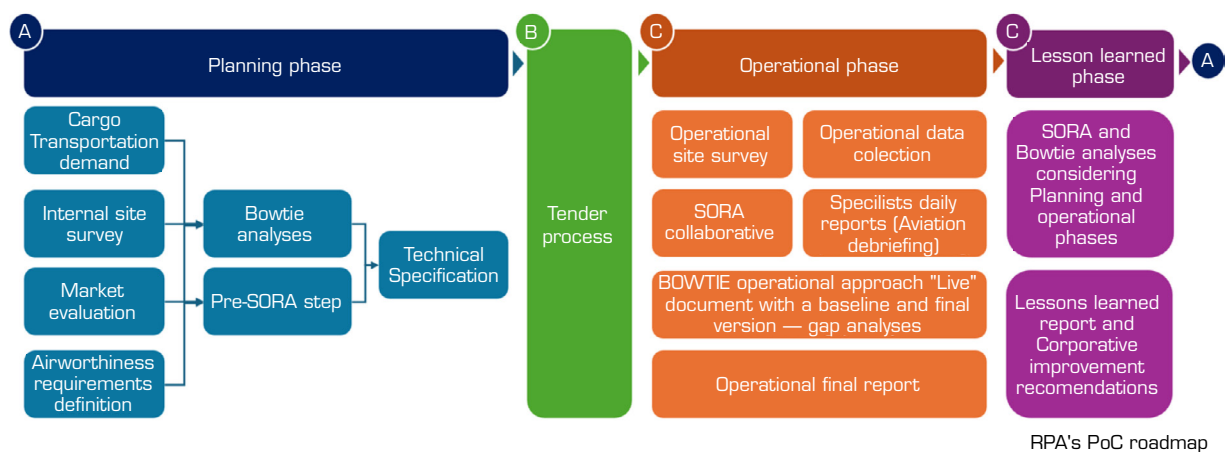
Considering PoC's results, it was possible to evaluate, based on the records, the main lessons learned that should be addressed in greater depth in future studies, to efficiently enable the entry of the technology into the offshore environment in the short term.

Thus, this article presents, through the analysis methodology guided by the Project Management Institute (PMI 2021), the lessons learned after applying the PoC. This article is organized as follows: "Proof of concept applied" presents more about the case; "Literature review" presents an academic review of the applied lessons learned methodology; and "Risk assessment: SORA, Bowtie

methodology and control variables” describes the Bowtie methodology and the details of the control variables. The last two section presents respectively the results and discussion. Then, we conclude the article, thinking about the potential application in future research focused on urban air mobility and remote logistics.

PROOF OF CONCEPT APPLIED

In 2023, Petrobras was monitoring the development of RPA operations in Brazil. Regulations from national authorities—National Civil Aviation Agency (Agência Nacional de Aviação Civil—ANAC) and Department of Airspace Control (Departamento de Controle do Espaço Aéreo—DECEA)—had been developed with rigor and technical competence, but did not address the offshore operational environment, which is characterized by distances between service points exceeding 2 km (BVLOS flights), specific meteoceanographic conditions, and airspace shared with helicopters. To identify the risks associated with this new mode of operation and its technical viability, as well as to conduct economic feasibility studies, Petrobras developed the following roadmap for a PoC regarding the use of RPAs in the oil basin region, as outlined in the introduction, shown in Fig. 2.



SORA: specific operational risk assessment. Source: Elaborated by authors.

Figure 2. Remotely piloted aircraft's proof of concept steps roadmap.

The RPA cargo transport PoC in Sergipe used a certified RPA by Brazilian regulation. The aircraft used had already performed numerous tests and services in Brazil and abroad. Speedbird, in partnership with the delivery company, has carried out operations (with a 5 kg maximum payload) in Aracaju, capital of Sergipe state, reducing the mission distance by 32 km.

The PoC test had four objectives:

- To demonstrate operational capability through an operations command center with the aim of eliminating the need for the RPA pilot to be on the platform;
- To identify possibilities for using an RPA variant with a winch to make deliveries on platforms without a landing area;
- To demonstrate the ability to quickly coordinate to the platform for emergency scenarios involving the operation of the aeromedical aircraft;
- To maintain the quality and safety of cargo transport, especially the transport of meals between platforms.

LITERATURE REVIEW

The remotely piloted aircraft context

Pimenta *et al.* (2022) highlight that the recent COVID-19 pandemic accelerated the adoption of RPAs as a logistics alternative, highlighting their applicability in hard-to-reach environments and their ability to operate minimizing human risk.

Mahmoodi *et al.* (2026) in their research over integrating regulatory risk considerations and comprehensive energy management frameworks highlight faster and cheaper delivery systems introducing fleet composition categories by single/multi-truck with multi-drones.

Asadzadeh *et al.* (2022) highlight six main application areas for the use of RPA in the oil and gas sector: oil spill detection in offshore environments, monitoring of leaks and onshore pipelines, sensing of gas emissions, remote inspection of facilities, geological and topographic mapping, and environmental monitoring. The versatility of RPA, combined with the miniaturization of optical, thermal, hyperspectral, and gas sensors, allows for collecting high-resolution data with greater safety, lower cost, and greater speed, overcoming the limitations of conventional platforms that use satellites and manned aircraft.

Petrobras (2024) explores alternatives for RPA cargo transport, including an aircraft with a 200 kg MTOW on long-distance missions (180 km per leg). The test verified the potential for transporting loads up to 50 kg, collecting data for sharing airspace with other aircraft: defining better routes, altitudes, and ascent and descent procedures. This type of technology also has the potential to reduce greenhouse gas emissions in the transport of light cargo. The test mentioned in this paper was carried out in partnership with DECEA, the national air traffic service provider NAV Brasil, ANAC, and the airlines OMNI Taxi Aéreo (a Brazilian company) and Nordic Unmanned Group (a Norwegian company).

Integrated tests are necessary to determine if the subsystems work together, the interfaces match, and the overall architecture performs as intended (Jones 2021).

Mahmoodi *et al.* (2024) go deeper in this subject when they develop a comprehensive multi-objective optimization model for the RPA delivery system and add the comparison of energy usage rates across different distances, by using Pareto's Front to calculate the amount of emitted CO₂.

Lesson learned review

The PMU (2021), by its PMBOK guide, presents the concept of lessons learned as the knowledge acquired during a project and which can be used to improve future performance. According to Kerzner (2020), in a knowledge management perspective, lessons learned emerge from the practical experience gained in a project execution and, when it is systematically captured and applied, contributes to improving efficiency and effectiveness in future projects.

Boin (2008) reveals important methodological lessons for the Challenger (1986) and Columbia (2003) space shuttle projects, under the management of the National Aeronautics and Space Administration (NASA). The analysis shows that, although NASA have adopted several technical recommendations after the Challenger disaster, it failed to promote profound structural changes in its organizational culture and risk conception, which contributed to the repetition of failures in the Columbia case. The main methodological lesson drawn is the distinction between single-loop learning—punctual corrections without altering fundamental assumptions—and double-loop learning—critical review of organizational paradigms and structures. This article does not address aspects of lessons learned from an organizational improvement perspective, only the technical one.

Single-loop learning refers to correcting errors without questioning the fundamental assumptions that led to the error; in NASA's case, this is translated into:

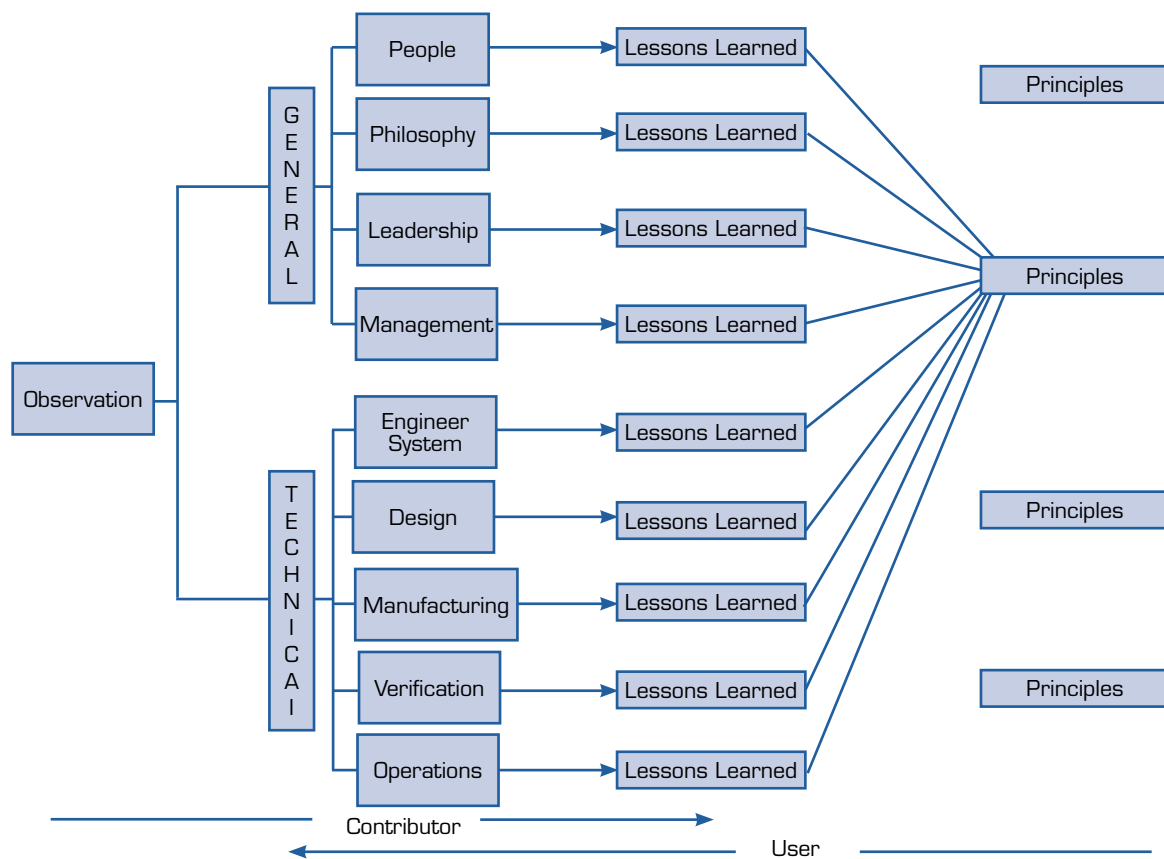
- Technical redesign of defective components (such as the Challenger's O-rings);
- Creation of safety departments and committees;
- Reinforcement of existing procedures.

Double-loop learning transcends technical issues, involving a review of the values, norms, and assumptions that reinforce organizational decisions and practices. According to Boin (2008), in the case of NASA, this would mean:

- Questioning the risk philosophy that prioritizes flight as the primary form of validation;
- Reviewing the decision-making and communication structure between engineers and managers;
- Reshaping the organizational culture that values technical success above prudence.

Therefore, it can be inferred that seeking lessons learned goes far beyond simply recording mistakes, successes, and improvements, as it is a process that allows for knowledge management and continuous improvement.

Blair *et al.* (2011), in their study over lessons learned in engineering, describe the process used for developing and describing the lessons learned starting from a list of several NASA project experiences and problems from which they developed the lessons. Then, they grouped the observations into generic and technical categories, as shown in Fig. 3.



Source: Blair *et al.* (2011).

Figure 3. Lessons learned process.

This study emphasizes the technical categories concerning engineer systems, design, manufacturing, verification, and operations. Engineering refers to the integration and coordination of all subsystems to form a complete and functional system. It includes architecture, interfaces, compatibility, and requirements of management to ensure that the operation occurs according to specifications. Design concerns planning and development of technical solutions, including material selection, sizing, tolerances, and performance analysis. The focus is on turning requirements into a feasible design. Manufacturing deals with the physical production of components and system assembly. It involves manufacturing processes, quality control, standardization, and failure prevention that could compromise reliability. Verification is related to testing the system to ensure it meets the defined requirements. It includes inspections, functional tests, compliance analyses, and procedures to detect failures before operation. Finally, operations consist of the use and maintenance of the system after its delivery. It encompasses operational procedures, performance monitoring, technical support, and strategies to extend its lifespan and reduce risks during operation.

Starting from Fig. 3, Blair *et al.* (2011) present the nine principles, as follows:

- System success depends on the creativity, judgment, and decision-making peoples' skills;
- Space systems are challenging;
- Everything acts as a system;
- The system is governed by the laws of physics;
- Robust design is based on our understanding of sensitivities, uncertainties, and margins;
- Project success is determined by life cycle considerations;
- Testing and verification have an essential role in development;
- Anticipating and surfacing problems must be encouraging;

- Leadership is the foundation.

Principles are general and timeless guidelines and have no sequence to follow.

On the other hand, the PMI (2021) methodology indicates structural steps for the lessons learned process, summarized as:

- Plan when and how the records will be made;
- Data collection with defined responsibilities;
- Analysis by theme;
- Documentation, preferably in a standardized way.

After applying the four steps, the lessons should be shared and incorporated.

The RPA cargo transport PoC in Sergipe does not have the same experimental focus as the tests conducted by NASA, given that the aircraft used had already performed numerous tests and services in Brazil and abroad.

Considering the PoC's four objectives, described in the study case section, based on the steps outlined by PMI (2021), the test objectives represent the themes for future analysis of lessons learned.

Risk analysis

Risk assessment at ICAO Annex 19 (2016) is the process of identifying hazards and evaluating the associated risks in terms of their likelihood and severity to determine their acceptability. Risk analysis refers to the examination of the likelihood and consequences of identified hazards as part of the broader risk assessment process. The PMI (2021) divides the risk analysis into two groups, qualitative and quantitative aspects.

Mahmoodi *et al.* (2024) conducted their research over comprehensive multi-objective optimization model for RPA delivery systems by adding the specific operational risk assessment (SORA) standard into the risk assessment, and the results showed enhancement, liability, and safety of RPA system operations, making the model more practical and applicable in real-world scenarios.

In other research (Millar *et al.* 2023), over integrating unmanned and manned aircraft data network, the input variables defined in the model are obtained via the qualitative Bayesian belief network technique and then weighted using an analytic hierarchy process. Later, the obtained qualitative indexes were classified and detected using the SORA standard. The results indicated that the designed network succeeded in determining the optimal trajectory for the unmanned aerial vehicle(UAV) and detecting the best possible policies by determining the most optimal possible states and actions.

Asghari *et al.* (2025) cataloged the existing reviews on RPA operation safety assessments, to identify:

- Safety assessment approaches;
- Employed methods/techniques;
- Defined and utilized safety metrics;
- Common tools/simulators;
- Stages of safety assessment addressed by each technique in the reviewed studies.

The research provided safety assessment categorization into five groups: model-based, analytical-based, data-driven, experimental-based, and hybrid approaches. Among the 16 methodologies and techniques identified by the authors, the presence of the Bowtie methodology (model-based), with scopes 4, 5 and 6; and the SORA methodology (analytical-based), with scopes 3, 5, and 6, were observed, as shown in Fig. 4. According to the research:

Stage 3: Hazards Identification. This step is sometimes used as a first point and first step of the safety assessment, and it is the most crucial part of the process. Hazard identification can be induced by concepts of operations, such as system-generated risks (hardware, software process, or/and human factors) and external events (e.g., weather conditions and electromagnetic interference, which can impact the system under assessment).

Stage 4: Integrating Hazards into the Risk Framework. In this stage, after identifying the hazards associated with the system under assessment, a comprehensive risk model is constructed to assess the overall risk of the system resulting from proposed modifications.

Stage 5: Risk Evaluation. The result of this stage is the evaluation of the risk model. According to the last stage, there are two risk model types: (1) a risk model created based on logic, and (2) a risk model created based on simulation.

Stage 6: Determining Potential Mitigating Measures. This stage consists of four steps. In the first step, it is determined whether risk mitigation is required and whether safety criteria and TLS are achieved. In the second stage, utilizing techniques like Fault Tree Analysis (FTA), it is possible to identify the primary focus for mitigation. This primary focus represents the foremost source of risk and serves as the optimal target for mitigation measures. The third step is liable to help the developers identify how much the mitigation plans and strategies can reduce the risks. On occasion, it may not be possible to mitigate the main component of the risk, thus necessitating the resolution of subsidiary factors that, when addressed collectively, would result in the desired reduction of risk. Subsequently, the fourth phase involves recalculating the risk after adjusting either the model or the quantitative inputs based on the implemented mitigations, referred to as safety requirements. This recalculation is carried out to ensure that the system meets the necessary safety standards (Asghari *et al.*, 2025, p. 266).

Techniques/Methods		Covered stage							
		1 Scoping the assessment	2 Learning the nominal operations and system modeling	3 Hazards identification	4 Integrating hazards into the risk framework and risk modeling	5 Risk evaluation	6 Determining potential mitigating measures to reduce risk	7 Safety monitoring and verification	8 Learning from safety feedback
1	Failure Mode and Effect Analysis (FMEA)								
2	Fault Tree Analysis (FTA)								
3	Event Tree Analysis (ETA)								
4	Hazard and Operability (HAZOP)								
5	Bow-Tie Analysis								
6	Structured What-IF Technique (SWIFT)								
7	Root Cause Analysis (RCA)								
8	Markov Analysis								
9	Formal Methods								
10	Reason's Model								
11	Multi-Agent Dynamic Risk Model (MA-DRM)								
12	Systems-Theoretic Accident Model and Processes (STAMP)								
13	Hazard Classification and Analysis System (HCAS)								
14	SESAR Safety Reference Material (SRN)								
15	Methodology for the U-space Safety Assessment (MEDUSA)								
16	Specific Operational Risk Assessment (SORA)								

Note: All the technique and methods are used at UAS operations in airspace domain.

Source: Adapted from Asghari *et al.* (2025).

Figure 4. Methods and techniques used for safety and safety risk assessment of remotely piloted aircraft.

Petrobras' aviation processes are established according to corporate standards, in line with international references, especially the best practices from the International Association of Oil and Gas Producers (IOGP). For the scope of the test, Petrobras applied an operational risk analysis, using the Bowtie methodology, that visually represents the pathways from hazards to consequences, including preventive and mitigative barriers. The Bowtie used in the PoC was developed (published in 2019) by Petrobras through a technical committee, drawing on experience from manned operations and input from Brazilian civil aviation authorities and the company's partners in the oil and gas sector.

While a conceptual similarity exists between the barrier-based approach of the Bowtie model and the operational safety objectives (OSOs) within the SORA framework—both structuring risk mitigation through explicit controls—, it is more appropriate to regard them as complementary. The Bowtie model provides a detailed causal representation of risk, linking threats, preventive and mitigative barriers, and potential consequences, thereby supporting a deeper understanding of risk pathways and control effectiveness. In contrast, SORA operates at a higher level, defining safety objectives and compliance requirements to ensure that overall operational risk remains acceptable. When combined, these approaches enhance risk management by integrating detailed causal analysis with a structured, regulatory-oriented framework.

Literature gap analysis

Table 1 summarizes the literature review by presenting scientific contributions and limitations.

Table 1. Literature gap analysis review.

Study	Context	Method	Risk framework	Empirical data	Contribution	Limitations
Boin (2008)	Learning from NASA disasters	Case study	Risk culture perspective	Yes	Introduction of single <i>versus</i> double-loop learning	Focus on NASA's cases
Blair <i>et al.</i> (2011)	Engineering lessons learned process	NASA-based analysis	Not explicit	Yes	Definition of engineering categories	Specific to aerospace
Kerzner (2020)	Knowledge management via lessons learned	Conceptual	Not explicit	No	Link of lessons learned to performance	No empirical evidence
Jones (2021)	Need for integrated system testing	Conceptual/ engineering lessons	Not explicit	No	Highlight of the subsystem integration importance	No empirical study
PMI (2021)	Definition of lessons learned in projects	Framework guideline	Risk process qualitative/ quantitative	No	Standardization of lessons learned process	Generic framework
Asadzadeh <i>et al.</i> (2022)	RPA applications in oil and gas sector	State-of-the-art review	Not explicit	Secondary data	Identification of six application areas	No empirical validation
Pimenta <i>et al.</i> (2022)	RPA adoption during COVID-19 for logistics	Literature analysis	Not explicit	Contextual examples	Highlight of the pandemic-driven adoption	Lacks quantitative analysis
Millar <i>et al.</i> (2023)	UAV network optimization with risk	Hybrid modeling (Bayesian belief network + analytic hierarchy process)	SORA	Model-based	Optimization of trajectory and decisions	Model assumptions
Mahmoodi <i>et al.</i> (2024)	Optimization of RPA logistics and emissions	Multi-objective optimization	SORA integrated	Model-based	CO ₂ reduction and efficiency analysis	Simulation-based
Asghari <i>et al.</i> (2025)	Review of UAV safety assessment methods	Systematic literature review	Bowtie and SORA	Secondary data	Classification of safety assessment methods	No empirical validation
Mahmoodi <i>et al.</i> (2026)	Integration of energy and regulatory risks in logistics	Optimization framework	Risk integrated model	Model-based	Introduction of fleet compositions	Model validation limited

NASA: National Aeronautics and Space Administration; RPA: remotely piloted aircraft; UAV: unmanned aerial vehicle; SORA: specific operational risk assessment. Source: Elaborated by authors.

Millar *et al.* (2023) and Mahmoodi *et al.* (2024) presents the SORA approach within a simulated environment and emphasizes the need for operational application to validate the proposed concepts. Asghari *et al.* (2025) conduct a risk analysis using the SORA and Bowtie methods from a literature review perspective, without empirical validation in real-world conditions. Although these studies are the closest to the present work, the offshore PoC introduced herein incorporates more objective operational elements, yielding results that are better aligned with scenarios in which ground and air risks are comparable.

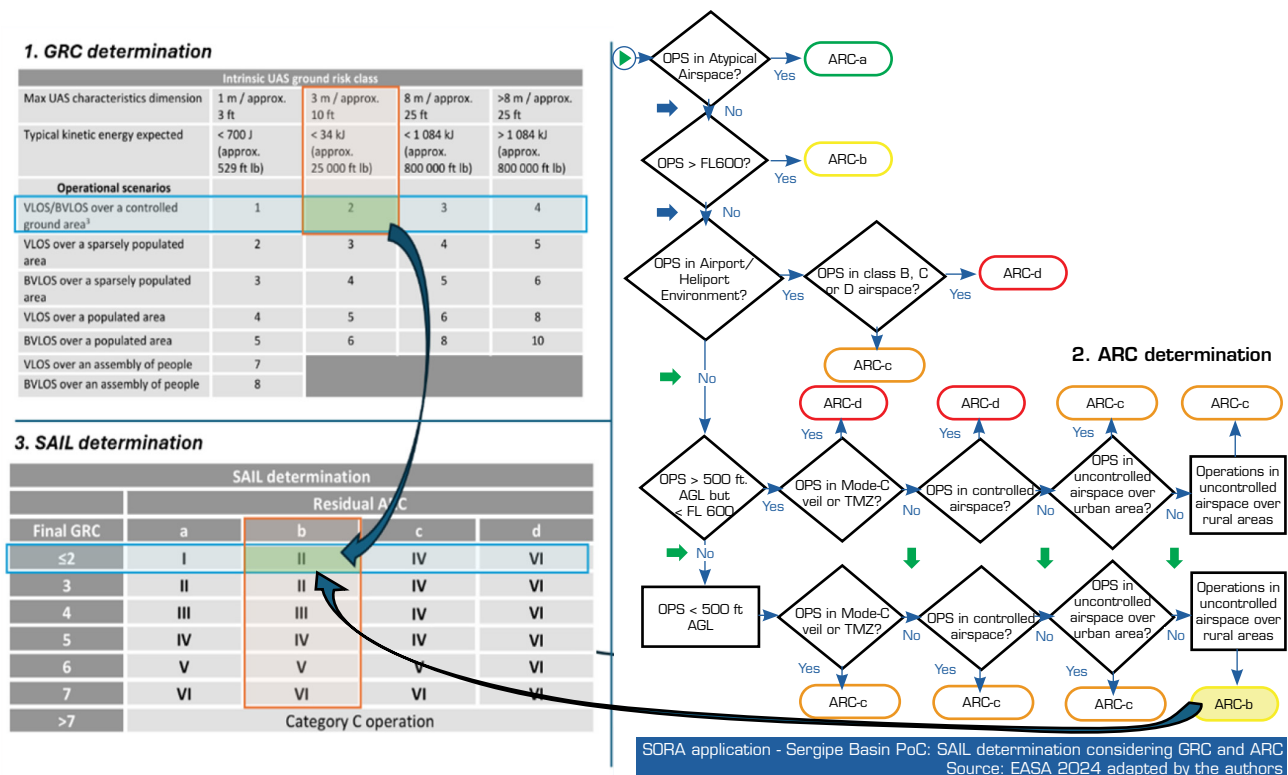
RISK ASSESSMENT: SORA, BOWTIE METHODOLOGY AND CONTROL VARIABLES

This article addresses three risk assessment methodologies: SORA, Bowtie, and other control variables.

Specific operational risk assessment

Applying the SORA methodology (EASA 2024), the ground and air risk classes (GCR and ARC, respectively) were determined. The collaborative study considered aspects of both the aircraft and the site of interest to calculate the GRC, resulting in a level of 4 on a scale of 1 to 10.

Regarding ARC (scale ARC-a to ARC-d), the ARC-b classification was assigned based on mission characteristics: BVLOS flights were below 500 feet in altitude, and operations carried out through the activation of segregated airspace. Based on the combination of GCR and ACR results, the safety assurance and integrity level (SAIL) for the operations was determined to be SAIL II, on a scale ranging from I to VI. Figure 5 presents the SAIL result for the PoC.



Source: Elaborated by authors.

Figure 5. Specific operational risk assessment application: Sergipe Basin, Brazil, proof of concept safety assurance and integrity level determination (SAIL II).

The final step of the SORA process consists of using the SAIL to evaluate the operational mitigations in terms of OSOs and to determine the corresponding level of robustness. The standard set of OSOs comprises four main categories: technical issues related to the RPA, degradation of external systems supporting RPA operations, human errors, and adverse operating conditions.

According to the European Union Aviation Safety Agency (EASA 2024), the OSOs reflect the consolidated experience of subject-matter experts and thus provide a robust foundation for defining safety objectives for a given operation. Competent authorities responsible for issuing operational authorizations may establish additional OSOs for a specific SAIL, along with the corresponding level of robustness.

Bowtie basis

The Bowtie method is considered a graphical evolution of James Reason's (1990) "Swiss cheese" model, integrating causes, barriers, and consequences into a single diagram centered on the main event. Unlike the original model, which represents flawed defenses in layers, the Bowtie methodology allows for a deeper operational and visual analysis of risks. Studies such as Alizadeh and Moshashaei (2015) and UK Civil Aviation Authority (UK CAA 2025) guidelines highlight its practical applicability, especially in aviation, by enabling organizational learning and proactive safety management.

The Petrobras operational risk analysis for the use of RPAs in its facilities was developed to assess the behavior of threats that could trigger a change in the intended trajectory of an aircraft mission. According to the Bowtie methodology, the aspect of normality for the mission is "RPA operation" and its correlated risk is "deviation from the intended trajectory".

The aforementioned risk may occur due to the following eight threats:

- Adverse environmental conditions;
- Unregulated airworthiness;
- Wildlife;
- Operational restrictions of the RPA or airspace;
- Operator qualification not conditioned by a RPA model below 25 kg MTOW;
- Proximity of other aircraft in flight;
- Unlawful interference;
- Human fallibility.

The three consequences correlated with the risk in question are: mid-air collision with a manned aircraft, ground collision with a critical installation, and ground collision with a person.

Among the eight threats, the research did not address aspects related to wildlife, given that the area of operation does not have reports about wildlife issues; operator qualification not conditioned by the RPA model below 25 kg MTOW, given that the contracted company was responsible for the operation with authorization granted by national authorities and security, with a special airworthiness certificate for RPA (CAER). Based on the steps outlined by the PMI (2021), the threats represent the data to be collected and recorded for future analysis of lessons learned.

The Bowtie organizational evaluating and learning at the proof of concept

During PoC planning phase, a risk assessment study was made by a multidisciplinary technical team, composed of engineers, pilots, mechanics, and risk management specialists. The main objective was to develop real missions' scenarios, previous map the threats and identify the control barriers. The Speedbird company's technical team consisted of three professionals, and the technical staff responsible for the operational control center were in Franca, a city in the São Paulo state, Brazil.

The flight schedule was set and, subsequently, a preliminary risk analysis was conducted considering the Petrobras management tool based on the operational risk assessment, in compliance with the regulations of ANAC (2017, 2023) through the Brazilian Civil Aviation Regulation (RBAC) No. 94 and Supplementary Instruction (IS) No. 94-003.

Through the combination of the SORA and Bowtie methodologies, four new barriers (Bowtie) were studied deep-down:

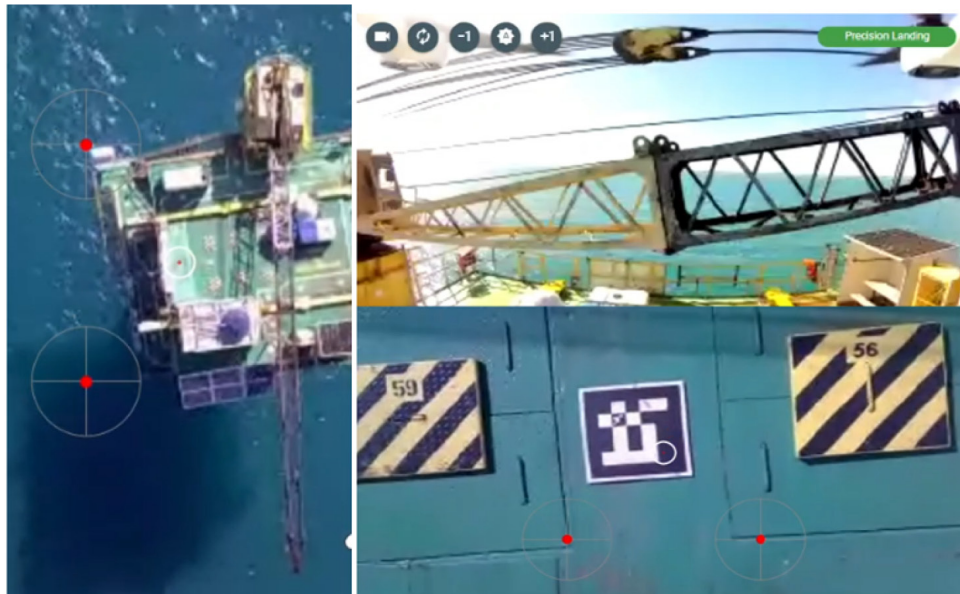
- Loss of airworthiness caused by loss of radio link signal between pilot in command and aircraft (C2 link);
- Loss of airworthiness caused by weather changes;
- Collision with obstacles in helideck's surrounding;
- Inadvertent contact with the RPA.

Risk mitigation was addressed by the following recommendations:

- Meteorological information shall be consulted before each flight and shall consider available applications, aeronautical databases, and a portable anemometer;
- The positioning of the platform crane shall be checked before each flight;
- The infrastructure requirements for landing at each one of the maritime units of interest shall be mapped. The identification will be carried out by aircraft, through photo records, to detect barriers and obstacles;

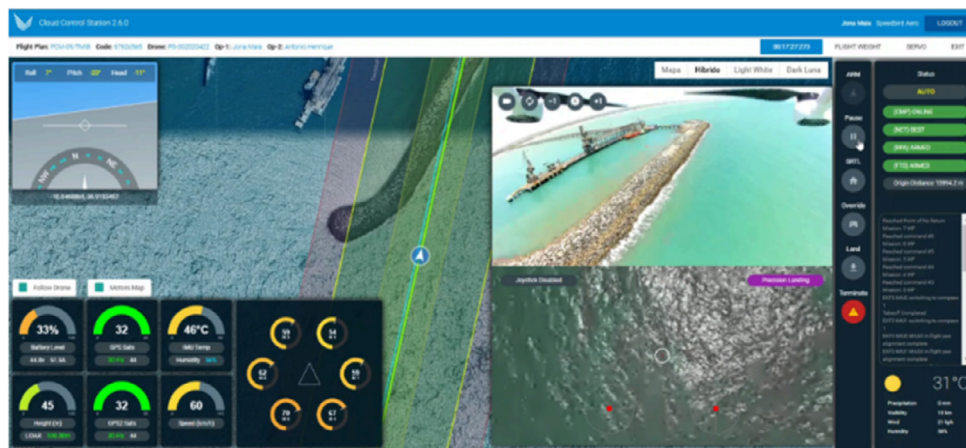
- Precise markings and isolating the landing and take-off area shall be performed;
- Initial briefing for the technical team, platform and TMIB port, previous tests shall be conducted;
- Coordination with the rescue air ambulance helicopter management team shall be conducted.

The second and third recommendations were implemented as shown in Figs. 6 and 7.



Source: adapted from Speedbird (2024).

Figure 6. Screenshot of the pilot in command of the remotely piloted aircraft during the approach phase to PCB-03.



Source: adapted from Speedbird (2024).

Figure 7. Screenshot of the pilot in command of the remotely piloted aircraft during mission PCM09—Inácio Barbosa Maritime Terminal port.

Figure 6 shows the horizontal marking used as a landing positioning guide called ArUco. ArUco is a bidimensional fiducial pattern binary encoded, designed to be quickly located by computer vision systems. The patterns of the ArUco markers are defined by a binary dictionary in OpenCV and the various functions of the library return pattern IDs and frame information from scanned images (Garrido *et al.* 2014).

After completing the analysis, the technical team carried out the planned missions. During the missions, the team from Speedbird, the company responsible for aircraft manufacturing and operations, conducted assessments based on the aircraft manual and recorded meteorological data using portable equipment. These operations took place in uncontrolled airspace (Class G, requiring pilot self-coordination) and involved constant communication with the platform's oil and gas operations teams, as well as other users of local air and maritime transport. Across all 27 missions, a need to improve safety barriers regarding five specific threats was identified:

- Adverse environmental conditions;
- Unregulated airworthiness;
- Operational restrictions of the RPA or airspace;
- Proximity to other aircraft in flight;
- Human fallibility.

Through the steps outlined by PMI (2021), the processes before and during the flight, based on the five selected threats, were recorded and documented. Figure 8 graphically presents all the safety barriers that require improvements.

It was determined that the OSOs presented in the SORA can be understood as the safety barriers used for the Bowtie model in the risk analysis of drone flight operations.

RESULTS AND DISCUSSION

Operational results

Regarding operational results related to cargo transportation between the PCM09 and the surrounding units, through 27 logistics missions, the use of RPA resulted in a reduction of 36% in service time (with a standard deviation of 8.7%) compared to the vessels typically used in the region. For the TMIB port, there was a more significant reduction of 49% in time.

Regarding the environmental aspect, the calculation methodology recommended by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (2004, 2015) for CO₂ emissions used and the introduction of RPA technology into the transport mode enabled a significant reduction in environmental impact. The calculation accounted for the fact that the RPA generates indirect CO₂ emissions, while for the vessel, the calculation was based on marine diesel consumption and the emission factor. For a typical 6 km mission in the PoC region, the following results were obtained (Eqs. 1 and 2):

$$\text{Drone CO}_2 \text{ emissions} = 0.05 \text{ kg/kWh (grid factor)} * 0.6 \text{ kWh} = 0.03 \text{ kg or } 30 \text{ g} \quad (1)$$

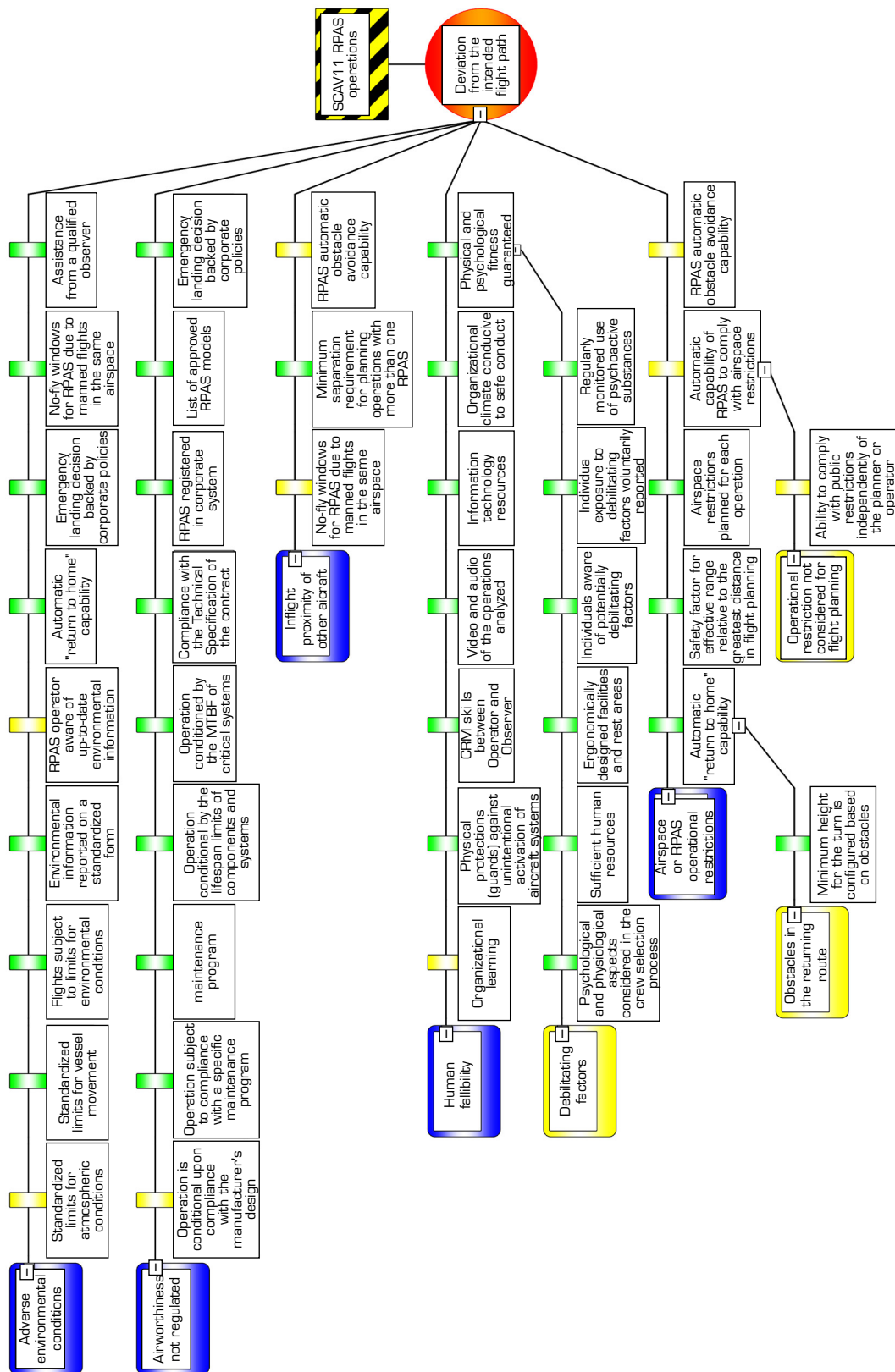
$$\text{Vessel CO}_2 \text{ emissions} = (250 \text{ L/minute} * 0.28 \text{ minutes}) * 2.68 \text{ kg/L (marine diesel conversion factor)} = 189.7 \text{ kg} \quad (2)$$

Risk assessment results

Considering the principles presented by NASA, the study results were grouped according to the principles of systems engineering, design, manufacturing, and operations.

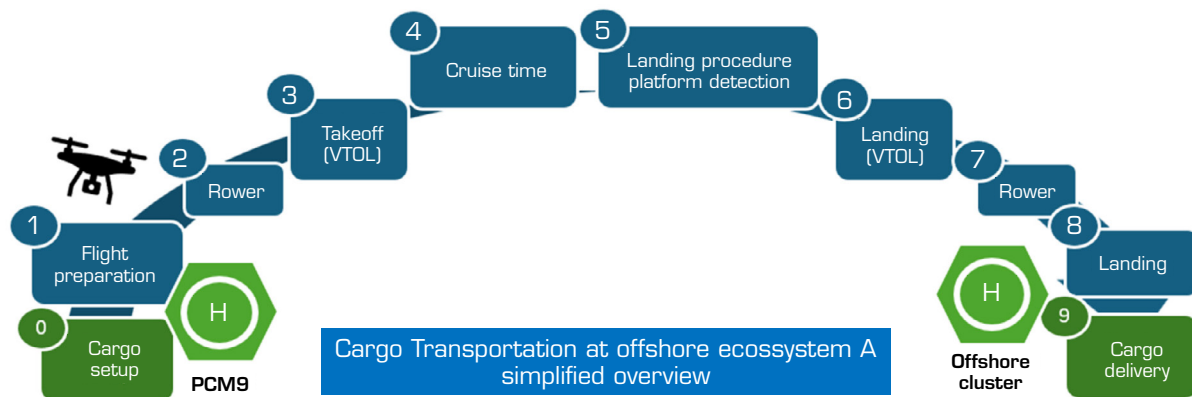
The verification principle was not analyzed, since it applies to a phase of aircraft development when aspects of airworthiness and reliability that support operations are verified, as well as validation of software logic, to prove that the system meets the requirements under real uncertainties and interactions. The object of the test was a broader evaluation, referring to improvements needed for the RPA air transport ecosystem.

Operational observations were conducted by analyzing the difference between planned and actual flight times for each flight segment, as well as for the stages involving cargo handling, preparation, and unloading, as shown in Fig. 9. This analysis was performed by the aircraft's onboard computer and monitored remotely from the central control center, with points of interest recorded daily by the PoC team.



Source: Adapted from a Petrobras' internal report (restricted-access document), with permission [2025].

Figure 8. Bowtie risk analysis performed after the completion of operational missions.



Source: Elaborated by authors.

Figure 9. Cargo operations flight phases.

The lessons learned are detailed below.

Use of a portable anemometer to measure wind speed instantaneously

Although Brazilian oil rigs equipped with helipads need to be provided by an anemometer sensor, only the PCM09 platform had this information available. Therefore, the barriers “Environmental information reported on a standardized form” and “RPA system operator aware of updated environmental information” were not initially met.

Considering that the RPA is more sensitive to changes in wind measurements, it was possible to record takeoffs with constant winds of 16 kt and above 22 kt of wind gusts, without any damage or loss of position and direction. As a mitigating measure to the process, operation on some platforms were carried out with the aid of a portable anemometer to measure the wind instantaneously. In other operations, the approach procedure for landing at reduced speed was adopted, by monitoring the local wind conditions, but with the “return to home” device parameterized, to mitigate any changes that could compromise the operation. Due to local weather conditions, the landing maneuver was not performed.

A portable anemometer provides an immediate and localized assessment of wind conditions, reducing reliance on static forecasts and enabling operators to validate operational limits before takeoff. As mentioned before, this approach aligns with SORA, which prioritizes environmental awareness for operational feasibility.

Register meteorological and oceanographic information in a more robust application or decision support tool

It is necessary to implement a procedure to be adopted through two-way contact between the pilot-in-command's location and the destination platforms, with intervals of 30 and 5 minutes prior to take-off, aiming to increase the pilot's situational awareness.

In the future, it is recommended that meteorological and oceanographic information be registered in a more robust application or decision support tool, given that meteorology plays a crucial role in offshore operations, as it directly influences the safety, efficiency, and economy of these activities. Adverse weather conditions, such as strong winds, high waves, and storms, can cause delays, interruptions, and even accidents on offshore Brazilian oil rigs and vessels.

Wanner *et al.* (2024) showed that integration of automation and immersive virtual reality displays has significantly enhanced UAV remote-control performance, improving accuracy and situational awareness in complex environments. NASA's applications of virtual reality for three-dimensional tasks demonstrate their value in emergency response and precision operations. These technologies strengthen decision-support systems by enabling operators to interpret environmental data effectively, thereby increasing safety and reliability in offshore missions, reducing pilot's workload.

On-site survey procedure before mobilization

It was found that it is important to implement a site survey before mobilization to ensure that the landing/takeoff site is safe to initiate operations.

The topic is better explored by the National Civil Aviation Agency of Canada (Transport Canada 2024), in Appendix G of the Remotely Piloted Aircraft Systems Operational Risk Assessment document (Guidance on Population Density and Site Surveys), and is carried out in stages:

- Virtual site survey aims to preliminarily assess population density using high-resolution census data and geospatial tools, ensuring compliance with operational criteria before in-person validation;
- “On-site survey” to confirm operational feasibility and validate population density criteria, ensuring that there are no built-up areas or points of population concentration not identified in census data.

Considering that oil rigs have a very particular infrastructure, given that the ultimate goal is to maximize the initial treatment of petroleum in the smallest possible physical space, the platforms have a high occupancy of physical space, with “land use” involving a large movement of people for the operation and maintenance of equipment. This characteristic presents a concept like the Canadian guideline presented earlier.

Determine a no-fly zone to be parameterized in the aircraft's navigation system

It was found that, unlike land-based aerodromes (airports and onshore heliports), Brazilian oil rigs are not registered on the georeferenced platforms used by RPA manufacturers, such as the registration database used by the manufacturer SZ DJI Technology Co. This platform only authorizes flights in the protection zone of land-based aerodromes after preliminary coordination and parameterization in the RPA's air navigation system. Considering that the platforms included in the scope are fixed, the parties envisioned the possibility of determining a no-fly zone to be parameterized in the aircraft's navigation system.

Defining and parameterizing no-fly zones within RPAS navigation systems is a critical measure to ensure operational safety in offshore environments. Unlike land-based aerodromes, helidecks on oil platforms are not typically included in georeferenced databases used by drone manufacturers, creating gaps in automated airspace protection. Incorporating these fixed offshore structures into RPA system flight control software mitigates risks of unauthorized entry and harmonizes operations with national airspace regulations. This approach reflects NASA's principle of design by converting environmental and regulatory uncertainties into deterministic constraints, enabling predictable and verifiable mission planning.

Konert and Kasprzyk (2020) explain that international regulatory trends reinforce this need. The Polish BVLOS framework and forthcoming European Union rules emphasize geofencing and dynamic airspace management through unmanned traffic management (UTM) systems and Notice to Air Mission (NOTAM) integration. These mechanisms aim to prevent conflicts between unmanned and manned aviation, particularly in uncontrolled airspace below 150 m above ground level. By adopting similar strategies, such as automated geofence enforcement and coordination with aeronautical authorities, offshore RPA system operations can align with global best practices, reduce collision risks, and support scalable integration into shared airspace.

Establish formal management, through procedures, among the actors in the process: information management

The opportunity to parameterize, initially manually, the information of Petrobras' industrial areas in the RPA management software was identified to establish the necessary restrictions for harmonizing the use of airspace, in compliance with DECEA's regulations. Regarding this topic, it was also identified that there is a need to improve information integration among stakeholders, as the organization responsible for airspace management (NAV Brasil) and the Aracaju International Airport (INFRAERO) lacked awareness of the technical details contained in the NOTAM on the eve of the test campaign.

Improve operational coordination with the management team regarding helicopter medical rescue

The “RPA interdiction window due to manned flights in the same airspace” barrier occurred during the test in which there was an activation of aeromedical transport by helicopter. The RPA operations team was informed through the platform. Considering that the project premise, according to NOTAM, established that the RPA mission would be carried out in segregated airspace without any other manned aircraft operations, the need for improvement in operational coordination with the management team for patient rescue activities by helicopter was verified. It was found that collaboration between different players, such as Aracaju Aerodrome Operator (INFRAERO Company) and the airline, and integration with air traffic control are fundamental points to ensure the safety and fluidity of operations.

The takeoff activation event was identified by the technical team on the platform, who assessed the best point for the RPA to proceed landing. Due to the proximity of the PCM09 platform, the landing was carried out, and the support infrastructure for operations was removed: starlink data link antennas and the ArUco system.



Provide horizontal signage and segregate remotely piloted aircraft operations from platform operations

Concerning the RPA's "automatic ability to avoid obstacles," although the RPA has this functionality available, it was found that the operational context used in the test presents distinct obstacles compared to the urban environment, especially the number of metallic infrastructure and equipment. This characteristic is a technological barrier, sometimes affecting the readings of the proximity sensors, requiring visual observation by the remotely-pilots to identify and avoid obstacles. This condition was carefully observed by the team and may limit the performance of flights during the night, given the reduced visual perception of the pilots.

Although operations with light RPA (MTOW below 25 kg) have occurred at Petrobras since authorizations were granted by the aeronautical authorities—DECEA and ANAC—, it has been observed that the workforce using the RPAs does not identify them as aircraft, especially regarding the legal implications in case of incidents or accidents. This fact is evidenced by the need for horizontal markings for RPA operations, aiming to segregate platform operations from RPA operations.

Considering that industrial operational areas will continue to be populated by professionals with little or no aviation knowledge, such as lack of knowledge of horizontal markings, the use of horizontal markings in the aircraft landing/takeoff area is recommended. This marking must be compatible with the aircraft landing safety zone and/or any degradation of navigation systems to allow the safe continuation of operations. The proposal is to create target-type "RPA safety landing zones" on the platform (green, yellow, and red) to delimit the RPA operating areas and increase safety. The measure has the potential to ensure that the area around the RPA is free of obstacles and that everyone involved in the operation is aware of the risk areas.

Introducing a routine of periodic training for platform professionals

During the test, informal interviews were conducted with the workforce, revealing the need for regular training platform professionals to raise awareness of aviation culture. Employee turnover on the platforms is a critical factor. Structuring and implementing continuous training so that platform personnel are always familiar with aircraft operation will help minimize errors and ensure greater efficiency and safety in deliveries. The platform operations environment shares similarities with aviation doctrine, especially in conducting operational briefings and using checklists to guide the operational roadmap.

Utilize moving baseline technology for magnetic issues

Additionally, as an opportunity for improvement, considering the aspects of navigation and electromagnetic interference, a barrier was identified along with the threat of unregulated airworthiness—operation conditioned by the offshore operational environment. During the operational tests of the RPA system below 25 kg model DLV-2, the influence of magnetic interference resulting from proximity to large metallic structures and high-power electrical elements, such as the cranes on platforms, was observed. Although the test area is free of other sources of interference, the presence of a concentrated metallic mass was identified as a determining factor for distortion in the compasses.

The number of readings from the DLV-2 magnetometers varied according to the position of the crane, especially when it was in active operation. Although it is not possible to state that this magnetic interference is the only factor responsible for these changes, the analysis indicated that its proximity may have impacted the sensors. However, no impacts were observed on global positioning system (GPS) modules. Given this scenario, it was proposed to implement a software parameterization that defines safe flight zones, to ensure that the aircraft avoids risk areas, which ensures greater stability and precision during operations. Furthermore, the use of moving baseline technology, known as GPS-for-YAW, was also proposed for operations that include flights near platforms.

In addition to greater adverse environments, the use of GPS-for-YAW brings direct benefits to operational safety and system autonomy. By eliminating the need for frequent compass calibrations and reducing the aircraft's stabilization time after takeoff, the system contributes to smoother operations, reduces the remote pilot's workload, and increases the predictability of RPA behavior in critical missions. Another relevant point is that the implementation of this technology can be done without physical modifications to the aircraft, since the DLV-2 models already have compatible hardware. This favors the agility in submitting changes to the project to the regulatory authority, making its adoption practical and feasible in the short term for offshore operational scenarios.

Consider more recent versions of DLV-2 for regular operations

Another relevant operational learning was that the latest versions of the DLV-2 were designed with a folding arm system, representing a significant advancement in terms of logistical and operational practicality. Unlike the variant used during the PoC, which required manual disassembly of the arms for transport, the new design allows the aircraft to be prepared for transport or

storage in seconds, without the need of tools or disassembly of structural components. This feature drastically reduces mission preparation time, simplifies maintenance procedures, and minimizes the risk of damage from incorrect assembly.

Furthermore, the compact dimensions of the DLV-2 with its arms retracted (approximately 805 mm in diameter and less than 670 mm in height) allow the aircraft to be stored in smaller volumes, optimizing the use of space in containers, vessels, or land vehicles. This is especially relevant for offshore operations, in which the space available on platforms is limited. The modularity maintained between variants also ensures compatibility with existing systems (winch, sensors, and payloads), making the new version even more attractive for routine operations, both in onboard environments and on land bases.

On December 3rd, 2024, while the Speedbird team was preparing between DLV-2 flights at PCM09, it was announced on the platform's sound system that the air ambulance was being activated. In 3 minutes and 40 seconds, all the equipment related to the RPA operation had already been removed, and the PCM09's helideck was clear to receive the helicopter in rescue and emergency.

Consolidated overview

Table 2 presents the description of the themes for data collection as input data based on the objectives of the PoC. The data collected was produced from the risks analyzed with the support of the Bowtie methodology. After the execution of the PoC test, it was possible to obtain 10 points of improvement, that will be the subject of feedback and further development in future studies.

Table 2. Lessons learned based on the proof of concept's primary objectives.

PoC primary objectives	Threats analyzed	Lesson learned	Lessons learned process principles: technical observations (Blair <i>et al.</i> 2011)			
			Engineering systems	Design	Manufacturing	Operations
Topics	Data collection					
Demonstrate operational capability through a remote operation command center	Adverse environmental conditions	Use of a portable anemometer to measure wind speed instantaneously (4.1)				X
Identify potential uses for a variant of the RPA with a winch	Unregulated airworthiness	Register meteorological and oceanographic information in a more robust application or decision support tool (4.2)	X			X
Demonstrate the ability to quickly coordinate with the platform for emergency scenarios	Operational restrictions of the RPA or airspace	Site survey procedure before mobilization (4.3)				X
Maintaining quality and safety in cargo transportation	Proximity to other aircraft in flight	Determine a no-fly zone to be parameterized in the aircraft navigation system (4.4)	X			X
	Human fallibility	Establish formal management, through procedures, among the actors in the process: information management (4.5)				X
		Improve operational coordination with the management team regarding helicopter medical rescue (4.6)				X
		Provide horizontal signage and segregate RPA operations from rigs operations (4.7)				X
		Introduce a routine of periodic training for platform professionals (4.8)				X
		Utilize moving baseline technology for magnetic issues (4.9)	X		X	
		Consider more recent versions of DLV-2 for regular operations (4.10)		X		

PoC: proof of concept; RPA: remotely piloted aircraft. Source: Elaborated by authors.

The results presented in Table 2 demonstrate the adherence of the technology employed to the service intended by Petrobras, which indicates a high degree of technological maturity.

Regarding the three aspects of systems engineering, design, and manufacturing, it was verified with the manufacturer (Speedbird) that the improvements are technically feasible, requiring design changes, more specifically in software, for subsequent coordination with ANAC.

The implementation of the improvements was estimated to take one year, with a target completion by the end of 2026. The eight operational items will be addressed through:

- Elaborate checklists that describe the internal processes at PETROBRAS;
- Share the study with the scientific community and regulatory agencies, materialized through official communications and workshops, aiming at disseminating operational technical knowledge;
- Establish an operational agreement letter for the circulation of RPA system in interest.

The last item is in accordance with regulations related to traffic management—DECEA (2023, 2025) and Transport Canada (2024). Therefore, the improvements and operational mitigations would be known by aviation community.

CONCLUSION

The PoC demonstrated that RPAs can significantly enhance offshore logistics by reducing service times, improving operational flexibility, and minimizing human exposure to risk. The observed time reductions—36% for inter-platform missions and 49% for port deliveries—validate the efficiency gains achievable through unmanned aerial systems in constrained environments. Beyond performance metrics, the study revealed critical operational and regulatory challenges that must be addressed to enable large-scale adoption.

From a technical perspective, environmental variability emerged as a key risk factor, reinforcing the need for real-time wind monitoring through portable anemometers and integration of meteorological data into decision-support systems. Navigation strength was improved by adopting moving baseline GPS technology and proposing geofencing for fixed offshore structures, aligning with international best practices and NASA's principles of system reliability and risk mitigation. These measures reduce uncertainties and enhance predictability in BVLOS operations.

These operational learnings transcend the offshore environment, which is relevant to the ongoing discussion about the feasibility of using RPAs in urban contexts and smart cities. From a risk management perspective, the risk assessment methodology, combining SORA and Bowtie, has proven effective in mapping risks and promoting technical learning. When combined, these approaches enhance risk management by integrating detailed causal analysis with a structured, regulatory-oriented framework, being a strategic tool to support the safe and efficient expansion of urban air mobility. From an operational perspective, the improvements identified through lessons learned such as the need for horizontal markings, continuous workforce training, and integration with air traffic control systems are equally applicable in dense urban environments.

Considering the unprecedented scope of the study, the results showed the robustness of the Bowtie risk analysis with SORA for RPA operations in the oil and gas environment, and that the identified points of attention are of low complexity, given there are few improvements regarding RPA airworthiness requirements, but rather for improvements in processes and procedures in the operations of the airline and the platforms.

Additionally, operational lessons emphasize the importance of structured coordination among stakeholders, including aeromedical teams and air traffic authorities, to ensure safe airspace sharing. Recommendations include formalized information flows, horizontal markings for landing zones, and continuous training for platform personnel to foster aviation culture.

Future work should focus on integrating RPAs into UTM systems, refining contingency protocols, and advancing aircraft design for modularity and rapid deployment. These improvements will consolidate RPAs as a strategic component of offshore logistics and urban air mobility, contributing to safer, more sustainable, and resilient operations in the oil and gas sector.

Finally, the results obtained not only validate the use of RPA in remote logistics operations but also offer concrete support for its application in future projects focused on urban air mobility, contributing to the advancement of smart cities and remote logistics.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable.

AUTHORS' CONTRIBUTION

Conceptualization: Hermeto TS, Soares PT, Sampaio BS, Souza FP, Silva BM, Coelho Neto MR and Tanure MH; **Formal Analysis:** Hermeto TS, Soares PT, Sampaio BS, Souza FP, Silva BM, Coelho Neto MR, Tanure MH, Rebouças LC, Santos CEAP, Maia JS, Dias VMR; **Investigation:** Hermeto TS, Soares PT, Sampaio BS, Souza FP, Silva BM, Coelho Neto MR, Tanure MH, Rebouças LC, Santos CEAP, Maia JS, Dias VMR; **Resources:** Hermeto TS, Souza FP and Coelho Neto MR; **Supervision:** Hermeto TS, Soares PT, Coelho Neto MR, Tanure MH, Rebouças LC and Santos CEAP. **Validation:** Hermeto TS, Soares PT, Sampaio BS, Souza FP, Silva BM, Torres RR, Coelho Neto MR, Tanure MH, Rebouças LC, Santos CEAP, Maia JS, Dias VMR; **Data curation:** Hermeto TS, Soares PT, Sampaio BS, Coelho Neto MR and Tanure MH; **Writing – original draft:** Hermeto TS, Soares PT, Sampaio BS, Souza FP, Torres RR, Coelho Neto MR and Tanure MH; **Writing – review and editing:** Hermeto TS, Soares PT, Torres RR and Coelho Neto MR; **Final approval:** Hermeto TS, Soares PT and Torres RR.

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DECLARATION OF USE OF ARTIFICIAL INTELLIGENCE TOOLS

In the preparation of this manuscript, artificial intelligence (AI) tools were utilized to support language refinement. Gemini (Google) was employed for translation and images improvements; and Copilot (Typeset) was used for grammatical correction and proofreading. No AI tool was involved in the conceptualization, methodology, data analysis, or interpretation of results.

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