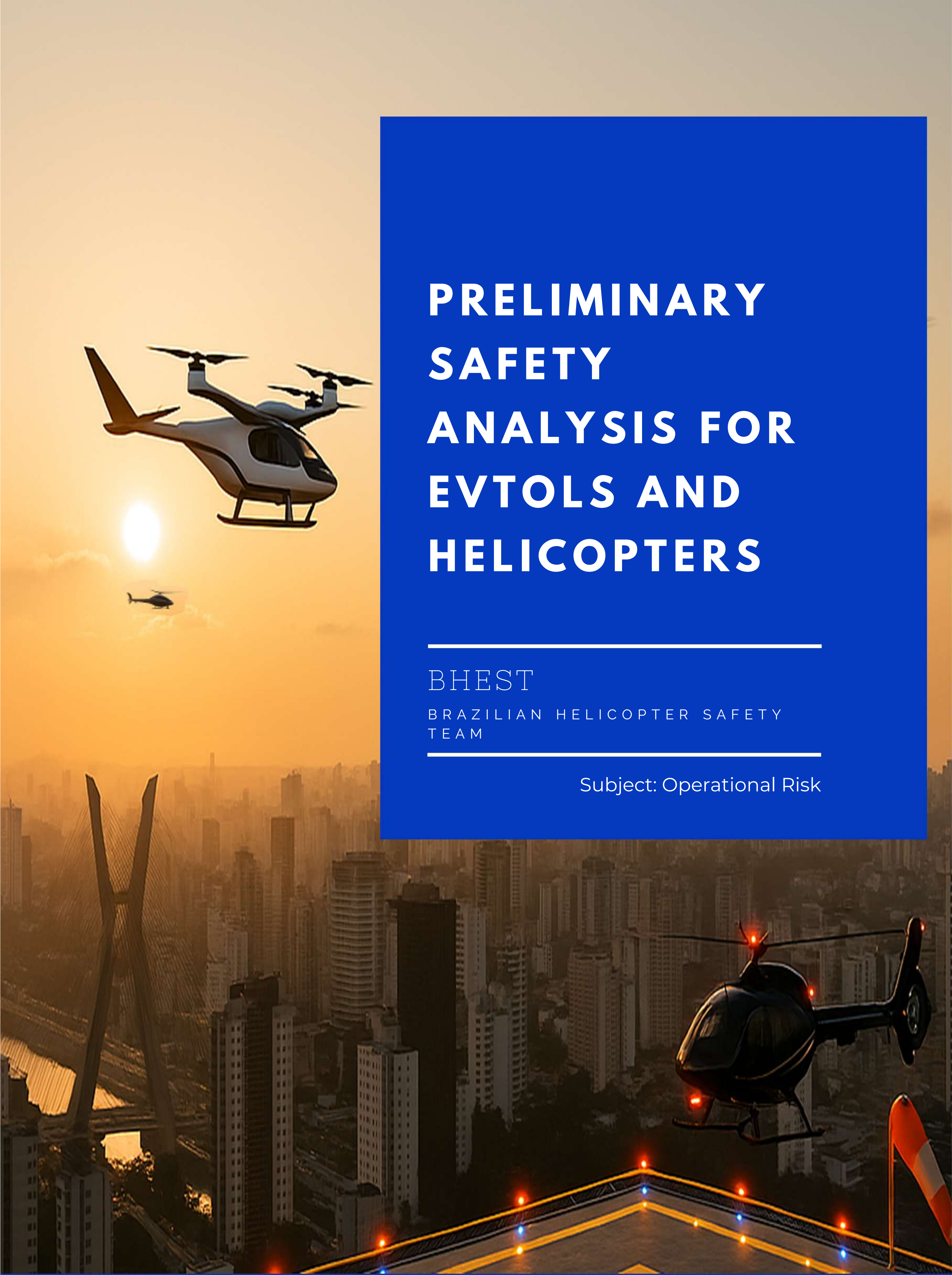

# PRELIMINARY SAFETY ANALYSIS FOR EVTOLS AND HELICOPTERS

BHEST

BRAZILIAN HELICOPTER SAFETY TEAM

Subject: Operational Risk

PUBLISHED IN AUGUST/2025

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SUMMARY

# ABOUT US

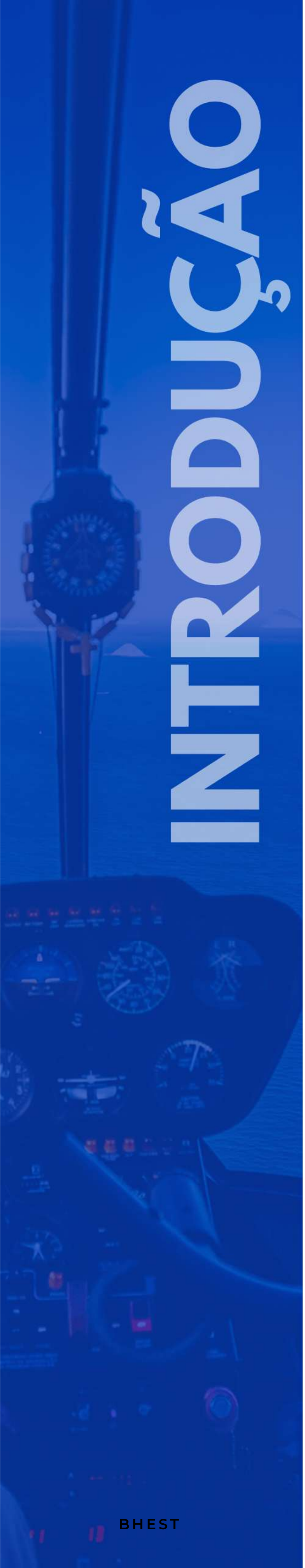
BHEST
Brazilian Helicopter Safety Team

The Brazilian Helicopter Safety Team - BHEST is a committee composed of representatives from civil aviation service providers and other entities with the capacity to propose and promote improvements in safety of activities involving helicopters. It includes professionals dedicated to enhancing the safety of Brazilian civil aviation.

As detailed in the Working Group Members, professionals from the industry and other organizations and companies linked to the sector actively participated in the group, by invitation of BHEST.

# OUR GOAL

**To provide regulators and the industry with an assessment of hazards and risks associated with helicopter and eVTOL operations, with the goal of contributing to new regulations and Safety Management.**



# INTRODUÇÃO

eVTOLs are electric vertical takeoff and landing aircraft that, in Brazil, will be certified under RBAC 21.17(b). These aircraft will mostly transport passengers over short distances, characterizing Urban Air Mobility (UAM), with an average range of 100 km (62 mi), and Regional Air Mobility (RAM), with a range of 300 km (186 mi).
The introduction of these new elements in aviation comes with different aircraft configurations and the use of lithium-ion batteries in their initial phase, requiring appropriate infrastructure for flight operations, passenger processing, battery charging, and emergency response specific to this type of electric aircraft.

The entry into service of these aircraft will result in significant changes to airspace control structures, new rules for infrastructure development and operations, and will generate new operational risks. It has prompted the need for the study to identify potential hazards and risks associated with eVTOL operations, thereby contributing to the enhancement of safety related to this new mode of air transportation.

As a document intended to explore safety threats for helicopter and eVTOL operations — and to provide recommendations to stakeholders across the three main areas (aircraft / airspace / infrastructure) — the topic is presented here for context. However, it is not intended to comprehensively explore the specific characteristics of these new vehicles, as the target audience is presumed to have prior knowledge of the subject, and these aircraft are still undergoing development and certification. Further details can be found in the reference documents listed in the final section (References, page 13).

# Helicopter Operations

Helicopter operations landscape

Helicopter operations exhibit higher accident rates per flight hour when compared to fixed-wing aircraft, primarily due to the nature of the missions conducted: short-duration flights that frequently involve the most critical phases of flight — vertical takeoffs and landings in proximity to obstacles and within densely populated areas. The inherent operational profile of helicopters typically results in shorter flight durations, as opposed to fixed-wing operations, which generally involve longer and more stable cruise segments. Given this distinction, it is essential to emphasize that, despite the relatively short duration of helicopter flights, continuous vigilance and a proactive safety culture remain imperative to support the ongoing enhancement of accident prevention within the rotary-wing aviation sector.

**Type of Helicopter Operation:**

**- Short missions**

**- Close to obstacles**

**- Densely populated areas**

There are numerous aspects inherent to the design and operation of helicopters that make this a new and significant challenge. From an aerodynamic standpoint, a helicopter begins its flight while still on the ground, as the rotor blades are already spinning at full speed, creating the potential for collisions with objects or personnel. The design itself presents substantial challenges due to the nature of the aircraft, which involves a high number of moving parts, significant vibration, excessive noise, and a consistently demanding power-to-weight ratio. Engineers are constantly striving to utilize lighter and stronger materials capable of withstanding greater and repetitive loads, making component and crew fatigue a constant and critical concern.

From an operational perspective, Igor Ivanovich Sikorsky — a pioneer in the invention and commercialization of helicopters — once said: "If you are in danger anywhere in the world, an airplane can fly over and drop flowers, but a helicopter can land and save your life." This unique capability justifies the continued relevance of helicopters and supports a large global market for this type of aircraft. However, it also places them in operational environments rich in hazards. Flying at low altitudes and operating or landing vertically, helicopters often operate near obstacles and in densely populated areas, where hazards may include power lines, nearby structures, kites, wires, cables, birds, and, more recently, drones.

In its ongoing commitment to enhancing operational safety in helicopter operations, the Brazilian Helicopter Safety Team (BHEST) established a working group to identify the hazards and risks associated with helicopter operations. The findings are intended to support BHEST's own strategic actions and may also be shared with the broader public. This effort soon expanded to encompass the operational aspects of eVTOLs, due to the high degree of similarity in vertical operations and technological challenges shared between the two types of aircraft.

Given the operational similarities between helicopters and eVTOLs, there is a need for specific studies aimed at preventing aviation accidents within the same airspace segment (low altitude). It is also essential to thoroughly examine the infrastructure requirements specific to eVTOLs, as it is evident that much of the current helicopter infrastructure will not be suitable for eVTOL operations without significant adaptations — particularly in areas such as battery charging systems and emergency response protocols.

# Overview of the AAM Ecosystem (eVTOLs and Drones)

Advanced Air Mobility (AAM) is composed of electric, hybrid, or sustainably fueled aircraft that incorporate new technologies in their operations — such as eVTOLs, drones, autonomous aircraft, hydrogen-powered vehicles, among others.
The primary use case for eVTOLs (which are the focus of this study) is the regular transport of passengers, with manufacturers, operators, and market studies forecasting a significant increase in both urban and interurban air traffic.

To enable these upcoming operations and their unique characteristics, the development of a supporting ecosystem — commonly referred to as the AAM ecosystem — will be essential. The new ecosystem includes the adaptation or implementation of infrastructure through the creation of vertipads/vertiports. These facilities must be capable of accommodating eVTOLs of various configurations and sizes, providing charging systems for electric aircraft as well as safety and emergency systems appropriate to the vehicles, with adequate signage and operational protocols.

In addition to infrastructure, new systems such as UATM (Urban Air Traffic Management) will be necessary to support operations. These systems are currently being developed in parallel with ongoing discussions regarding future navigation rules for eVTOL operations.

The introduction of these new vehicles also requires highly trained professionals in emerging technologies — both for flight crews during the initial phase, when autonomous passenger flights will not yet be authorized, and for ground support teams, where applicable. It will demand detailed and specialized training covering operations, maintenance, and air traffic management.

By bringing together experienced professionals in regulation, helicopter operations, operational safety, and the manufacturing and operation of eVTOLs, the present study aims to identify hazards and risks, and to recommend risk mitigation actions, resulting in a non-exhaustive list that is expected to evolve and improve in future editions.

# PAVE Methodology

## Methodology description

Through the study and discussion of documents produced by industry and regulators — such as Concepts of Operations, Implementation Plans, Safety Alerts, and others — operational analyses were carried out, and potential hazards were identified using the PAVE framework as a guiding structure. The PAVE model outlines four key areas for identifying flight-related risks. These factors are categorized as follows:

- **P**ILOT
- **A**IRCRAFT
- EN**V**IRONMENT
- **E**XTERNAL FACTORS

### Pilot

Identification of issues that may affect pilot performance, such as competence (knowledge, skills, and attitude), experience, fatigue, pressure, stress, illness, and other personal or psychological factors.

### Aircraft

Assessment of the aircraft's readiness for flight, including: airworthiness, weight and balance, maintenance program, fuel and range, equipment, and other operational conditions.

### Environment

Evaluation of weather conditions, terrain, airspace, and surrounding obstacles such as towers, as well as factors like night operations.

### External Pressures

Pressure from the owner or operator, passengers, family, flight schedules, and other external influences.

# Hazard and Risk Identification Using the PAVE Method

Identification

The list of identified hazards and risks is published alongside this document in a spreadsheet, which facilitates visualization, as shown in the example below.

This document considers only operations with an onboard pilot, as ANAC has not yet authorized operations with passengers and remote pilots.

Below are some examples of what you will find in the analysis included with this report.

## PILOT

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-001 | Pilot | Both | Inadequate training | Incorrect decision-making | - Updated training programs for pilots and mechanics (RBAC 61, 65, IS 145.010) |

## AIRCRAFT

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-015 | Aircraft | Both | Fuel contamination | Engine failure due to adulterated fuel | - Fuel testing (applicable to hybrid aircraft)<br>- Reliable suppliers and clear protocols |

## ENVIRONMENT

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-031 | enVironment | Both | Low visibility / adverse weather / night conditions | Controlled Flight Into Terrain (CFIT) | - Understanding METAR<br>- Checking METAR, TAF, and reliable weather information<br>- Clear operational limits for IFR or MVFR conditions<br>- Training for marginal conditions and instrument flight systems, if applicable |

## EXTERNAL PRESSURES

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-036 | External Pressures | Both | Failure in management or supervision | Inadequate planning | - Internal audits and inspections (LOSA)<br>- Timely consultation of NOTAMs<br>- Awareness of operational risks and establishment of Safety Management System (SMS) |

# CONCLUSION

Operational safety is continuously striving for improvement and risk mitigation to achieve acceptable levels of safety. The maintenance of groups such as CASTs is essential, promoting discussions between industry and regulators, bringing stakeholders closer together, and developing support materials made available to the public to be used in pursuit of increasingly safer aviation.

Bringing together various sectors of the rotary-wing aviation industry, the discussions resulted in a list of the main threats and possible mitigations, which can be considered in the creation of new regulations, improvement of existing rules, development of training programs, and programs related to human factors, among other operational safety actions in aviation. However, the list of hazards and risks presented here should not be considered exhaustive, as the group involved focused on the most relevant points of attention. The list may be updated and improved in the future whenever deemed necessary and feasible.

# REFERENCES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15. Manual de Orientações de Infraestrutura de Helipontos, Anac.
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17. PAVE Checklist, FAA.
18. Portaria Decea N° 77/DGCEA, Decea.
19. RBAC 117, Anac.
20. RBAC 120, Anac
21. RBAC 155, Anac.
22. Resolução 234, Anac.
23. Vertiport Prototype Technical Specifications, EASA.

# Working Group Members

1. Fernanda Siniscalchi – Advanced Air Mobility Institute – AAMI, GRU Airport and Working Group Coordinator
2. Reynaldo Ribeiro - President of BHEST and Representative of Helipark
3. Eduardo Alexandre Beni – Vice President of BHEST and Technical Director at the Brazilian Association of Aeromedical Operations (ABOA)
4. Fabio Padilla Castro - ANAC / ASSOP (Coordination and Executive Secretary of BHEST)
5. Carlos Schönhardt – Pilot and Former President of BHEST
6. Gilvan Barros – Pilot and former president of BHEST
7. Luis Celles - Brazilian Air Force (FAB)
8. Ricardo Leão Correia - AeroTD
9. Bruno Limoeiro - Vertimob
10. Desuita Campelo - Venture-U
11. Manuel Ayres - Vertimob
12. Vinicius Fernandes - GOL Linhas Aéreas

# Annex I – Hazards and Risks Library

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-001 | Pilot | Both | Inadequate training | Poor decision-making | Updated Training Program for pilots and mechanics (RBAC 61, 65, IS 145.010)<br>Recent and recurrent experience |
| PAVE-002 | Pilot | Both | Being under the influence of performance-reducing substances (alcohol and/or drugs, medications) | Poor decision-making | Fatigue and Well-being Programs |
| PAVE-003 | Pilot | Both | Poor physical or mental health condition | Poor decision-making | Nutrition and proper hydration |
| PAVE-004 | Pilot | Both | Fatigue or excessive workload | Poor decision-making | Updated Fatigue Management Program for eVTOL operations (RBAC 117)<br>Pilot Flying and Pilot Monitoring philosophy<br>Adoption of Workday Limits (Brazilian Aeronaut Law nº 13.475/2017) |
| PAVE-005 | Pilot | Both | Being under stress and mental pressure | Poor decision-making | Development of a Stress Management Program |
| PAVE-006 | Pilot | Both | Improper use of automation (configuration mistakes) | Unstable approach (lateral/vertical deviation; excessive or insufficient horizontal speed) | Pilot Flying and Pilot Monitoring philosophy<br>Knowledge of automation usage |
| PAVE-007 | Pilot | Both | Inadequate planning (weather, fuel, battery charge, weight & balance) | Low fuel level<br>Operating the aircraft beyond its limitations | SOP includes a fuel management section |

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-008 | Pilot | Both | False and/or misinterpreted sensory impressions | Poor decision-making | Proper nutrition, hydration, sleep, and health care |
| PAVE-009 | Pilot | Both | Inefficient communication | Failures in information exchange between crew members or with air traffic control | Application of ICAO standard phraseology<br>Continuous training in Clear and Concise Communication |
| PAVE-010 | Pilot | Both | Poor Crew Resource Management (CRM) | Problems in coordination and use of available resources in the cockpit and/or operational environment | Extended CRM (E-CRM), including Maintenance Teams, Operational Dispatchers, Air Traffic Controllers (ATC), Ground Operations Teams, and Safety Coordinators of Operators |
| PAVE-011 | Pilot | Both | Poor adherence to Standard Operating Procedures (SOP) | Deviation from procedures due to complacency, operational pressure, or lack of knowledge | Creation of an Operational Safety Group for eVTOL operations |
| PAVE-012 | Pilot | Both | Generic training (if certification is by aircraft class) | Inadequate or incomplete training<br>Operational failure | Development of specific training tailored to the type of eVTOL<br>Need for pilot adaptation |
| PAVE-013 | Aircraft | Both | Aircraft released in a non-airworthiness condition | Loose cowlings, open oil caps, inoperative equipment, etc. | Use of MEL respecting deadlines<br>Well-executed pre-flight checklist |
| PAVE-014 | Aircraft | Both | Inadequate maintenance | Use of unapproved (non-certified) parts | ANAC-certified maintenance facilities<br>Compliance with manufacturer’s maintenance manuals<br>Use of original parts and component traceability |

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-015 | Aircraft | Both | Fuel contamination | Engine shutdown due to contaminated fuel | Fuel testing (if applicable for hybrid aircraft)<br>Reliable suppliers and clear protocols |
| PAVE-016 | Aircraft | Both | Improper maintenance procedures | Errors or omissions during maintenance leading to critical failures in aircraft components | Manufacturers must define preventive maintenance programs, certified and monitored by aviation authorities |
| PAVE-017 | Aircraft | Both | Material wear and fatigue | Structural fatigue due to continuous and prolonged use | Manufacturers must define detailed periodic inspections to detect and correct wear or damage before they become critical<br>Battery manufacturers must provide information on performance monitoring and support<br>Operators must monitor battery performance |
| PAVE-018 | Aircraft | Both | Design or manufacturing defects | Design issues inherent to the aircraft that may not be detected during development or defects introduced during the manufacturing process | Certification process by ANAC<br>Continuous monitoring and updates of aircraft in operation by manufacturers and operators<br>Occurrence reports and data sharing through CENIPA<br>Continuous updating of standards and regulations by ANAC |
| PAVE-019 | Aircraft | Both | Propulsion system malfunctions | Mechanical or electrical failures leading to power loss or complete engine failure | Manufacturers must define preventive maintenance programs, certified and monitored by aviation authorities |
| PAVE-020 | Aircraft | Both | Instrumentation issues | Incorrect indications or failures in flight instruments that can disorient pilots | Manufacturers must define preventive maintenance programs, certified and monitored by aviation authorities |
| PAVE-021 | Aircraft | Both | Navigation and communication system failures | Failures in electronic systems that support navigation and communication | Manufacturers must define preventive maintenance programs, certified and monitored by aviation authorities |

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-022 | Aircraft | eVTOL | Approach, boarding, and disembarking with rotors in motion | Injuries to people or animals in the vicinity of the aircraft | Proper signage, ground support, and cabin briefings<br>Control of people and animals approaching the aircraft |
| PAVE-023 | EnVironment | Both | High air traffic / Unfamiliar aerodrome / Surveillance failure | Traffic conflicts / Aircraft collisions | Compliance with ICA100-4 and ICA100-12 visual separation requirements<br>Operational TCAS<br>Coordination with ATC or UAM (Urban Air Mobility) traffic management<br>Digital navigation systems |
| PAVE-024 | EnVironment | Both | Runway/taxiway signage failure | Runway incursion / Runway excursion | Prior assessment of site conditions<br>Standardized signage<br>Pre-flight briefing on lighting and markings |
| PAVE-025 | EnVironment | Both | Presence of wildlife | Bird strike / Bird ingestion | Wildlife control programs<br>Use of repellents and sound systems at vertiports |
| PAVE-026 | EnVironment | Both | Unsuitable terrain for landing | Aircraft rollover / Aircraft skid / Presence of FOD (Foreign Object Debris) / Suspension of solid particles and coating damage | Evaluation of landing sites (e.g., slope landing capability)<br>Procedures for landing and takeoff on inclined surfaces<br>Regular maintenance and inspections, especially of landing gear (skids, wheels) and control systems to prevent failures |
| PAVE-027 | EnVironment | Both | Kites, balloons, or unauthorized drones near the aircraft | Damage caused by FOD or collisions | Obstacle sensing (short-range cameras, radar, or Lidar)<br>Educational campaigns about urban airspace<br>Immediate reporting of obstacle sightings |
| PAVE-028 | EnVironment | Both | Rotor downwash and outwash | Brownout and FOD (lifting of loose objects on the ground) / Suspension of solid particles | Obstacle sensing (short-range cameras, radar, or Lidar)<br>Educational campaigns about urban airspace<br>Immediate reporting of obstacle sightings |

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-029 | EnVironment | Both | Power lines | Collision with towers and power lines | Prior risk analysis (FRAT), FOD ramp inspection<br>Low altitude route planning using updated charts (eVTOL corridors)<br>Specific anti-collision systems and situational awareness tools (HUD, Synthetic Vision) |
| PAVE-030 | EnVironment | Both | Failure in terrain/obstacle separation / Mountainous terrain | Controlled Flight Into Terrain (CFIT) | Operational radar altimeter and EGPWS<br>Terrain awareness and use of approach charts<br>Route planning considering safety zones |
| PAVE-031 | EnVironment | Both | Low visibility / Adverse weather conditions / Night operations | Controlled Flight Into Terrain (CFIT) | Understanding METAR reports<br>Consultation of METAR, TAF, and reliable weather information<br>Clear operational limits for IFR or MVFR conditions<br>Training for marginal weather operations and instrument flight systems if applicable |
| PAVE-032 | EnVironment | eVTOL | Extreme temperatures (intense heat or cold) | Reduced efficiency of batteries and electrical systems | Prior analysis of expected performance (derating or performance limitations)<br>Battery heating/cooling systems<br>Contingency planning (e.g., nearby alternate landing sites) |
| PAVE-033 | Environment | Both | Deficiencies in safety culture | Complacency / Communication failures | CRM and SRM training required under eVTOL regulations (for both onboard and remote pilots)<br>Use of standard phraseology |
| PAVE-034 | Environment | Both | Deficiencies in organizational culture and climate | Complacency / Communication failures | CRM and SRM training required under eVTOL regulations (for both onboard and remote pilots)<br>Use of standard phraseology |
| PAVE-035 | EnVironment | eVTOL | Poor planning of network and battery charging logistics | Inability to conduct the operation, delays, cancellations | Certified vertiports<br>Continuous status updates on charging systems |

| ID | PAVE | VEHICLE | THREATS | LEADS TO... | WHAT TO DO TO AVOID |
|---|---|---|---|---|---|
| PAVE-036 | External Factors | Both | Failure in management or supervision | Inadequate planning | Internal audits and inspections (LOSA)<br>Timely consultation of NOTAMs<br>Awareness of operational risks and implementation of a Safety Management System (SMS) |
| PAVE-037 | External Factors | Both | Failure to comply with procedures | Accident / Loss of life | Proper control of legislation and best practices<br>Clear safety policies and a strong reporting culture<br>Incentives for compliance and positive reinforcement of safety behaviors |
| PAVE-038 | External Factors | Both | Crew pressure to reach the destination | Accident / Loss of life | Crew members have the autonomy to refuse or cancel flights in favor of safety |
| PAVE-039 | External Factors | eVTOL | Infrastructure and certification challenges (vertiports, ground services) | Operational difficulties, delays, and unsafe landings | Route planning considering certified vertiports<br>Clear procedures for ground movements and battery charging<br>Coordination with local air traffic and municipal authorities (dynamic geofencing, altitude, and speed restrictions)<br>Fail-safes and anti-hijacking measures (e.g., return-to-safe-base function, emergency lockdown) |
| PAVE-040 | External Factors | Both | Cybersecurity issues (potential system hacking) | Loss of flight data, remote control hijacking | Robust encryption and network security protocols<br>Protected firmware/system updates<br>Real-time monitoring for unauthorized access |
| PAVE-041 | External Factors | Both | Market pressures (competition, cost reduction) | Safety compromised in pursuit of cost reduction | Corporate governance with defined safety targets<br>Clear separation between financial goals and SMS goals<br>Transparency and stakeholder engagement (pilots, maintainers, regulators) |

# Annex II – Reference Links

1. PAVE 001 - https://www.faa.gov/newsroom/integration-powered-lift-pilot-certification-and-operations-miscellaneous-amendments
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5. PAVE 015 - https://www.youtube.com/watch?v=S0MpUVjTQiM
6. PAVE 031 - https://www.youtube.com/watch?v=dEdPKBx9ZCc
7. PAVE 033 - https://www.youtube.com/watch?v=w6zSCuT2RsM