AIRCOPTER eVTOL SYSTEMS ENGINEERING PROJECT

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CONTENT

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1. INTRODUCTION

Urban traffic congestion, which is a big problem today, directly contributes to environmental pollution and gives people a negative transportation experience. In order to prevent this from happening, sustainable transportation options are becoming increasingly necessary. The eVTOL (Electric Vertical Takeoff and Landing) product represents a transformative approach to tackling pressing challenges in modern transportation, including traffic congestion, carbon footprint reduction, sustainability and improved mobility. This product aims to leverage advanced electric propulsion technology to revolutionize the way people and goods move in urban and suburban environments.

There's growing global concern about transportation's environmental impact and its role in climate change. Countries aim to eliminate greenhouse gas emissions by mid-century. Therefore, they are urging the development of environmentally sustainable transportation solutions. eVTOL technology shows promise in this regard, as it doesn't rely on traditional infrastructure and employs methods of ascending and descending vertically. However, despite its potential, eVTOL technology faces several challenges. These include technological limitations like battery energy density and noise levels. It includes as well as regulatory hurdles and the need for infrastructure such as vertiports and charging stations.

Therefore, eVTOL could be a game-changer for city transportation. It could revolutionize urban transportation. However, it presents a complex and multifaceted problem to be solved. Collaborative efforts between engineering, regulatory, and public stakeholders are crucial to ensure its success. By this way, it transforms transportation and improves the quality of citizens.

The aim of this project is to address these problems by developing a fleet of electric vertical take-off and landing (eVTOL) aircraft for people-centered, sustainable urban air taxi services. eVTOLs, whose acceptance in our lives is increasing day by day and which are just beginning to be adopted by people, may be everywhere in our lives in a few years. eVTOL aims to develop and deploy electrically powered aircraft capable of vertical takeoff and landing, thus providing efficient, environmentally friendly alternatives to traditional ground transportation. Using airspace and offering direct point-to-point travel, eVTOLs have the potential to significantly ease traffic congestion while reducing carbon emissions.

The product's Acquisition Strategy (AS) emphasizes the integration of sustainable practices, technological innovation and strategic partnerships to achieve its goals. The Systems Engineering Plan (SEP) is adapted to ensure effective execution of purchasing strategies. This includes a comprehensive approach to systems integration, risk management and stakeholder engagement. The SEP outlines clear goals, milestones, and performance measurements that align with the product's overall goals. Additionally, it incorporates feedback from stakeholders, including regulators, industry partners and end users, to ensure successful development and deployment of eVTOLs. It has established mechanisms to align the Main Contractor's Systems Engineering Management Plan (SEMP) with the PMO SEP. This aligns the SEMP with the SEP, increasing communication, transparency, and accountability throughout the project lifecycle.

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Currently, the eVTOL product is in development with entry criteria focused on the completion of preliminary design reviews and feasibility studies. Exit criteria for this phase include successful prototype testing, regulatory approval, and production readiness. Ultimately, the eVTOL program represents a visionary approach to sustainable transportation, with a robust Acquisition Strategy, dedicated Systems Engineering Plan, and collaborative management approach driving its success. The program aims to reshape the future of urban transportation by relieving traffic congestion, reducing carbon emissions and increasing mobility.

In conclusion, the eVTOL program represents a visionary approach to sustainable transportation, with a robust Acquisition Strategy, tailored Systems Engineering Plan, and collaborative management approach driving its success. By addressing traffic congestion, reducing carbon emissions, and enhancing mobility, the program aims to reshape the future of urban transportation.

2 SYSTEM OVERALL VIEW

Airframe Group: This group of items/sumbsytems serves as the structural foundation of the eVTOL, encompassing the:

- Cabin/Body: The central compartment designed to accommodate passengers or cargo.
- Landing Gear: The assembly that allows for safe takeoff, landing, and support when the vehicle is on the ground.
- Wings: Fixed structures that may provide additional lift during horizontal flight.
- Electrical Motors: Devices that convert electrical energy into mechanical energy to drive the rotors or propellers.
- Flaps: Control surfaces on the wings that can alter the aircraft's lift characteristics during flight.

Propulsion System: This system is responsible for generating the necessary thrust to achieve and sustain flight, consisting of the motors and possibly additional components like rotors or propellers not explicitly shown in the diagram.

- Power System: It supplies and manages the energy requirements for the eVTOL, comprising:
    - Batteries: They store electrical energy and supply power to the aircraft systems, especially the motors for propulsion.
    - Power Distribution System: It ensures the proper allocation of electrical power to various components of the eVTOL, managing both supply and demand.

Control System: It governs the operational aspects of the eVTOL, including:

- Flight Control System: The interface that processes pilot input and autonomously generated commands to maneuver the eVTOL safely.
- Avionics: The electronic systems used for communication, navigation, the display and management of multiple systems, and other flight-critical functions.

Each subsystem plays a vital role in the functionality and performance of the eVTOL. The Airframe Subsystem is the backbone, providing the physical structure that houses other

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systems. The Propulsion Subsystem is crucial for the unique vertical takeoff and landing capabilities and for sustained horizontal flight. The Power System is the lifeline of the eVTOL, as it powers all electrically dependent systems, particularly important in an all-electric vehicle like an eVTOL. Finally, the Control System is the brain of the operations, ensuring that the eVTOL responds accurately to pilot commands or autonomous flight plans, maintains stability, and navigates safely through airspace.

Together, these subsystems integrate to form the operational eVTOL system, enabling it to perform its intended functions efficiently and safely, from takeoff to landing, in various urban air mobility scenarios.

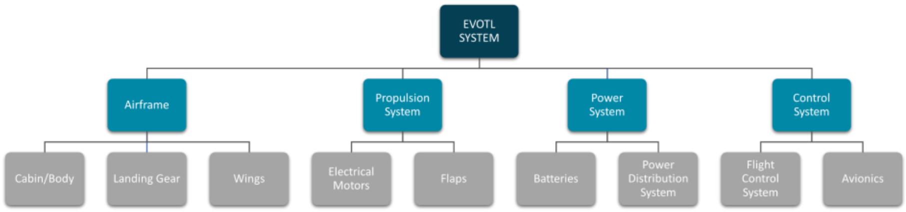

Figure 1-System Overall View

3 DESIGN CONSIDERATIONS

Design considerations within the project are divided into two:

- **Technical:** It includes design parameters that must be taken into account for the design of the aircraft.
- **Geographical:** It contains legal parameters that must be taken into account within the scope of the regulations of the geographical region.

Although these considerations are considered separately, considerations regarding the geographical region in which the product will be used are the primary factor affecting the design.

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3.1 Technical Design Considerations

Designing an eVTOL aircraft involves considering numerous design parameters to ensure the aircraft's performance, safety, efficiency and environmental compatibility. Technical design considerations that need to be taken into account in this regard are as follows:

Vertical Takeoff and Landing Capability: Without a runway, the aircraft must be able to take off and land vertically. Specialized propulsion devices, like electric ducted fans or rotors, are needed for this.

Electric Propulsion System: Lightweight, powerful, and efficient electric motors are the basis of propulsion for eVTOL aircraft. Systems for energy management and battery technology are important components of the design that ensure there is enough power for flight.

Battery Technology: In order to maintain flight while minimizing weight, high-energy-density batteries are necessary. Technological developments in batteries are essential for increasing cargo capacity and flight range.

Flight Control Systems: Advanced flight control systems are essential for maintaining aircraft stability, particularly during vertical takeoff and landing operations. To ensure stability and control, these systems usually use a mix of computer algorithms, actuators, and sensors.

Aerodynamics: Optimizing performance and range while consuming the least amount of energy requires effective aerodynamic design. To increase lift and decrease drag, the aircraft's design, wing arrangement, and control surfaces must all be optimized.

Structural Design: The propulsion system, batteries, and passenger/cargo compartments must all be accommodated by an aircraft's structure that is both lightweight and robust enough to endure the rigors of flight.

Noise Reduction: Because eVTOL aircraft operate in metropolitan areas, reducing noise pollution is crucial to winning over the public and winning over regulators. Noise levels can be lowered with the aid of design elements like enclosed rotors and optimum blade designs.

Safety Systems: To safeguard travelers, crew members, and onlookers, strong safety systems are essential. This covers collision avoidance technologies, emergency landing protocols, and redundancy in crucial systems.

Autonomy and Flight Management: To minimize the need for human pilots and allow accurate navigation in intricate urban situations, several eVTOL designs have autonomous flying capabilities. In order to ensure safe operation, flight management systems must be able to perform autonomous takeoff, landing, and navigation.

Regulatory Compliance: In order to be certified and given permission to operate commercially, an eVTOL aircraft must be designed in a way that satisfies all applicable regulations on airworthiness, noise emissions, and safety.

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By addressing these basic issues, eVTOL aircraft that offer efficient, sustainable and safe urban air mobility solutions may differ for the relevant geographical region. However, these are the parameters that should be taken into consideration in general terms.

3.2 Geographical Design Considerations

Although many eVTOL aircraft design concerns are regionally unique, some are not, including as market preferences, airspace management, and regulatory needs. The following are some key design factors for eVTOL aircraft intended for use in the USA and Europe:

For Europe:

- Regulatory Compliance with EASA: In Europe, aviation safety and certification are governed by regulations set forth by the European Union Aviation Safety Agency (EASA). Achieving certification and acceptance for commercial operation in European airspace for eVTOL aircraft requires their design to adhere to EASA criteria.

- Infrastructure Integration for Metropolitan Air Mobility (UAM): European cities frequently have highly populated metropolitan regions with intricate airspace and infrastructure. For eVTOL aircraft to be successfully deployed in European cities, they must be designed such that they can smoothly connect with the current UAM infrastructure, such as vertiports and air traffic management systems.

- Noise Regulations: European towns have stringent laws governing noise pollution in order to preserve the well-being of their citizens. In order to win over regulators and the public, eVTOL aircraft must be designed with low noise levels through features like enclosed rotors and cutting-edge noise reduction technologies.

Market Preferences: There may be differences in consumer demand and market preferences between the USA and Europe. Enhancing market competitiveness and acceptance can be achieved by designing eVTOL aircraft that cater to the distinct demands and preferences of American consumers, including comfort, affordability, and convenience.

- Environmental Sustainability: Reducing carbon emissions and promoting environmental sustainability are top priorities in Europe. In line with European sustainability aims, designing eVTOL aircraft with electric propulsion systems driven by renewable energy sources may result in favorable regulatory treatment.

For the USA:

- FAA Certification: In the US, civil aviation is governed by the Federal Aviation Administration (FAA). eVTOL aircraft must be designed in accordance with FAA certification standards in order to be approved for commercial operation in the USA.

- Airspace Integration: Commercial airlines, general aviation, and unmanned aircraft systems (UAS) are just a few of the many users of the intricate airspace system in the United States. For safe incorporation into US airspace, eVTOL aircraft must be

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designed with cutting-edge sense-and-avoid technology and be compatible with the FAA's NextGen air traffic management system.

- Market Preferences: There may be differences in consumer demand and market preferences between the USA and Europe. Enhancing market competitiveness and acceptance can be achieved by designing eVTOL aircraft that cater to the distinct demands and preferences of American consumers, including comfort, affordability, and convenience.

- Infrastructure Development: Vertiports, charging stations, and airspace management systems are among the UAM infrastructure projects that are currently receiving funding in the USA. Entering the market and deploying eVTOL aircraft in the USA can be made easier by designing them to take use of current infrastructure or even help develop it.

During the design process within the scope of the project, eVTOL will be adapted to meet regulatory requirements, market demands and infrastructure constraints in Europe and the USA, taking into account design issues specific to the relevant geographical region.

4 PROGRAM TECHNICAL MANAGEMENT

4.1 Technical Tracking

4.1.1 Technical Reviews

The technical reviews planned based on project phases are as below. The document set for exit criteria is held under Section 4.2.1 Technical Planning. The minimum technical performance measures can be seen under 4.6. Technical Performance Measures.

The sets of documents to be released according to the project phases and the durations of the project phases are provided in Section 4.2.1 Technical Planning.

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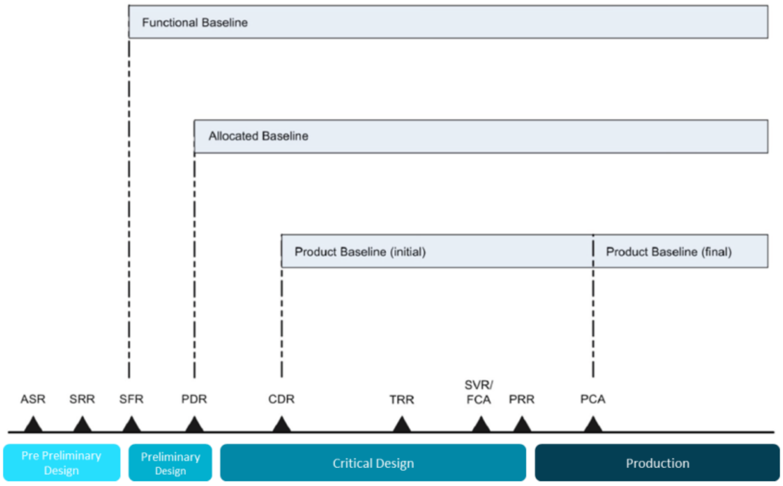

Figure 2-Technival Reviews and Baselines

Technical reviews are a series of formal examinations applied at key points in the product development process to ensure that the system meets the specified requirements and is on the correct path for development and deployment. In the context of an eVTOL systems engineering project, the following technical reviews would typically be included:

4.1.1.1 System Requirements Review (SRR)

- Objective: To confirm that the system requirements align with the customer's needs and expectations.
- Focus: Evaluate the completeness of the system requirements, their feasibility, and the risk associated with them.

4.1.1.2 System Functional Review (SFR)

- Objective: To ensure that the system's proposed functional architecture can fulfill all defined requirements.
- Focus: Examine the functional analysis, the allocation of functions to system elements, and initial performance models.

During the SFR stage, initial R&M requirements are allocated based on system-level functional needs and performance goals. The R&M team assesses system functions, identifies critical components, and assigns preliminary R&M requirements to ensure each part meets performance targets. Block diagrams are created in the SFR phase to visualize the system architecture, focusing on major components and functionality. As the project advances to the

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PDR phase, these diagrams are refined with detailed analysis for accuracy, offering a comprehensive view of the EVTOL aircraft's architecture and component relationships.

Also, conceptual mathematical models are developed to represent system behavior and performance based on high-level requirements. These models offer an initial understanding of system dynamics, supporting early feasibility assessments and trade-off analyses.

4.1.1.3 Preliminary Design Review (PDR)

- Objective: To evaluate the preliminary design and ensure that it meets all system requirements with acceptable risk and within the cost and schedule constraints.
- Focus: Review the proposed design to verify that the preliminary design solutions are viable and that the design approach is sound.

During the PDR phase, R&M allocations are refined and finalized, building upon initial allocations made during SFR. Detailed analyses ensure alignment with evolving specifications and project objectives. Final allocations consider factors like criticality and failure modes, enhancing operational effectiveness and safety of E-VTOL aircraft.

In the PDR phase, these conceptual models undergo refinement into detailed mathematical representations that accurately simulate the behavior of individual components and subsystems. Advanced techniques such as system dynamics, finite element analysis, and computational fluid dynamics are employed to capture the intricate interactions within the E-VTOL aircraft. This detailed modeling enables in-depth analysis of system performance aspects including reliability, maintainability, aerodynamics, structural integrity, and control dynamics.

4.1.1.4 Critical Design Review (CDR)

- Objective: To ensure that the detailed design satisfies the specified performance and engineering standards before production.
- Focus: Confirm that the final design is ready for manufacturing, testing, and sustainment.

4.1.1.5 Test Readiness Review (TRR)

- Objective: To determine if the system is ready to proceed into formal testing.
- Focus: Review the test strategy, test plans, test cases, and the readiness of the test environment.

4.1.1.6 System Verification Review (SVR)

- Objective: To confirm that all system requirements are met and verified.
- Focus: Assess the completeness of the system verification efforts, ensuring all requirements have been addressed.

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4.1.1.7 Functional Configuration Audit (FCA)

- Objective: To verify that the system's functional characteristics are according to the documentation.
- Focus: Check that the system performs all functions as intended, typically performed alongside or as a part of the SVR.

4.1.1.8 Production Readiness Review (PRR)

- Objective: To assess whether the design is ready for mass production without undue risk.
- Focus: Evaluate production samples, manufacturing processes, quality control, and logistical systems.

4.1.1.9 Full Rate Production (FRP) Decision Review

- Objective: To decide if the system is ready to enter full-rate production and deployment.
- Focus: Ensure the system can be produced at full capacity while maintaining quality, meeting the cost requirements, and being adequately supported.

Each review is an opportunity to assess risk, refine requirements, validate design choices, and ensure that the eVTOL project is progressing towards a viable and successful product. The documentation, analyses, and demonstrations provided at each review are critical to obtaining the necessary approvals to move to the next phase of development.

4.2 Program Technical Management

4.2.1 Technical Planning

The sets of documents to be released according to the project phases and the durations of the project phases are provided under this section.
The project enable signature date is demonstrated as T0:

- T0: Project enable signature date

Conceptual design phase (Start: T0, End: T0+6m)

- Concept operation document
- Operational concept document
- Systems engineering plan draft
- System engineering requirement document draft
- System architecture document draft

Preliminary design phase (Start: T0+7m, End: T0+12m):

- System engineering plan
- System architecture document
- Subsystem development plan

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- System engineering requirement document
- Subsystem requirement document
- System verification plan
- Procurement plan
- Preliminary hazard analysis

Design phase (Start: T0+13m, End: T0+32m):

- Failure Mode and Effects Analysis Report (FMEA) and Failure Mode, Effects, and Criticality Analysis (FMECA) Expectation
- System Safety Hazard Analysis Report (SSHA)
- Failure Definition and Scoring Criteria Expectation
- Reliability Growth Testing at the System and Subsystem Level Expectation
- Battery Endurance Analysis Report
- Lift-to-drag Ratio Analysis Report
- Noise Levels Analysis Report
- Component Stress Analysis
- Comprehensive block diagrams (Reliability Block Diagram) and mathematical models (Reliability Growth Modeling) shall be developed to represent the intricate configuration of system components and subsystems within the E-VTOL aircraft. These diagrams and models serve as visual representations of the system architecture, facilitating a deeper understanding of the interconnections and interactions between various elements.

Production Phase (Start: T0+32m, End: T0+40m):

Açıklamalı [1]: Bu sectiondaki ilk 3 maddenin yerinden emin olamadık. Design phase'inde mi olmalı? - Hocaya sorulacak

- Manufacturing plan
- Production readiness review report (PRR)
- Final System Safety Assessment (SSA) Report
- Configuration Management (CM) Documentation
- Airworthiness Certificates
- Certificate of Conformity
- Production Quality Assurance Records
- Failure Reporting, Analysis, and Corrective Action System (FRACAS) Expectation
- Test Records
- Hardware Accomplishment Summary
- Environmental Test Results
- Supplier and Subcontractor Documentation

Utilization/Maintenance Phase (Start: T0+40m, End: T0+100m):

Açıklamalı [2]: Bu evre ürünün uçtuğu ve istenen servisi sağladığı evre olduğu için daha uzun tutuldu. - Hocaya sorulacak

- Operational manuals
- Maintenance manuals
- Airworthiness Directives (ADs)

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- Service Bulletins
- Safety Assessments Reports
- Modification Records
- Reliability Reports
- Incident and Accident Reports
- Flight Data Monitoring (FDM) Records
- Technical Logbooks
- Configuration Management Records
- Regulatory Compliance Documentation
- Maintainability and Built-In Test Demonstrations

Retirement Phase (Start: T0+100m, End: T0+105m):

- Decommissioning Plan
- Deregistration Documentation
- Environmental Impact Assessment
- Storage Records
- End-of-Life Certificate
- Insurance Cancellation Documents
- Urban Operability Analysis Report

4.3 Technical Tracking

Technical reviews are a series of formal examinations applied at key points in the product development process to ensure that the system meets the specified requirements and is on the correct path for development and deployment. In the context of an eVTOL systems engineering project, the following technical reviews would be included:

4.3.1 System Requirements Review (SRR)

To confirm that the system requirements align with the customer's needs and expectations, the focus will be on evaluation of the completeness of the system requirements to the operational concept document, their feasibility, and the risk associated with them. Whole project stakeholders will come together to check the feasibility of system and the requirements.

4.3.2 System Functional Review (SFR)

To ensure that the system's proposed functional architecture can fulfill all defined requirements. Here, the focus is to examine the functional analysis, the allocation of functions to system elements, and initial performance models.

4.3.3 Preliminary Design Review (PDR)

To evaluate the preliminary design and ensure that it meets all system requirements with acceptable risk and within the cost and schedule constraints, the focus will be on reviewing the proposed design to verify that the preliminary design solutions are viable and that the design

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approach is sound. Whole project stakeholders will come together to ensure that all system level requirements have a traceability back to their subsystem requirement documents.

4.3.4 Critical Design Review (CDR)

To ensure that the detailed design satisfies the specified performance and engineering standards before production, the focus will be on confirmation of the final design being ready for manufacturing, testing, and sustainment. Whole stakeholders will come together to make sure the system level requirements are traced all the way to subsystem levels. Matrix methodologies will be used to make sure all the requirements are seen.

4.3.5 Test Readiness Review (TRR)

To determine if the system is ready to proceed into formal testing, examination of the test strategy, test plans, test cases, and test environment preparedness will be evaluated.

4.3.6 System Verification Review (SVR)

To confirm that all system requirements are met and verified, Assessment of completeness of the system verification efforts will take place ensuring all requirements have been addressed.

4.3.7 Functional Configuration Audit (FCA)

To verify that the system's functional characteristics are according to the documentation, Verification that the system operates as intended in all respects will be the aim of this chapter. This is usually done in conjunction with or as a component of the SVR.

4.3.8 Production Readiness Review (PRR)

To assess whether the design is ready for mass production without undue risk, Analyze of manufacturing procedures, quality assurance, logistical systems, and production samples will be made.

4.3.9 Full Rate Production (FRP) Decision Review

To determine whether the system is prepared for deployment and full-rate production, ensuring that the system can be produced at maximum efficiency while upholding quality, adhering to budgetary constraints, and receiving sufficient assistance.

The risk assessments will lead to refinement of requirements, validation of design choices, and ensuring that the eVTOL project is progressing towards a viable and successful product.

The documentation, analyses, and demonstrations provided at each review are critical to obtaining the necessary approvals to move to the next phase of development.

4.4 Technical Risk Issue Management:

Strategies for identifying and managing technical risks and opportunities inherent to eVTOL development will be handled under this chapter.

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4.4.1 Risk Tools

JIRA tool will be primarily used for the project management in order to ensure that all parties have up-to-date information and can make informed decisions based on collective risk intelligence.

4.4.2 Requirement Management Tools

DOORS will be used to maintain traceability and manage baselines.

4.4.3 Project Evaluation Tools

Metrics will be prepared using Excel to evaluate project progress.

4.4.4 Program Office and Contractor(s) Tools:

Inside the programs office and between the contractors, MS Project program will be used to ensure seamless project schedule planning. Unresolved problems will be handed to systems engineering team to create “Issues” using Jira.

4.5 Technical Risk and Mitigation Planning

In order to mitigate engineering, integration and specialized engineering risks, documents such a

- Risk Tools Plan
- Failure Mode and Effects Analysis (FMEA) and Failure Mode, Effects, and Criticality Analysis (FMECA)
- Failure Definition and Scoring Criteria Expectation
- Failure Reporting, Analysis, and Corrective Action System (FRACAS) Expectation
- Reliability Growth Testing at the System and Subsystem Level Expectation
- Final System Safety Assessment (SSA)
- Failure Reporting, Analysis, and Corrective Action System (FRACAS)
- Safety Assessments Reports
- Reliability Reports

will be prepared. The timeline and in which release phase the documents will be released can be found under section 4.2.1 Technical Planning.

4.6 Technical Performance Measures:

Technical Performance Measures (TPMs) are critical in systems engineering as they help in monitoring the performance of the system against its specifications and requirements throughout the project lifecycle. TPMs are quantifiable figures derived from system requirements, which define the standard by which the performance of the system is judged.

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They are used to track the maturity and progress of a product's development, identifying potential risks and technical challenges early in the development cycle.

The technical reviews will be defined under 4.1.1 Technical Reviews chapter. The Plan/Actual column presents the minimum pass criteria for the related technical review. After the completion of each review, the actual row will be marked and unless reaches the planned minimum criteria, the related box will be painted red. If the planned number is reached, the box will be painted green. The performance measures which are not colored green will end up with new Jira tasks until the problem gets fixed and the boxes are colored green.

Table 1-Performance Measures

Technical Performance Measure	TPM Category	Responsible IPT	TPM Goal	Plan /Actual	SRR Status	SFR Status	PDR Status	CDR Status	TRR Status	SVR/FCA Status	PRR Status	FRP Status
Software Schedule/ Duration	Software Schedule	Software	>%100	P	50	60	70	80	100	100	100	100
				A	-	-	-	-		-	-	-
Software Defects	Software Quality	Software	<0	P	0	0	50	40	30	20	10	0
				A	-	-	-	-		-	-	-
Requirements Verification - % verified	Test Management	System Engineering	<%100	P	0	0	0	0	100	100	100	100
				A								
Interface Definition(External/ Internation ICDs Preparation)	Mission Integration Management	Mission Integration	100%	P	10	20	30	80		80	100	100
				A	-	-	-	-		-	-	-
Noise Level	System Performance/ Propulsion System Management	System Performance/ Propulsion System Management	<200dB	P	300	300	300	200		200	200	<200dB
				A	-	-	-	-		-	-	-
Operational Resilience	System Performance	Specification – verify system performance related TPMs with cyber effects as informed by MBCRA	100	P	0	0	20	20	100	100	100	100
				A	-	-	-	-		-	-	-

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4.7 Reliability and Maintainability Engineering:

Plans to ensure eVTOL systems are reliable and maintainable, considering the unique operational environment. In line with the program objectives and guidelines outlined by the Joint Capabilities Integration and Development System (JCIDS), this document presents a comprehensive overview of the Reliability and Maintainability (R&M) engineering program implemented within Aircopter. The program aims to ensure that all R&M requirements are met effectively to achieve the desired system-level performance while integrating seamlessly with Systems Engineering (SE) processes.

Activity	Planning and Timing
R&M Allocations	***Expectation:*** *R&M requirements assigned to individual items to attain desired system-level performance. Preliminary allocations by System Functional Review (SFR) with final by PDR.*
R&M Block Diagrams	***Expectation:*** *Block diagrams and math models to reflect the equipment/system configuration. Preliminary by SFR with final by PDR.*
R&M Predictions	***Expectation:*** *Predictions to provide an evaluation of the proposed design or for comparison of alternative designs. Preliminary by PDR with final by CDR.*
Failure Definition and Scoring Criteria	***Expectation:*** *Failure definitions and scoring criteria to make assessments of R&M contract requirements.*
Failure Mode, Effects, and Criticality Analysis (FMECA)	***Expectation:*** *Analyses to assess the severity of the effects of component/subsystem failures on performance. Preliminary by PDR with final by CDR.*
Maintainability and Built-In Test Demonstrations	***Expectation:*** *Assessment of the quantitative and qualitative maintainability and built-in test characteristics of the design.*
Reliability Growth Testing at the System and Subsystem Level	***Expectation:*** *Reliability testing of development systems to identify failure modes, which if uncorrected could cause the equipment to exhibit unacceptable levels of reliability performance during operational usage. At the system level, assessments of development test data provide measures of effectiveness for the R&M engineering program and are used to track progress on reliability growth planning curves. At the subsystem level ALT and HALT (qualitative to eliminate failure modes) may be used.*
Failure Reporting, Analysis, and Corrective Action System (FRACAS)	***Expectation:*** *Engineering activity during development, production, and sustainment to provide management visibility and control to improve R&M of HW and associated SW. Requires timely and disciplined use of failure data to generate and implement effective corrective actions to prevent a recurring failure.*

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4.7.1 Reliability and Maintainability Requirements and Engineering Activities

The R&M engineering program is structured to encompass various phased activities as follows:

R&M Allocations: It includes allocation of R&M requirements to individual system components and subsystems. During this phase, the R&M engineering team meticulously assigns reliability and maintainability (R&M) requirements to each individual system component and subsystem. This process is essential to ensure that the desired system-level performance is achieved while maintaining optimal reliability and maintainability characteristics at the component level.

4.7.2 Allocation of R&M Requirements

The allocation of R&M requirements is performed comprehensively for each individual system component and subsystem. This includes the following components and subsystems:

4.7.2.1 Propulsion System Components

It includes allocation of reliability requirements to engine modules, propulsion control systems, electrical motors and flaps. The assignment of maintainability requirements facilitates efficient maintenance and servicing of propulsion components for reliable services.

4.7.2.2 Flight Control System and Its Subsystems

It includes allocation of reliability requirements to flight control actuators, sensors, and avionics interfaces. The assignment of maintainability requirements ensures the ease of access for maintenance and troubleshooting of flight control subsystems. It helps for quick recovery of system in case of failure and maximization of utility.

4.7.2.3 Power Distribution Components

It includes allocation of reliability requirements to power generation units, distribution systems, and backup power sources. The assignment of maintainability requirements enables rapid repair service and replacement of power distribution components.

4.7.2.4 Airframe (Structural Components)

It includes allocation of reliability requirements to critical structural elements which includes airframe components and load-bearing structures. The assignment of maintainability requirements facilitates inspection, repairment, and structural integrity assessments.

4.7.2.5 Avionics Subsystems

It includes allocation of reliability requirements to avionics hardware, software modules, and communication interfaces. The assignment of maintainability requirements ensures timely diagnosis and repair of avionics subsystems in the event of failures.

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4.7.3 Root Causes for Reliability Issues

This subsection identifies key factors contributing to reliability issues in system components, detailed as follows:

- Component Deficiencies: It addresses how inadequate design margins, poor quality control, and susceptibility to environmental factors can lead to premature failures.
- Insufficient Testing: It highlights the risk of latent defects or weaknesses remaining uncovered due to inadequate testing during the design phase, which leads to reliability issues during operational use.
- Inadequate Maintenance Procedures: It discusses how a lack of accessibility to critical components for maintenance and repair can reduce system reliability by increasing downtime and delaying necessary repairs.
- Lack of Redundancy: It explains that the absence of redundancy in critical systems or subsystems may create single points of failure, compromising overall system reliability under certain failure scenarios.
- Material Degradation: This covers how material degradation over time due to environmental conditions, fatigue, or wear and tear can degrade system reliability if not adequately addressed in design and maintenance plans.

Supportive ideas for maintainability evaluation include the following tasks:

- Task Analysis: Identifying necessary maintenance tasks and procedures to optimize maintenance procedures and identify design improvement opportunities.
- Accessibility Assessment: Evaluating accessibility of critical components for maintenance and repair to minimize downtime and maintenance costs.
- Built-In Test (BIT) Systems: Implementing automated diagnostics and fault detection to streamline maintenance procedures.
- Standardization of Components: Standardizing components and modularizing subsystems to simplify maintenance procedures and reduce spare part inventory requirements.
- Training and Documentation: Providing comprehensive training and documentation for maintenance personnel to improve the efficiency and reliability of maintenance operations.

4.7.4 Failure Definition and Scoring Criteria

Failure definition and scoring criteria is provided below:

- **Failure Definition Clarity:** The definition of failure should be clear and unambiguous, providing a precise understanding of what constitutes a failure event. Clear and consistent failure definitions are essential for effective communication and understanding among stakeholders, ensuring alignment on the criteria used for assessing failures.
- **Severity Levels:** It defines different severity levels of failures to distinguish between minor, moderate, and critical failures based on their impact on system performance and safety. By defining severity levels, stakeholders can prioritize their focus and resources

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on addressing critical failures that pose the highest risks to system performance and safety.

- **Mission-Critical Considerations:** It assesses the impact of failures on mission success, operational capability, and overall system effectiveness. Understanding the impact of failures on mission success allows stakeholders to prioritize reliability and maintainability improvements that directly contribute to achieving operational objectives.
- **Safety Risk:** It evaluates the safety risk associated with each failure mode, considering potential hazards to operators, passengers, and bystanders. Prioritizing safety considerations ensures that failures with the potential to cause harm are identified and addressed promptly, mitigating risks to personnel and the public.
- **Operational Downtime:** It considers the duration and frequency of downtime resulting from each failure event, including time required for troubleshooting, repair, and system restoration. Minimizing downtime and streamlining maintenance activities enhance operational efficiency and system availability, ultimately reducing costs and improving mission readiness.
- **Maintenance Complexity:** It assesses the complexity and resource requirements for maintenance and repair activities associated with each failure mode. Assessing the complexity of maintenance tasks helps identify opportunities for simplifying procedures, reducing turnaround times, and optimizing resource allocation for maintenance activities.
- **Cost Implications:** It considers the financial impact of failures, including direct costs associated with repair and replacement of components, as well as indirect costs related to system downtime and operational disruptions. Understanding the financial implications of failures enables stakeholders to make informed decisions regarding investments in reliability and maintainability improvements, balancing cost considerations with performance objectives.

- **Customer Impact:** It evaluates the impact of failures on customer satisfaction, reputation, and trust in the reliability and quality of the product. Prioritizing customer impact ensures that reliability and maintainability efforts align with customer expectations and contribute to building trust and loyalty in the product and brand.

4.7.5 Assessment of Potential Component and Subsystem Failures

Failure Mode, Effects, and Criticality Analysis (FMECA) is provided below. The criteria for severity assessment include safety, mission criticality, system functionality, operational downtime, environmental impact, cost implications and customer impact.

- **Impact on Safety:** It evaluates the potential for component or subsystem failures to pose safety hazards to operators, passengers, or bystanders. Prioritizing safety considerations ensures that efforts are focused on mitigating risks to personnel, passengers, and the public, safeguarding human lives and property.

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- **Mission Criticality:** It assesses the impact of failures on mission success, operational capability, and overall system effectiveness. Ensuring the reliability and performance of critical components and subsystems is essential for achieving mission objectives and operational success.
- **System Functionality:** It considers the extent to which failures affect the primary functions and performance of the system.
- **Operational Downtime:** It evaluates the duration and frequency of system downtime resulting from failures and their impact on mission readiness. Minimizing system downtime and disruptions improves operational efficiency, reduces costs, and enhances overall mission readiness.
- **Environmental Impact:** It assesses the environmental consequences of failures, including risks to the environment and surrounding ecosystems. Mitigating environmental risks and impacts aligns with ethical and regulatory obligations and demonstrates corporate social responsibility.
- **Cost Implications:** It considers the financial costs associated with failures, including direct repair and replacement costs, as well as indirect costs related to operational disruptions.
- **Customer Impact:** It evaluates the impact of failures on customer satisfaction, reputation, and trust in the reliability of the system. Delivering a reliable and resilient system enhances customer satisfaction, trust, and confidence in the product and brand.

FMECA aims to minimize failures during integration. Therefore, critical failure modes are identified. By this way, it prioritizes the identification of critical failure modes that have the highest severity and potential impact on system performance. It is introduced redundancy in critical components or subsystems to mitigate the impact of single points of failure and enhance system reliability advanced monitoring and diagnostic systems to detect potential failures early and enable proactive maintenance interventions. The system design adopt design for easy maintenance principle. Therefore, design components and subsystems provide ease of maintenance, accessibility for inspection, repairment, and replacement activities. Contingency plans are developed and emergency procedures to respond effectively to unexpected failures and minimize their impact on operations. Continuous training and education are provided to operators and maintenance personnel to ensure they are equipped to respond to and address failures efficiently and effectively. Lastly, for continuous monitoring and improvement, procedures are established to monitor system performance and identify failure data to detect trends, patterns, and areas for improvement.

By conducting a thorough Failure Mode, Effects, and Criticality Analysis (FMECA) and implementing appropriate mitigation strategies, this project] can minimize the severity of potential component and subsystem failures during integration, ensuring the reliability and performance of the overall system.

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4.7.6 Assessment of Quantitative and Qualitative Maintainability and Built-In Test Characteristics

The quantitative maintainability assessment can be categorized into five main domain. The detailed explanations are given below.

- **Mean Time to Repair (MTTR):** It evaluates the average time required to restore a failed component or subsystem to operational status. Lower MTTR values indicate higher maintainability.
- **Mean Time Between Failures (MTBF):** It assesses the average time interval between consecutive failures of a component or subsystem. Higher MTBF values indicate greater reliability and ease of maintenance.
- **Availability:** It calculates the proportion of time that the system is operational and available for use. Higher availability values reflect improved maintainability and reduced downtime.
- **Predictive Maintenance Intervals:** It determines the optimal intervals for conducting preventive maintenance activities based on predictive models and historical failure data. Longer maintenance intervals indicate improved maintainability and reduced maintenance burden.
- **Repair Parts Inventory:** It evaluates the quantity and variety of spare parts required to support maintenance activities. A well-managed inventory with sufficient stock of critical parts enhances maintainability by minimizing downtime due to parts shortages.

The qualitative maintainability assessment can be categorized into five main domain. The detailed explanations are given below.

- **Accessibility:** It assesses the ease of access to critical components and subsystems for inspection, maintenance, and repair activities. Components needs to be easily accessible to facilitate faster turnaround times for maintenance tasks.
- **Modularity:** It evaluates the degree to which components and subsystems are modularized. It allows for easy replacement and upgradeability. Modular designs simplify maintenance and reduce system downtime.
- **Standardization:** It determines the extent to which standardized components and interfaces are used within the design. Standardization streamlines maintenance procedures by reducing the need for specialized tools and training.
- **Diagnostic Capabilities:** It assesses the effectiveness of built-in diagnostic systems for identifying and troubleshooting faults. Advanced diagnostic capabilities enable rapid fault isolation and resolution, improving maintainability.
- **Prognostics and Health Management (PHM):** It evaluates the integration of prognostics and health management systems for predicting component failures and scheduling maintenance proactively. PHM systems enhance maintainability by reducing unplanned downtime and optimizing maintenance schedules.

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Besides quantitative and qualitative maintainability assessments, there are **built-In test characteristics assessment.** The detailed explanations are provided below.

- **Coverage:** It evaluates the range of system components and subsystems covered by built-in test capabilities. Comprehensive coverage ensures thorough fault detection and diagnosis.
- **Speed:** It assesses the time required to execute built-in test routines and generate diagnostic results. Faster test execution speeds reduce system downtime and minimize impact on operational readiness.
- **Accuracy:** It determines the accuracy of built-in test results in identifying and diagnosing faults. High accuracy ensures reliable detection and diagnosis of system anomalies.
- **Automation:** It evaluates the degree of automation in built-in test procedures, including automatic fault detection, isolation, and reporting. Automation reduces the need for manual intervention, improving efficiency and reliability.
- **Integration:** It assesses the integration of built-in test capabilities with overall system architecture and maintenance processes. Seamless integration ensures smooth operation and interoperability with other system functions and maintenance procedures.

To sum up, quantitative metrics such as MTTR, MTBF, and availability directly impact operational efficiency by minimizing downtime and maximizing system uptime. Efficient maintenance practices, supported by qualitative factors like accessibility and modularity, optimize resource utilization by reducing labor and material costs. Built-in test capabilities contribute to overall system reliability by facilitating proactive fault detection and diagnosis, preventing potential failures before they occur. Enhanced maintainability and built-in test features improve customer satisfaction by ensuring reliable system performance and minimizing disruptions to operations. I addition, effective maintainability and built-in test characteristics lead to lower lifecycle costs through reduced maintenance expenses, spare parts inventory, and operational downtime. By conducting a comprehensive assessment of both quantitative and qualitative maintainability characteristics, as well as built-in test capabilities, this project can optimize the design of the E-VTOL aircraft to ensure ease of maintenance, reliability, and operational readiness throughout its lifecycle.

4.7.7 Reliability Growth Testing: Enhancing System Reliability

Reliability growth testing is a systematic approach to improving the reliability of development systems over time. It involves rigorous testing and analysis to identify and address potential failure modes. It ultimately ensures that the system meets specified reliability thresholds. This activity is essential for validating the system's performance and enhancing its reliability before deployment.

Identification and addressing failure modes are provided below.

- **Failure Mode Analysis:** It conducts a comprehensive analysis to identify potential failure modes and their root causes. This analysis may involve techniques such as Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA).

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- **Real-world Simulation:** It subjects the development systems to a variety of stressors and environmental conditions to simulate real-world operating conditions. This helps uncover latent defects and failure modes that may not be apparent under normal testing conditions.

- **Continuous Monitoring:** It helps implementation of robust monitoring systems to track the performance of critical components and subsystems during testing. Real-time data collection allows for early detection of anomalies and potential failure modes, enabling prompt corrective action.
- **Failure Thresholds:** It defines specific reliability thresholds that the system must meet to achieve operational readiness. These thresholds may be based on industry standards, customer requirements, or project-specific objectives.

Failure modes are determined according to risk mitigation, cost saving, performance optimization, customer satisfaction and regulatory compliance. Risk mitigation systematically identifies and addresses potential failure modes during the development phase. Reliability growth testing reduces the risk of unexpected failures in operational environments and enhances system safety and reliability. Reliability growth testing also allows for iterative improvements to the system design and components, leading to optimized performance and increased operational efficiency. Early detection and mitigation of failure modes during development testing help avoid costly rework and retrofitting efforts that may be required if reliability issues are discovered post-deployment. Delivering a reliable product improves customer satisfaction and confidence in the system's capabilities, leading to enhanced brand reputation and customer loyalty. In addition, many industries have stringent reliability requirements and standards that must be met for regulatory compliance. Reliability growth testing ensures that the system meets or exceeds these requirements, avoiding potential legal and financial implications.

As a result, reliability growth testing is a vital activity in the development process, aimed at improving the reliability and performance of systems before deployment. By systematically identifying and addressing potential failure modes, setting reliability thresholds, and conducting rigorous testing, the company ensures the delivery of a robust and dependable product to customers, ultimately contributing to overall mission success and customer satisfaction.

4.7.8 Failure Reporting, Analysis, and Corrective Action System (FRACAS)

FRACAS is an engineering process implemented throughout the development, production, and sustainment phases of a project to enhance Reliability and Maintainability (R&M) by systematically identifying, analyzing, and addressing failures. It involves a structured approach to collecting failure data, conducting thorough analysis, and implementing corrective actions to improve system reliability and maintainability continuously.

Engineering Activities:

Failure reporting establish a robust system for reporting failures encountered during development, production, and operational use. It encourages proactive reporting by all

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stakeholders which includes engineers, technicians, and end-users. It helps to ensure comprehensive coverage of failure data.

Failure Analysis:

It conducts in-depth analysis of reported failures to identify root cause. It contributes to the factors, and failure modes. Failure analysis utilizes techniques such as Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and Root Cause Analysis (RCA) to systematically investigate failure events.

Corrective Action Development:

It develops corrective action plans based on the findings of failure analysis. It is aimed at addressing root causes and preventing recurrence of similar failures. It prioritizes corrective actions based on severity, impact on system performance, and likelihood of recurrence.

Implementation of Corrective Actions:

It implements identified corrective actions in a timely manner. It is important to take into account resource availability, schedule constraints, and potential impacts on other system components or processes. By this way, it ensures effective communication and coordination across relevant stakeholders to facilitate seamless implementation of corrective actions.

Verification and Validation:

It verifies and validates the effectiveness of implemented corrective actions through testing, simulation, or field trials. It helps to monitor system performance post-implementation to ensure that the desired improvements in reliability and maintainability have been achieved.

FRACAS provides many benefits. It promotes a culture of continuous improvement by systematically addressing identified failures and implementing corrective actions to enhance system reliability and maintainability over time. It helps risk reduction by timely identification and resolution of failure issues to mitigate risks associated with system downtime, operational disruptions, and potential safety hazards. It proactively addresses failure issues during the development phase helps avoid costly repairs, warranty claims, and customer dissatisfaction associated with unreliable systems. By systematically analyzing and addressing failure events, FRACAS contributes to the overall quality of the product and it leads to improved customer satisfaction and brand reputation. Lastly, it contributes to the regulatory framework. Many industries have regulations and standards governing reliability and safety requirements. FRACAS helps ensure compliance with these requirements by systematically addressing failure issues and implementing corrective actions.

As a result, FRACAS is a vital engineering process that plays a critical role in enhancing Reliability and Maintainability (R&M) throughout the lifecycle of a system. By establishing a systematic approach to failure reporting, analysis, and corrective action implementation, the company ensures the continuous improvement of system reliability and maintainability, ultimately leading to improved performance, customer satisfaction, and overall mission success.

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4.8 Manufacturing and Quality Engineering

Description of the manufacturing and quality-related acitivites' comprehensive plans and programs with the SE integrated approach.

The documents provided below will be published to ensure the seamless operation of the manufacturing and quality engineering operations;

Preliminary design phase:

- Procurement plan
- Quality engineering plan
- Validation and verification plan
- Configuration management plan

Production phase:

- Manufacturing plan
- Production readiness review report (PRR)
- Final System Safety Assessment (SSA) Report
- Configuration Management (CM) Documentation
- Certificate of Conformity
- Production Quality Assurance Records
- Failure Reporting, Analysis, and Corrective Action System (FRACAS) Expectation
- Test Records
- Environmental Test Results
- Supplier and Subcontractor Documentation

Utilization/Maintenance Phase:

- Operational manuals
- Maintenance manuals
- Airworthiness Directives (ADs)
- Service Bulletins
- Safety Assessments Reports
- Modification Records
- Reliability Reports
- Incident and Accident Reports
- Flight Data Monitoring (FDM) Records
- Technical Logbooks
- Configuration Management Records
- Regulatory Compliance Documentation
- Maintainability and Built-In Test Demonstrations

Retirement phase:

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- Decommissioning Plan
- Deregistration Documentation
- Storage Records
- End-of-Life Certificate
- Insurance Cancellation Documents

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