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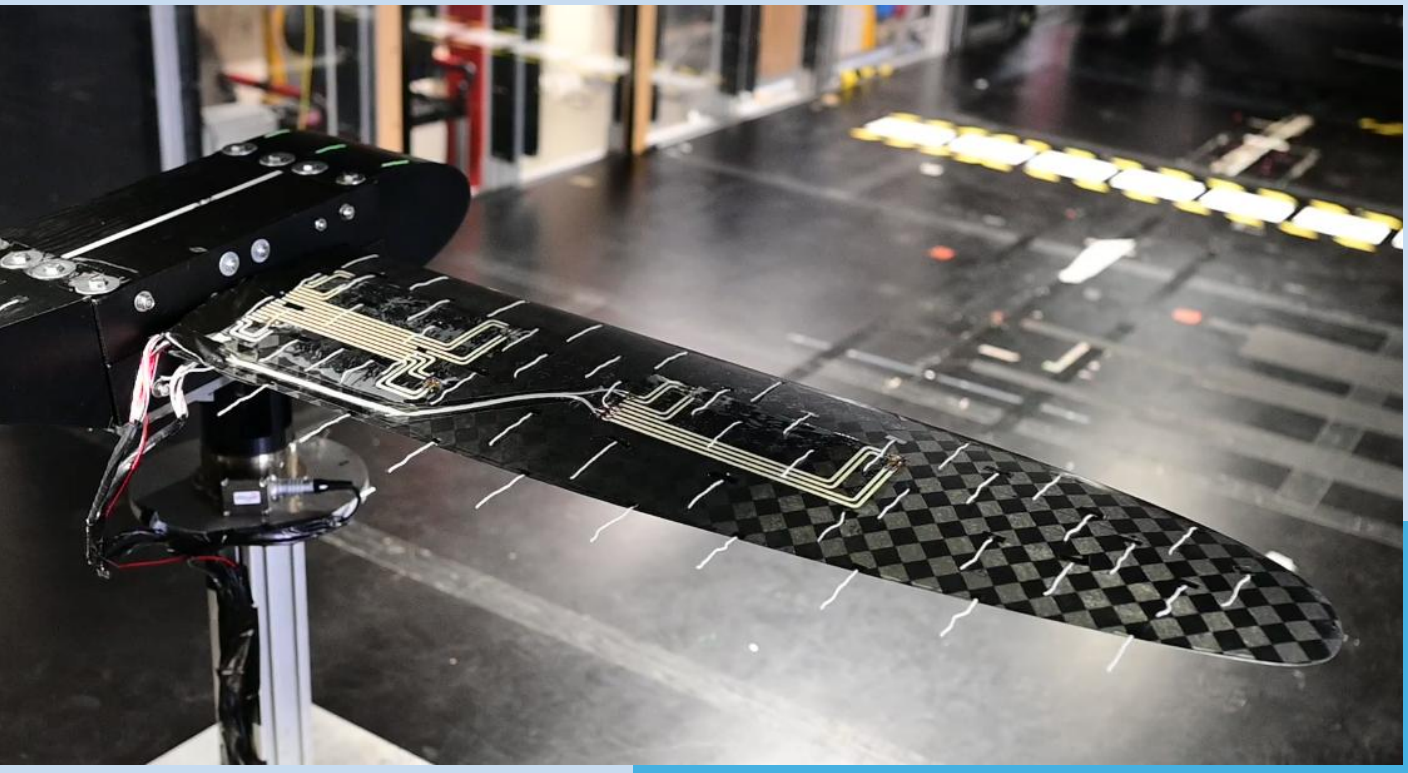


AVATAR

Transformative Air Vehicle enabled by IoT Sensors and Digital Twin

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Project Aims and Objectives

The overall objective of AVATAR is to create a Digital Twin (DT) by continuously monitoring the operation of transformative air vehicles (TAV) through an innovative smart IoT sensing skin, informed by accurate physical models and advanced analytics, resulting in **reduced direct operative costs, extended service life and enhanced safety**. AVATAR's DT framework builds on verified physical models for design of TAVs, with the potential to contribute to an extended safe-life design of TAVs.

The 4 key objectives include:

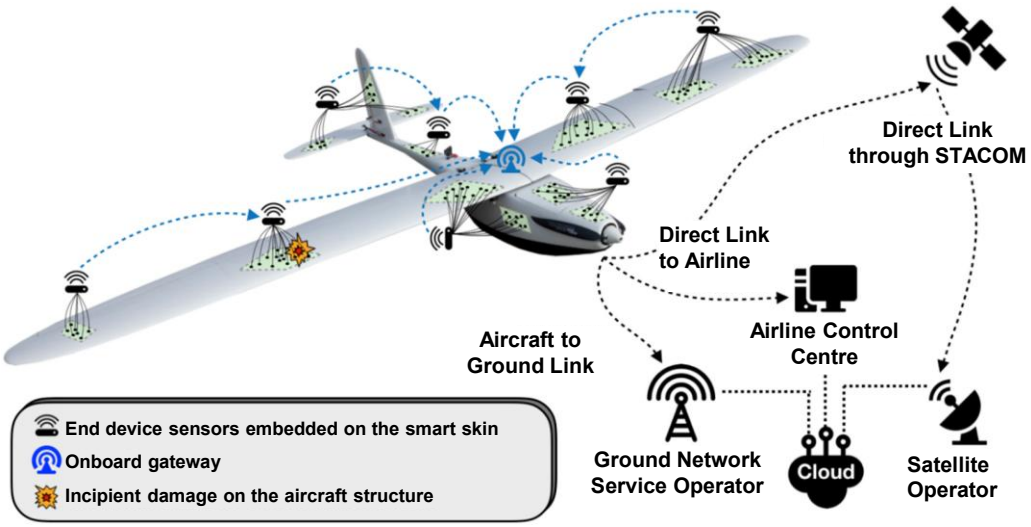
1. **IoT Sensing Skin:** Development of a multifunctional, self-powered smart skin embedded with sensors that provide real-time data on structural health (strain, acceleration, temperature, etc.).

2. **Digital Twin:** Creating a virtual model that mirrors the physical air vehicle, predicting its behaviour, and providing early warnings of potential failures.

3. **Advanced Analytics:** Implementation of machine learning (ML) and artificial intelligence (AI) techniques for fault detection, remaining useful life (RUL) estimation, and flight profile optimization.

4. **Communication and Cloud Platform:** Ensuring secure data transmission from the vehicle to a cloud platform for real-time processing and storage, while maintaining high levels of data security and reliability.

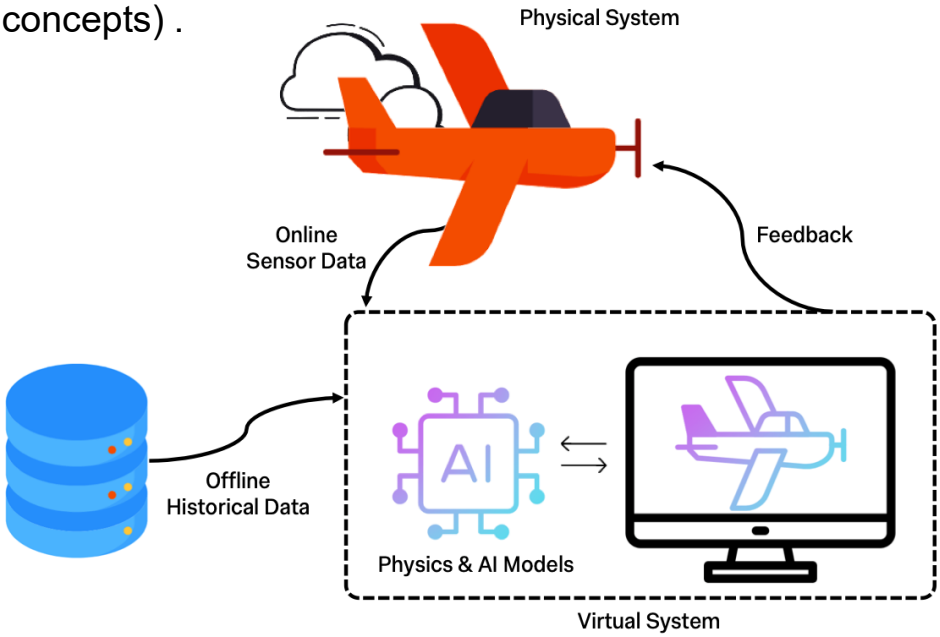
The **expected impacts** of AVATAR include reducing **operational costs** through predictive maintenance, improving **safety** by continuous monitoring, and providing insights to **optimize vehicle design** for future generations.



AVATAR's Key Achievements

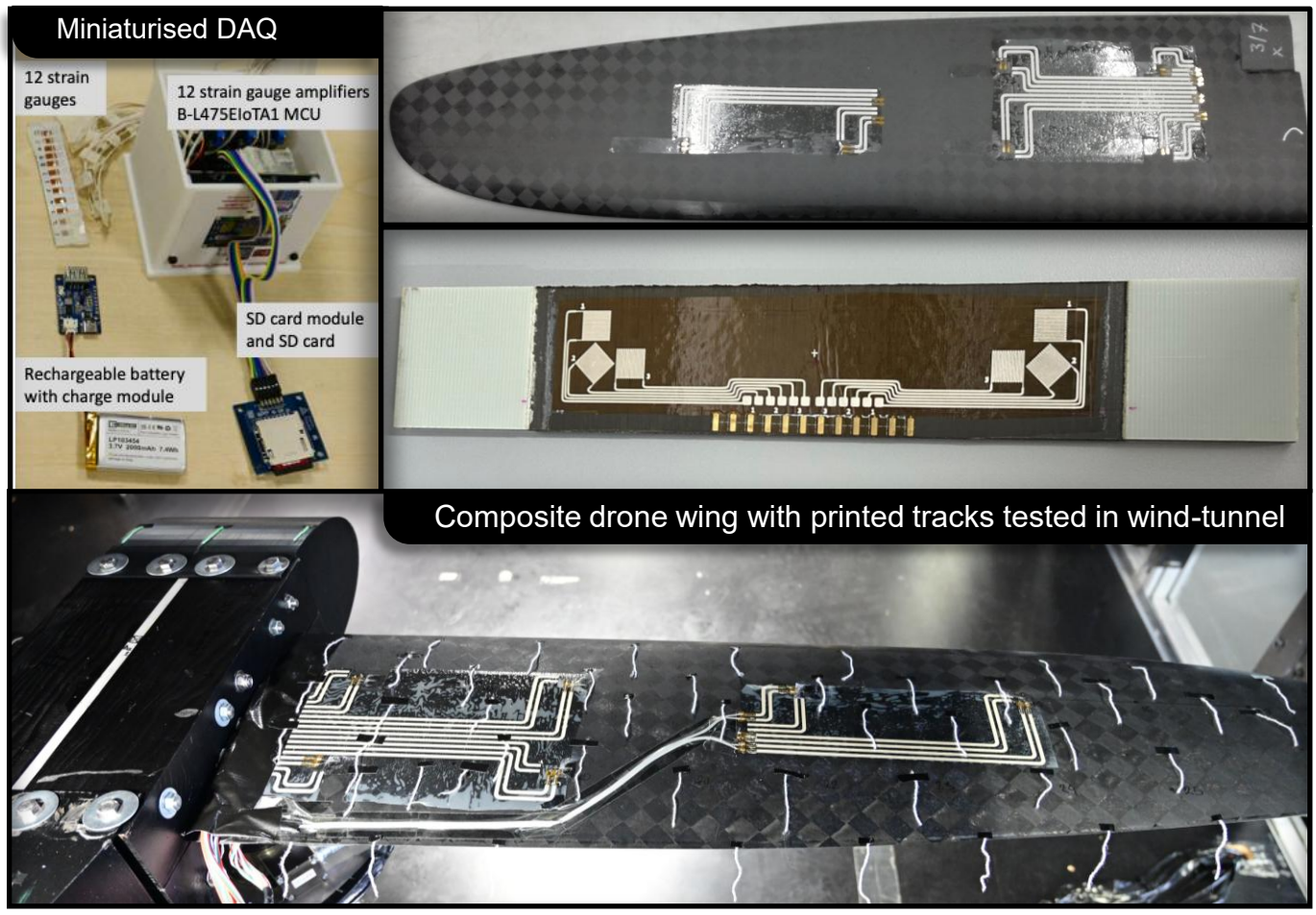
To ensure a systematic progression from concept to deployment, he developments within AVATAR was structured around a **building block** approach. The achievement of each key objective was enabled through the following developments:

1. **Developing a smart skin concept (IoT):** Diagnosis of the structure in real-time was pursued through two main developments in parallel: the multi-functional flexible sensor and a miniaturised and lightweight data acquisition (DAQ) unit. The development of the first item was abandoned at last due to current technological limits of 3D printing. The effort thus focused more on producing high-quality printed sensors or wire paths, see the next page.
2. **Developing Standardized & Secured communication interfaces**: A Robust Data Communication Platform is developed enabling seamless data flow from sensors to the cloud, where it is processed, stored, and visualized. The platform integrates cloud-based analytics to ensure real-time data acquisition, secure transmission, and structured storage.
3. **Advanced Analytics for remaining useful life estimation**: It includes the development of models that support the computational requirements of the digital twin platform (e.g. clustering approach for flight-phase categorisation, operator learning neural network for surrogate modelling).
4. **Developing a Digital Twin concept** employing AI to optimize the maintenance, and operation by integrating three modules: Structural Health Monitoring (SHM), In-service monitoring (flight-phase categorisation & load reconstruction), and Remaining useful life of the structure (safe-life and fail-safe concepts) .



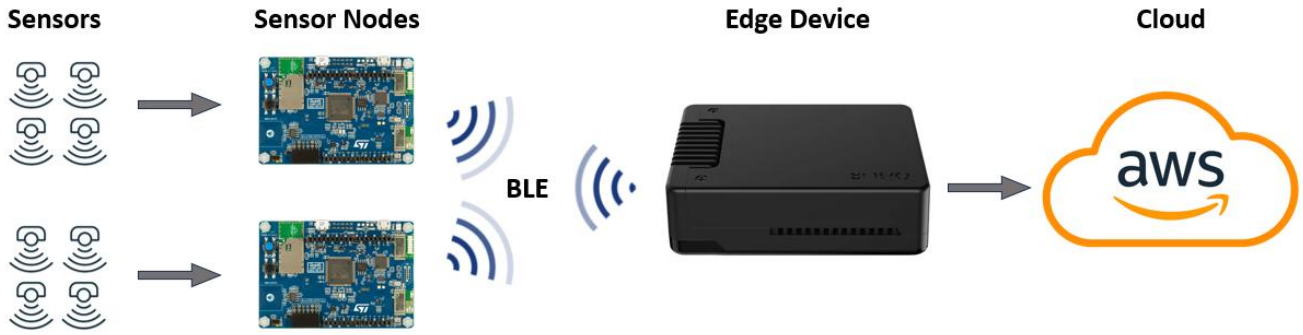
Multi-functional sensing skin

1. **Miniaturised DAQ:** To establish a real-time link between the physical aircraft and its digital counterpart, an integrated low-power DAQ system has been developed in AVATAR, capable of multi-sensor acquisition (strain, accelerometer, thermistor) with 12 channels for simultaneous strain gauge and accelerometer connection.
2. **Printed Flexible Strain Gauges and Thermistors**: Screen printing solution for a carbon-based strain sensor has been developed and tested, for fatigue strain measurement in both metallic and composite structures. Few challenges have been identified which highlight the importance of the base materials used, as well as installation procedure which should be tailored differently for composite and metallic host structures.
3. **Printed tracks**: To reduce the weight and interference of many wires needed for sensorisation of large structures, screen printing of tracks was successfully carried in a modular design, ensuring repeatability and reliability.
4. **Energy Harvester:** A non-linear piezoelectric energy harvester has been developed to assist the power efficiency of IoT sensing skins. It enables energy harvesting within a wide range of operating conditions.



Edge Computing Framework and Cloud Infrastructure

1. **Real-Time Data Acquisition:** Ensuring continuous and accurate data collection from multiple sensors installed on aircraft and drones.
2. **Secure & Robust Data Transmission:** Implementing encryption and communication protocols to safeguard data during transmission. Ensuring data completeness and integrity with local storage and transmission triggers on network availability.
3. **Structured Data Storage:** Organizing data in a structured format for efficient processing and retrieval. Using scalable cloud storage to power the analytics.
4. **Advanced Analytics:** Enabling real-time monitoring, predictive maintenance, and decision-making through cloud-based analytics and visualization tools.
5. **Scalability and Adaptability:** Designing a modular system that can be scaled for use in large fleets and adapted for other industries, such as automotive, manufacturing, and energy.





Advanced Analytics for Diagnosis and Prognosis

1. **Passive SHM:**

   a) **Anomaly detection:** Damage, accidental impact, or high stress/strain identification is achieved through machine learning model enabling categorization of flight regimes and detection of extraordinary signal features.

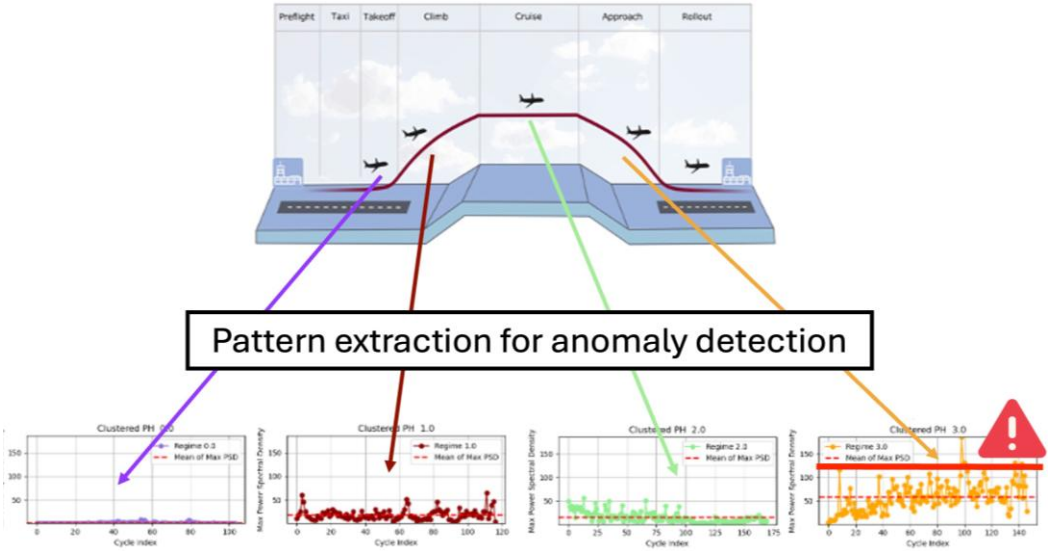
   b) **Fatigue life analysis – Fail safe:** A baseline free damage detection method based on nonlinear analysis is developed for fail-safe analysis, where cracks as small as 1mm are automatically detected, and their propagation is estimated, following probabilistic EIFS concept, to estimate the remaining number of flight hours to failure, for that particular component.

   c) **Fatigue life analysis – Safe life:** Based on real-time strain sensing and load reconstruction, the cumulative damage metric is updated after each flight (based on rainflow count and linear damage accumulation). Remaining useful fatigue life is projected based on the current flight or multiple past flights. This allows the operator to see how was that flight ranked, in relation to the design fatigue life of the structure or to other flights or pilots.

2. **Active SHM**: A Baseline-free damage detection module has been developed for detecting damage in complex composite structures such as the drone wing, based on guided wave analysis.

3. **Flight Phase Estimation**: Automatic regime identification to support diagnostics.

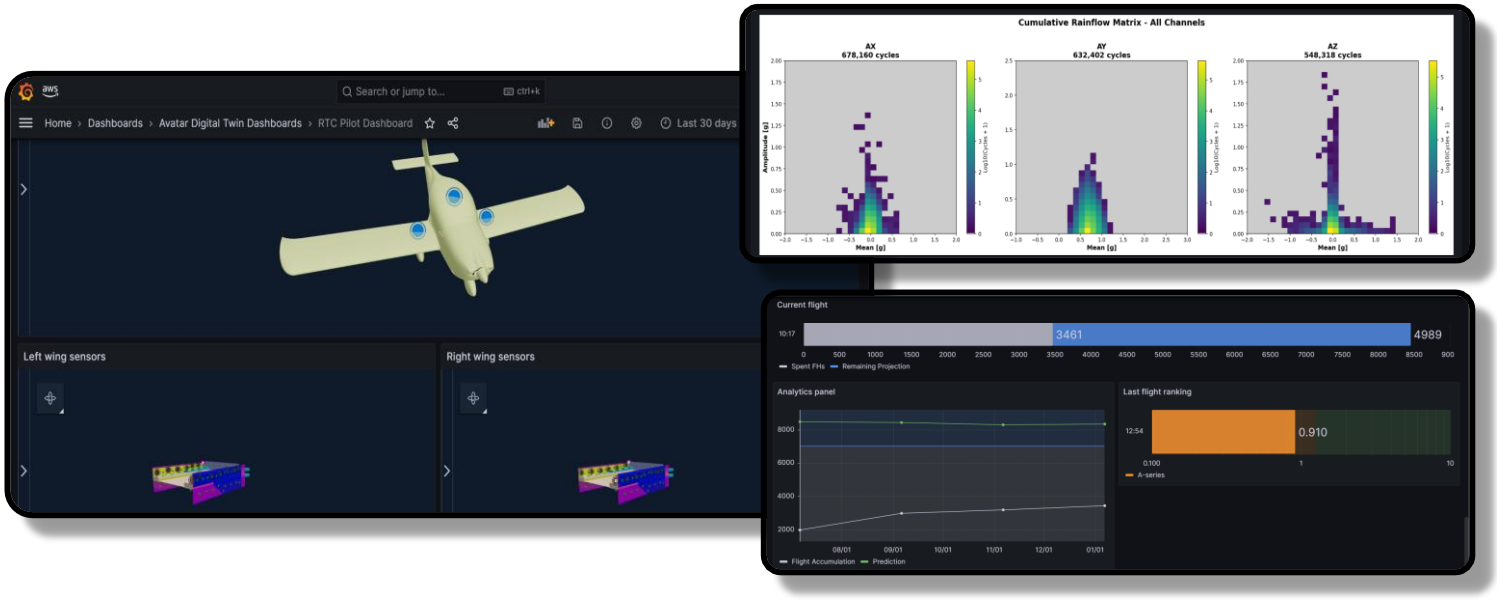
4. **Load reconstruction:** This module is developed to reconstruct the load on the structure, based on point strain readings in order to use it in the fatigue analysis and optimise the RUL of each aircraft at an individual level, and not the fleet level which is the current practice.



Digital Twin Platform

AVATAR's DT platform is a cloud-based solution that enables users to perform post-flight and aggregate flight assessments and analysis based on real data collected from the aircrafts. The platform consists of multiple dashboards designed specifically for the needs of different user profiles including the "Analyst" and the "Pilot". The platform also covers two aircraft type use cases; the EVEKTOR's metallic aircraft, and the Nordic Wing's composite drone. Since each use case follows a different design philosophy (fail-safe and safe-life for metallic structures and damage tolerant for composite), the DT platform for each use case is tailored to their design concept and specific operations, to optimise its usage. The DT platform specifications include:

1. **Interactive dashboard:** A human-centric dashboard is developed utilising Grafana Managed Services, AWS IoT SiteWise and AWS IoT TwinMaker for both pilot and analyst to ensure a user-friendly information sharing, after each flight. The dashboards are powered by AI-driven predictive maintenance, and decision-making components.
2. **Optimise Service life:** Optimised remaining useful life **(RUL)** concept for fail safe and safe life based on real load that the structure has experienced during each flight (rainflow count & cumulative damage).
3. **Secure Data Transfer and Storage:** AWS S3 is used as part of the platform which is a scalable cloud storage service that enables the storage, management, and retrieval of data securely over the internet.
4. **Scalability and Adaptability:** Designing a modular system that can be scaled for use in large fleets and adapted for other industries.



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Topic Reference: Project 101096073 – AVATAR
Call: HORIZON-CL5-2022-D5-01
Start date: February 1, 2023
End date: January 31, 2026





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