ecoLYFE: Discrete-Event Life Cycle Assessment in Aviation

A New Era of Aviation Life Cycle Assessment – Event-Based Simulation of Aircraft from Manufacturing to End-of-Life

LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is a standardized tool for investigating the potential environmental impacts of a product or product system.

The LCA methodology based on DIN EN ISO 14040/14044 [1] consists of the four phases: goal and scope, life cycle inventory, life cycle impact assessment and interpretation as illustrated in Figure 1. It involves defining the goal and scope of the assessment, collecting data on materials and energy flows, assessing the environmental impacts and interpreting the results to draw conclusions. This structured approach evaluates the environmental impact of a concept throughout its whole life cycle.

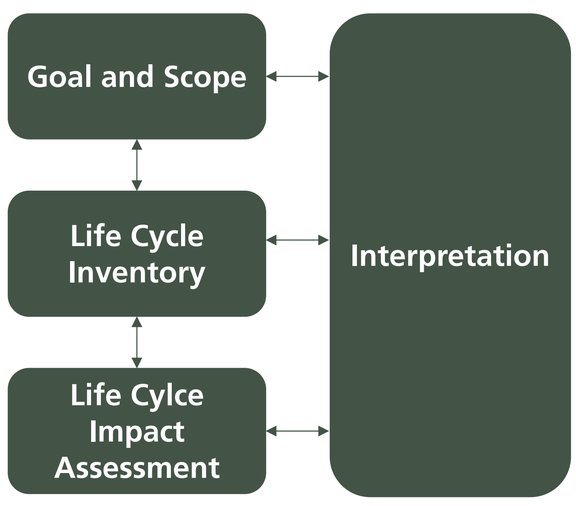

Figure 1: Life cycle assessment stages based on DIN EN ISO 14040/14044.

LIFE CYCLE PHASES

In ecoLYFE, the entire life cycle of the aircraft, as shown in Figure 2, is covered - from raw material extraction to the end-of-life. The LCA is hereby applied for all ground-based impacts including the climate impact for flight operations.

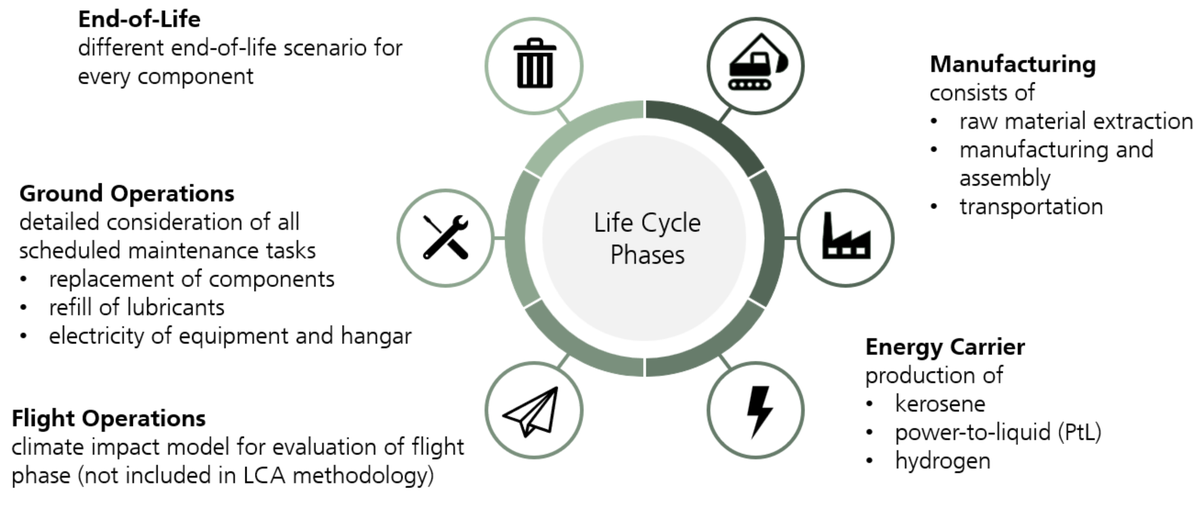

Figure 2: Life cycle phases of an aircraft analyzed in ecoLYFE.

A COMBINED APPROACH FOR LIFE CYCLE ASSESSMENT AND DISCRETE-EVENT SIMULATION

Aviation accounts for about 3.6% of human-induced greenhouse gas emissions, underscoring the need for effective environmental assessment. An LCA evaluates the environmental impact of an aircraft throughout its lifetime, but this process is often overly simplified, neglecting key phases like maintenance. This can lead to significant uncertainties in the results. To enhance accuracy, discrete-event simulation offers a more detailed and flexible modeling approach, as demonstrated by the example in Figure 3. Integrating discrete-event simulation with LCA allows for better comparison of conventional and future aircraft concepts, providing more reliable insights into both economic and environmental impacts.

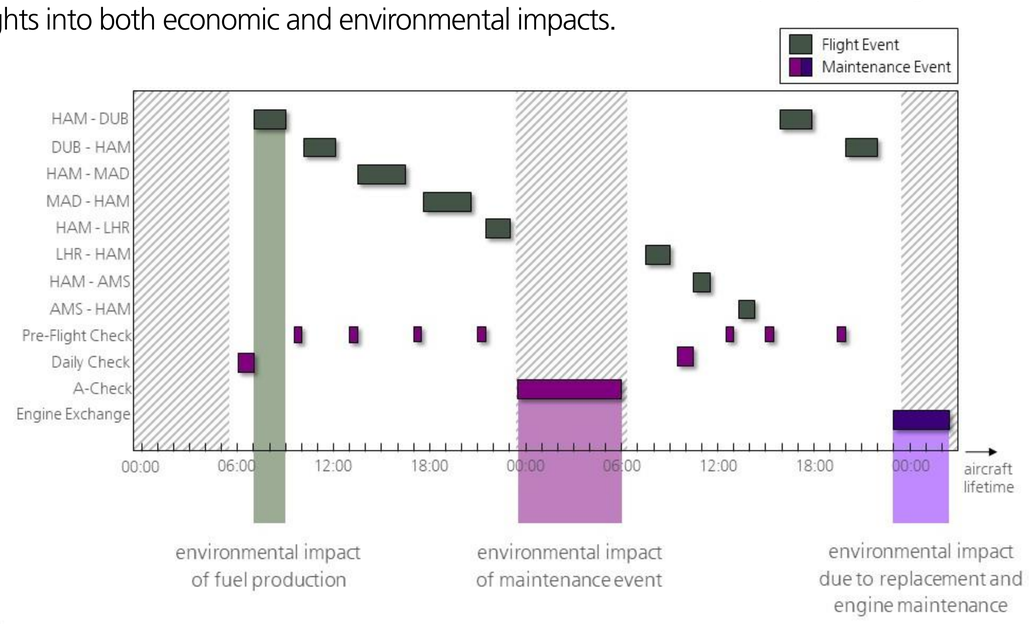

Figure 3: Operating schedule for two days including flight and maintenance events [3].

BENEFITS OF DISCRETE-EVENT SIMULATION

- LCA with discrete-event simulation offers detailed analysis of **individual events** and **life cycle variations** in environmental impact.
- **Modifications**, such as fuel efficiency improvements, can balance additional maintenance with operational savings.
- It enables **real-time** schedule adjustments and **new technology** integration, but demands high **data availability** and careful sensitivity analysis.

ecoLYFE SIMULATION ENVIRONMENT

The foundation of ecoLYFE, as illustrated by Figure 4, is a modular, discrete-event simulation to evaluate the aircraft life cycle from purchase to disposal [2]. It processes user inputs, models all life cycle events - including flights, maintenance and modifications - and calculates flight emissions. The event calendar manages and updates these events, triggering maintenance based on aircraft age and flight cycles. The post-processing module analyzes both economic and ecological data, producing detailed reports on the impacts of maintenance and assesses each life cycle event individually from an environmental perspective.

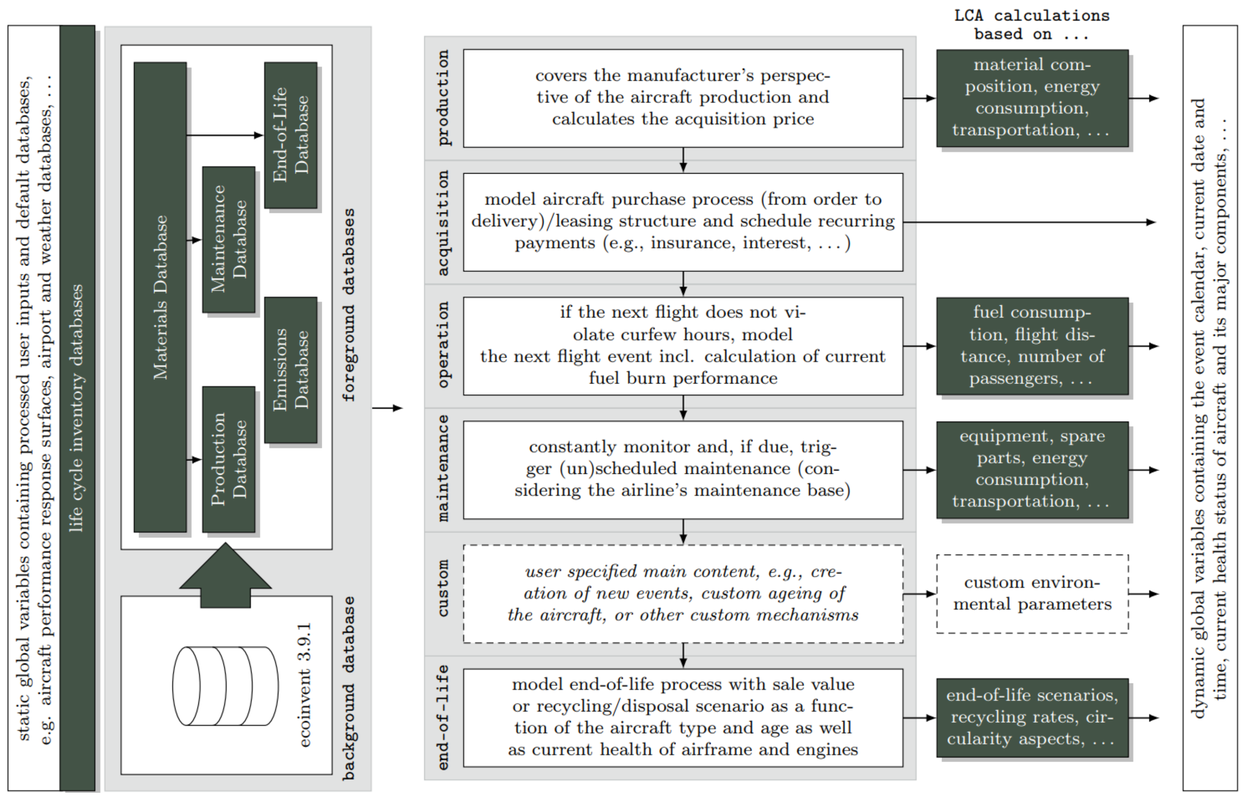

Figure 4: Illustration of the integration and structural setup of LYFE and Brightway within the ecoLYFE system.

In order to calculate the environmental impact, ecoLYFE integrates the Brightway2 framework [4] in conjunction with the ecoinvent 3.9.1 database. A custom *materials database* was developed from ecoinvent, comprising all essential materials for the aircraft, engine, interior, kerosene and other resources required for operations and maintenance. The *materials database* is referenced by the *production*, *maintenance* and *end-of-life databases*, while a separate *emissions database* is utilized to track the environmental impact of flight operations. Brightway extracts data from these sources for each event in the simulation, thereby enabling ecoLYFE to evaluate the aircraft's total ecological footprint throughout its life cycle.

References
[1] ISO 14040/14044. Environmental Management — Life Cycle Assessment — Principles and Framework. 2nd ed., International Organization for Standardization, Geneva, Switzerland. ISO 14040:2006.
[2] Pohya, A.A.; Wehrspohn, J.; Meissner, R.; Wicke, K. A Modular Framework for the Life Cycle Based Evaluation of Aircraft Technologies, Maintenance Strategies, and Operational Decision Making Using Discrete Event Simulation. In: Aerospace 2021, 8, 187.
[3] Rahn, A.; Wicke, K.; Wende, G. Using Discrete-Event Simulation for a Holistic Aircraft Life Cycle Assessment. In: Sustainability 2022, 14, 17.
[4] C. Mutel, Brightway: An Open Source Framework for Life Cycle Assessment, Journal of Open Source Software 2 (12) (2017) 236.

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