Implications for the Design of Battery-Powered Propulsion Systems from a Maintenance Perspective

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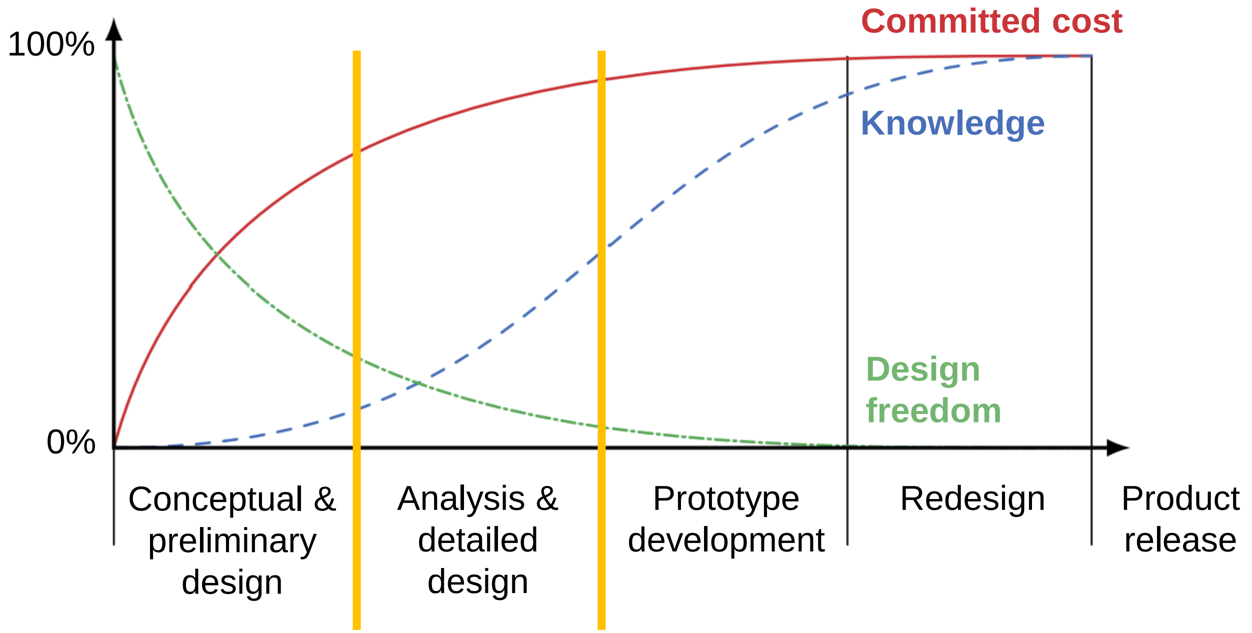
Aircraft development process: A challenge for novel concepts



Assessment of maintenance scope

Conventional concepts

Estimations fairly accurate due to decades of experience

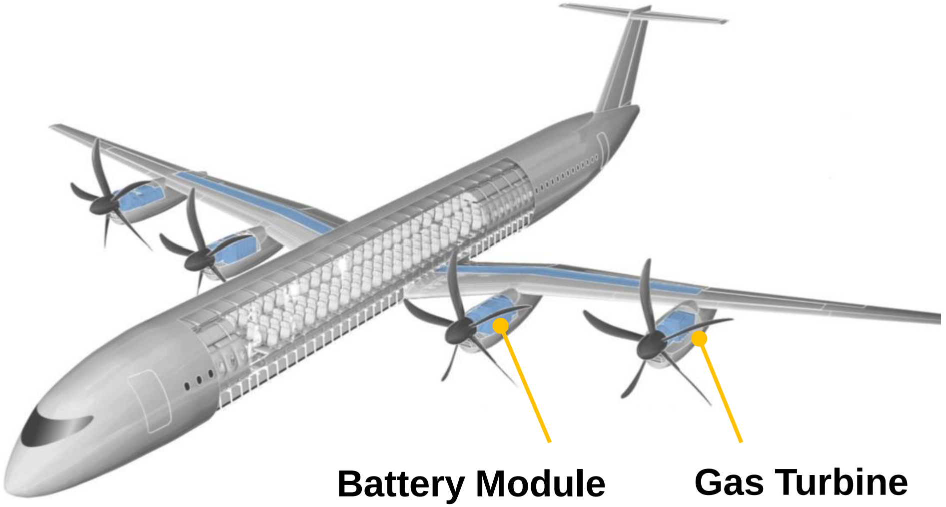
Novel concepts

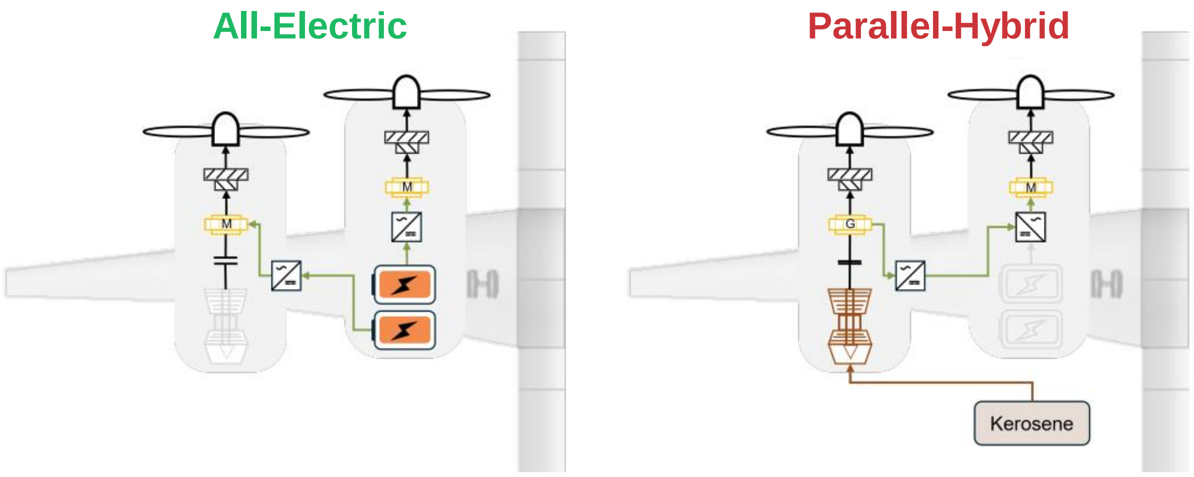
Significant cost uncertainties due to a lack of empirical data

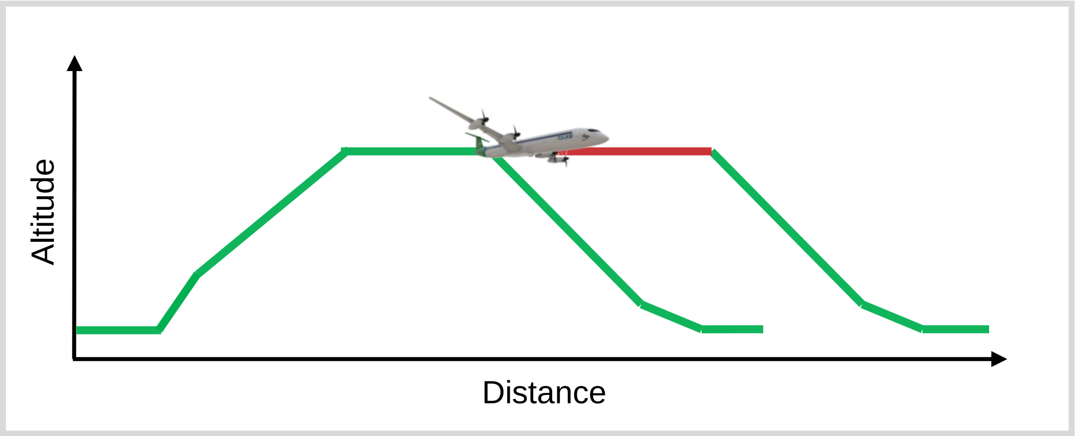
Jan-Alexander Wolf, DLR Institute of Maintenance Repair and Overhaul

What potential targets could be aimed at for battery-powered aircraft?

Use case: Battery-powered parallel-hybrid aircraft concept







Aircraft reference: DLR project EXACT2
Atanasov et al., EXACT sustainable aircraft concepts results and comparison
Weber et al., Collaborative Propulsion System Design: A Framework for the Sizing of a Plug-In-Hybrid-Electric Aircraft Powertrain

Design-driven targets for the battery system

At aircraft level

At system level

1 Low system mass

Maximizing the use of stored energy for all flights

Minimizing the oversizing of battery capacity

2 High utilization rate

Minimizing turnaround times for the aircraft

Minimizing charging time for the battery

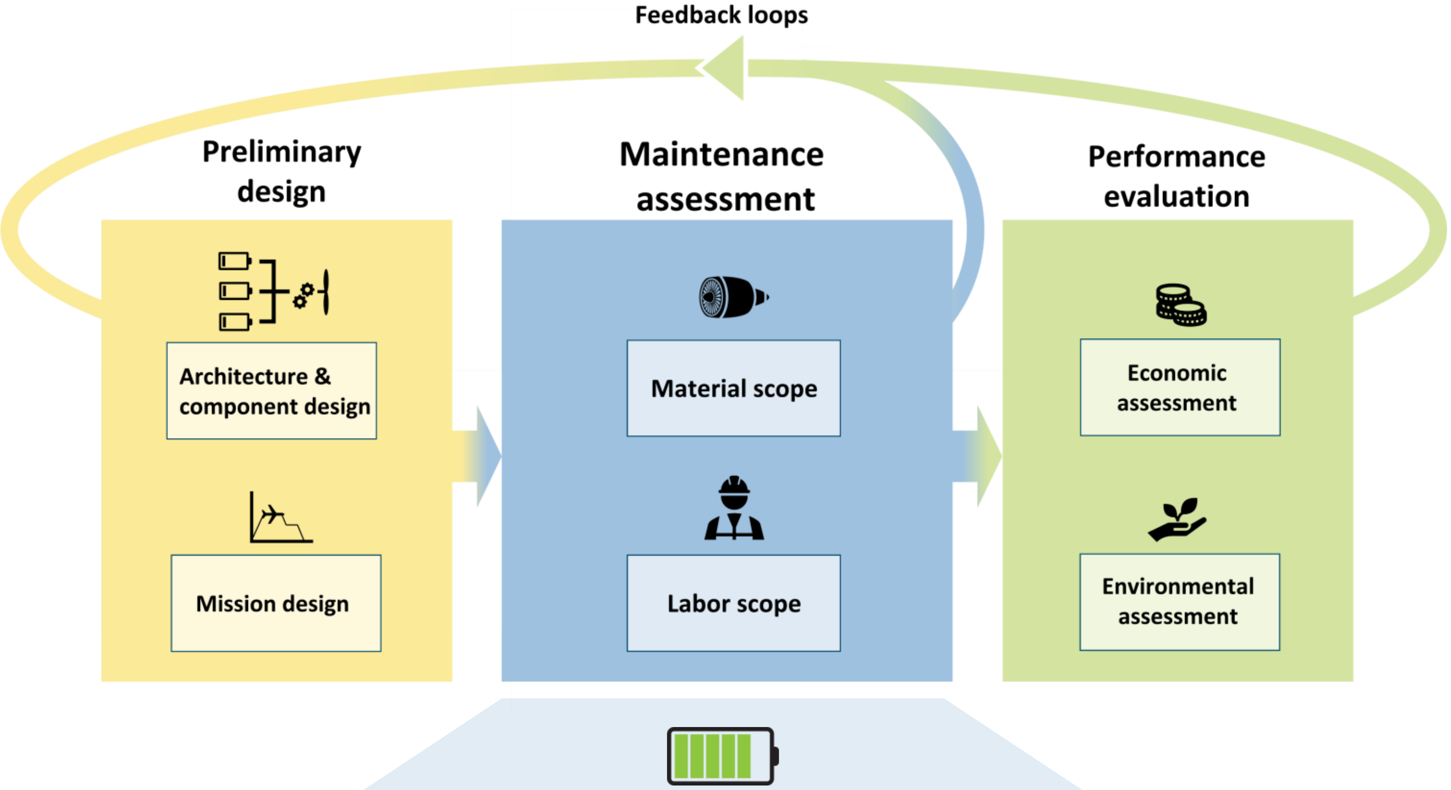
3 Low system complexity

Minimizing the requirements for the cooling system

Maximizing the operational temperature of the battery

How do these targets translate to a maintenance perspective?

Our approach of an integrated maintenance assessment



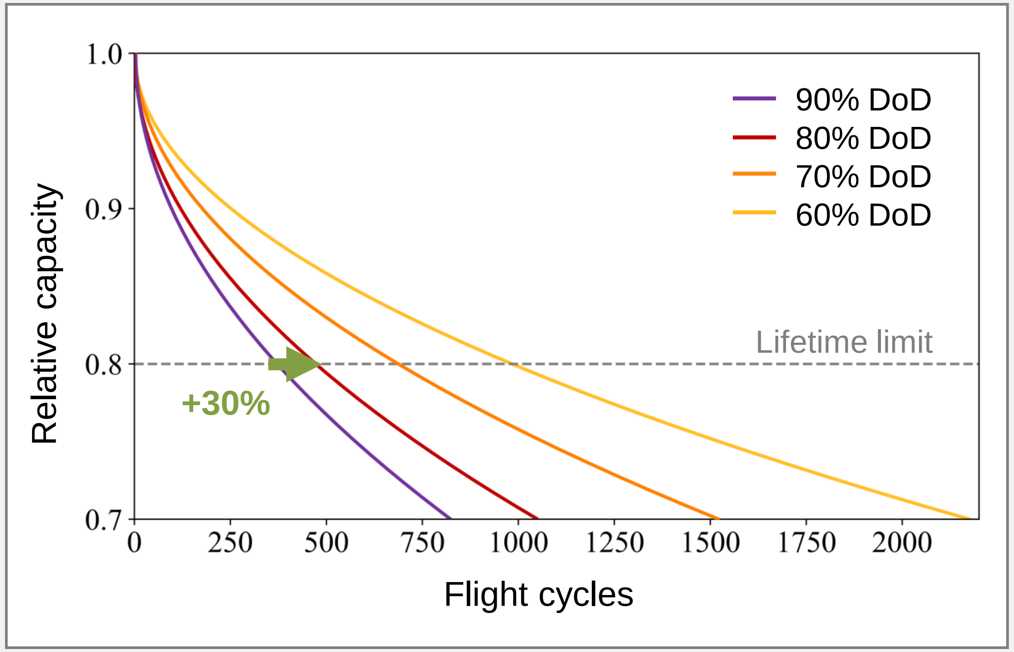
1. Battery **sizing and operating** parameters
2. Applying a semi-empirical **degradation model** and simulating the flight profile
3. Iterating through the mission and derive the **useful lifetime** of the battery

Evaluating the targets from a maintenance perspective

1 Low system mass due to maximizing the use of stored energy

Impacts on battery lifetime

High Depth of Discharge (DoD) mainly impacts **cycle battery aging.** Primary degradation mechanisms are particle cracking and formation of passivation layers.



MRO recommendation at system level

Reducing battery discharge depth from 90% to 80% can extend battery lifetime by about 30%

→ **Reduced replacement cost by about 25%**

Tradeoffs at aircraft fleet level

Optimized battery costs must be evaluated against:

a) Battery oversizing by additional 10%
→ **Reduced mass efficiency**

b) Propulsive energy availability reduced by 10%
→ **Shorter range or higher kerosine demand**

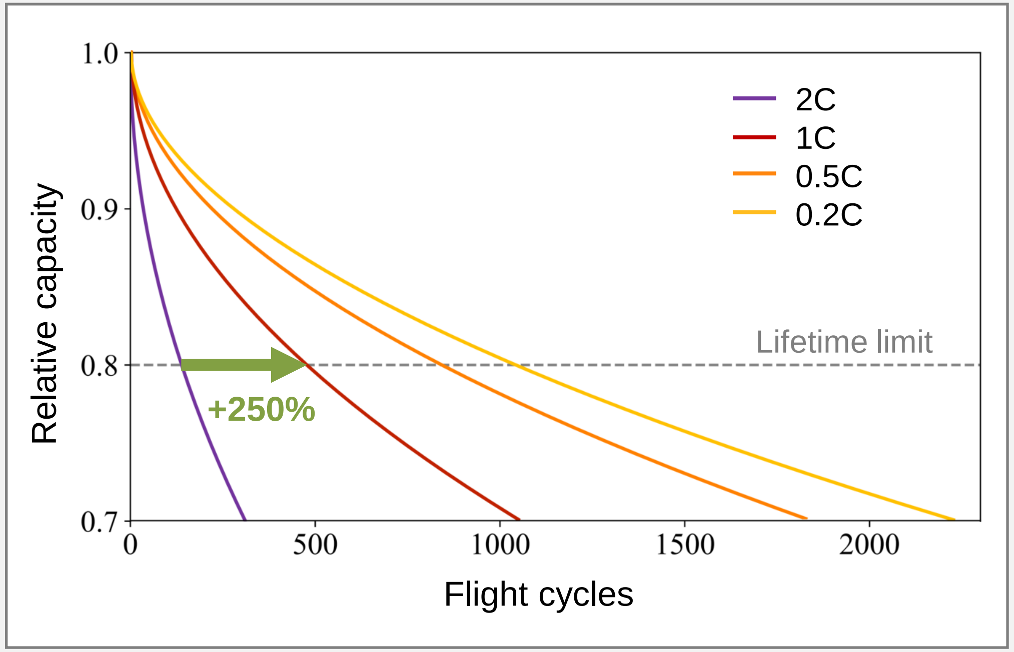
Evaluating the targets from a maintenance perspective

2 High utilization rate due to minimizing turnaround times

Impacts on battery lifetime

High charge rate mainly impacts **cycle battery aging.**

Primary degradation mechanisms are lithium plating and particle cracking.



MRO recommendation at system level

Reducing battery charge rate and doubling the charging time can extend battery lifetime by about 250%

→ **Reduced replacement cost by about 70%**

Tradeoffs at aircraft fleet level

Optimized battery costs must be evaluated against:

a) Increased turnaround time from approx. 30 to 60 min
→ **Decreased utilization**

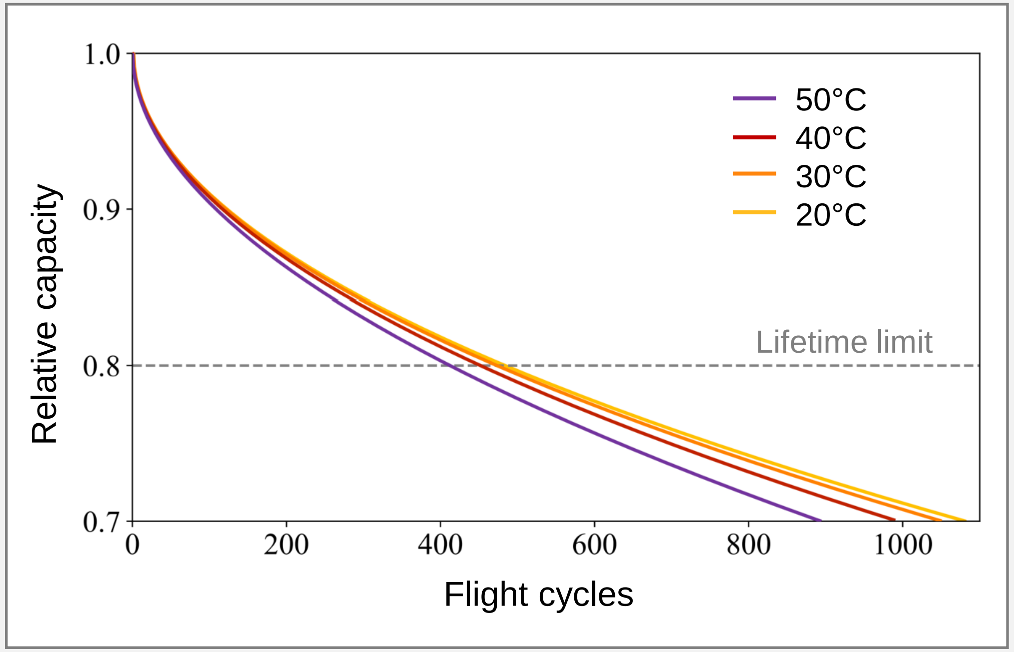
b) Further optimizations likely require battery swapping
→ **Infrastructure required**

Evaluating the targets from a maintenance perspective

3 Low system complexity due to minimizing cooling requirements

Impacts on battery lifetime

High operating temperature mainly impacts **calendar battery aging.** Primary degradation mechanisms are formation of passivation layers and structural changes.



MRO recommendation at system level

Significant temperature reductions only result in **moderate lifetime improvements.** If a certain temperature range is maintained, an extremely **powerful cooling system is likely not required**.

Tradeoffs at aircraft fleet level

From a degradation perspective, an extremely complex, heavy, and expensive cooling system **can be avoided.**

How can we support?

Our roadmap & vision

Defining maintenance scopes and assessing maintenance needs for novel aircraft systems in early design stages

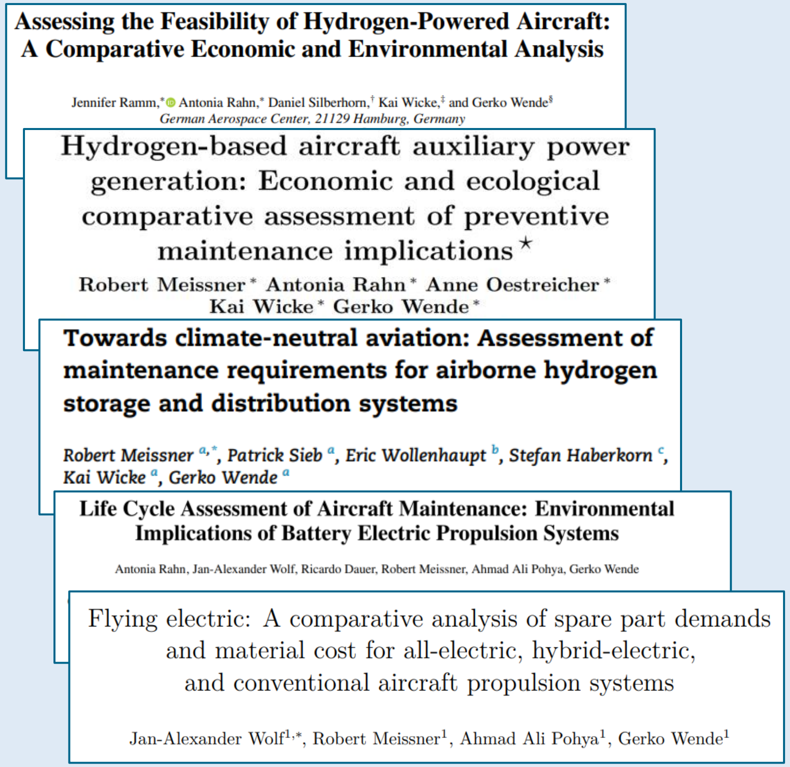
Battery — H_2 — SAF — Technology X

We know ... the correlations between design specifications, operating conditions, and resulting maintenance implications.

We perform ... holistic maintenance assessments of novel systems and improve established evaluation methods.

We support ... technology experts in the development of viable and cost-efficient designs from a maintenance perspective.

Publications



Assessing the Feasibility of Hydrogen-Powered Aircraft: A Comparative Economic and Environmental Analysis

Jennifer Ramm,* Antonia Rahn,* Daniel Silberhorn,† Kai Wicke,‡ and Gerko Wende§
German Aerospace Center, 21129 Hamburg, Germany

Hydrogen-based aircraft auxiliary power generation: Economic and ecological comparative assessment of preventive maintenance implications

Robert Meissner* Antonia Rahn* Anne Oestreicher* Kai Wicke* Gerko Wende*

Towards climate-neutral aviation: Assessment of maintenance requirements for airborne hydrogen storage and distribution systems

Robert Meissner [a,*], Patrick Sieb [a], Eric Wollenhaupt [b], Stefan Haberkorn [c], Kai Wicke [a], Gerko Wende [a]

Life Cycle Assessment of Aircraft Maintenance: Environmental Implications of Battery Electric Propulsion Systems

Antonia Rahn, Jan-Alexander Wolf, Ricardo Dauer, Robert Meissner, Ahmad Ali Pohya, Gerko Wende

Flying electric: A comparative analysis of spare part demands and material cost for all-electric, hybrid-electric, and conventional aircraft propulsion systems

Jan-Alexander Wolf[1,*], Robert Meissner[1], Ahmad Ali Pohya[1], Gerko Wende[1]

And many more…

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Meet our department

Imprint

Topic: **Implications for the Design of Battery-Powered Propulsion Systems from a Maintenance Perspective**

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