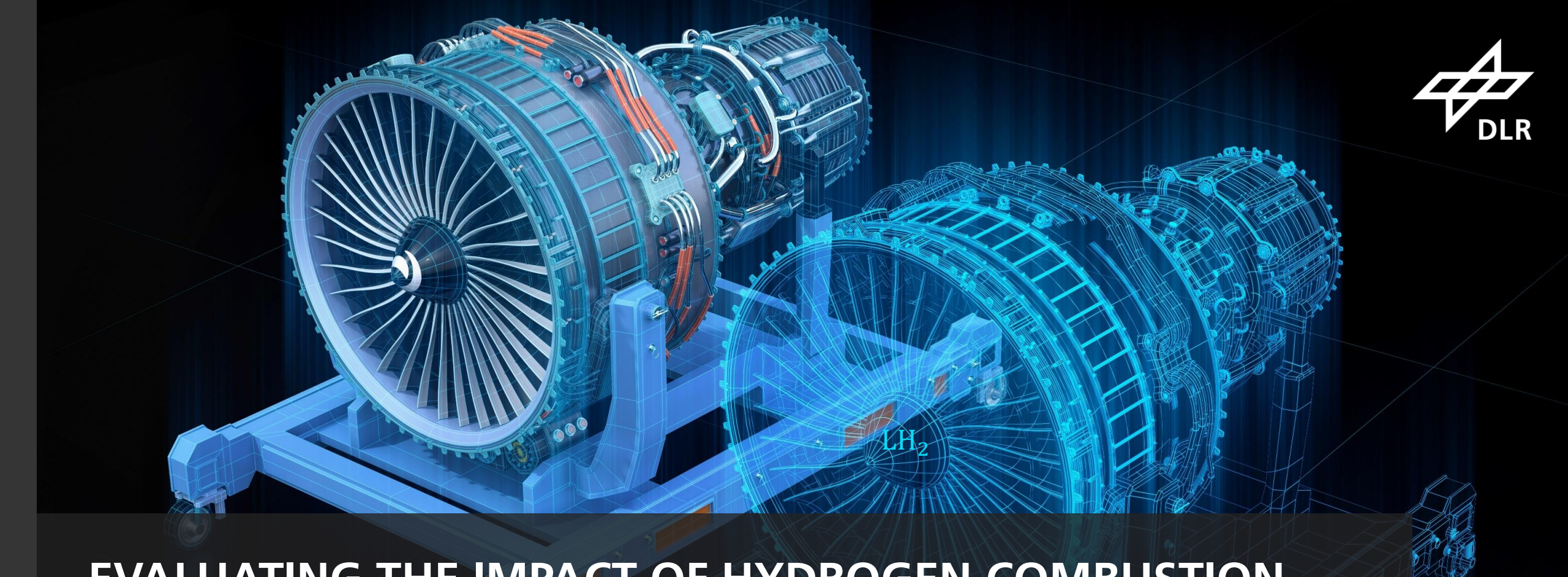

EVALUATING THE IMPACT OF HYDROGEN COMBUSTION MAINTENANCE ON AIRCRAFT ECONOMICS

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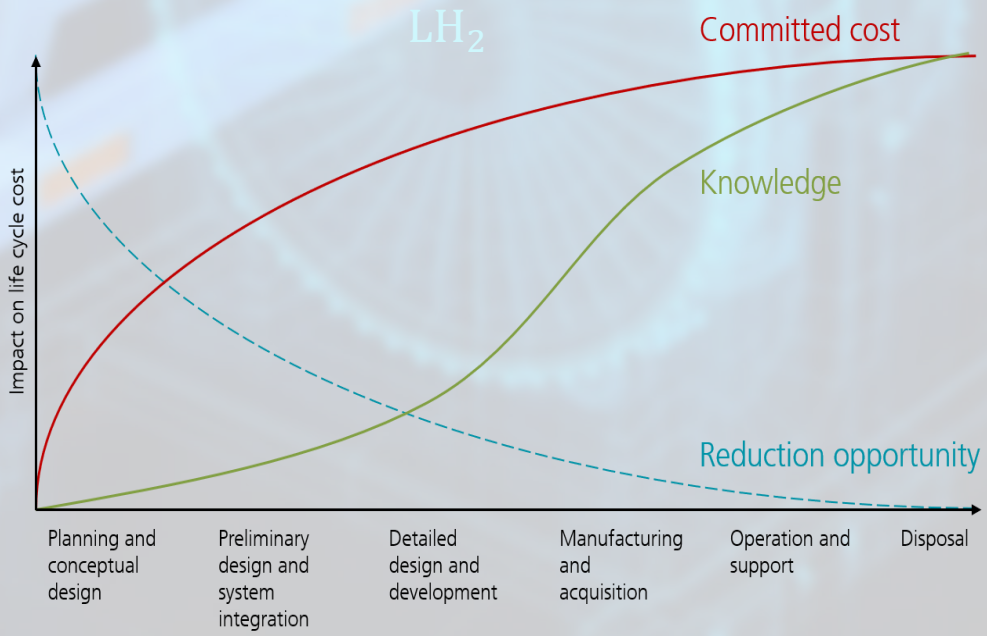
Rising global **climate impact** from **aviation** sector:

Innovative solutions for **low-emission aircraft** concepts

Early estimation of technology potential



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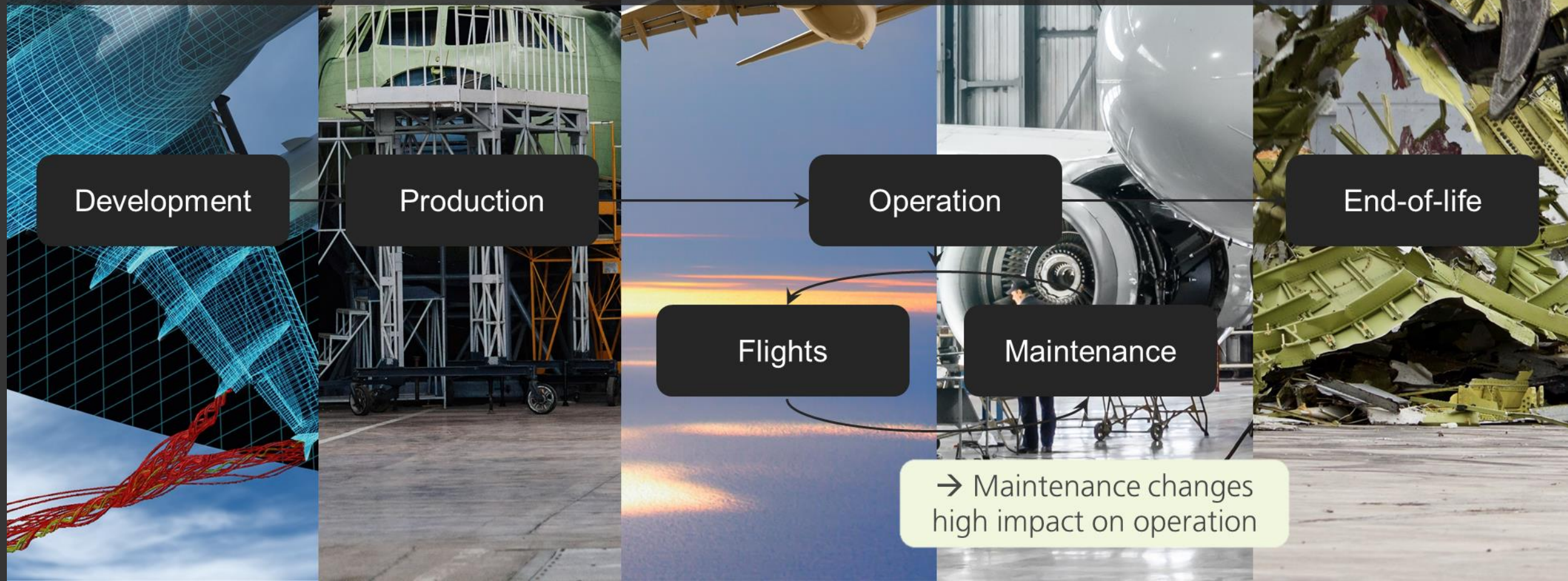
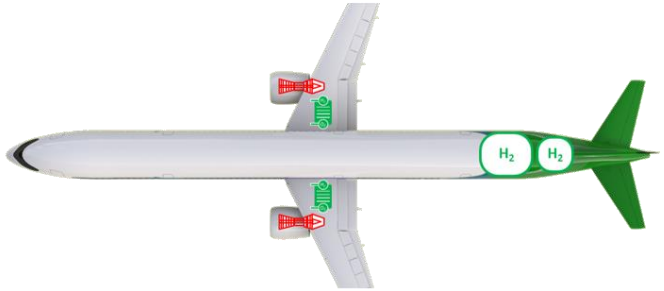


Changes Towards LH_2 Aircraft

Show stopper?

Focus on epistemic uncertainties

Conventional aircraft



Hydrogen powered aircraft

Hydrogen tanks

Tank exchange uncertainties:

Ramm et al. 2024

Hydrogen combustion

Hydrogen Combustion Engines?

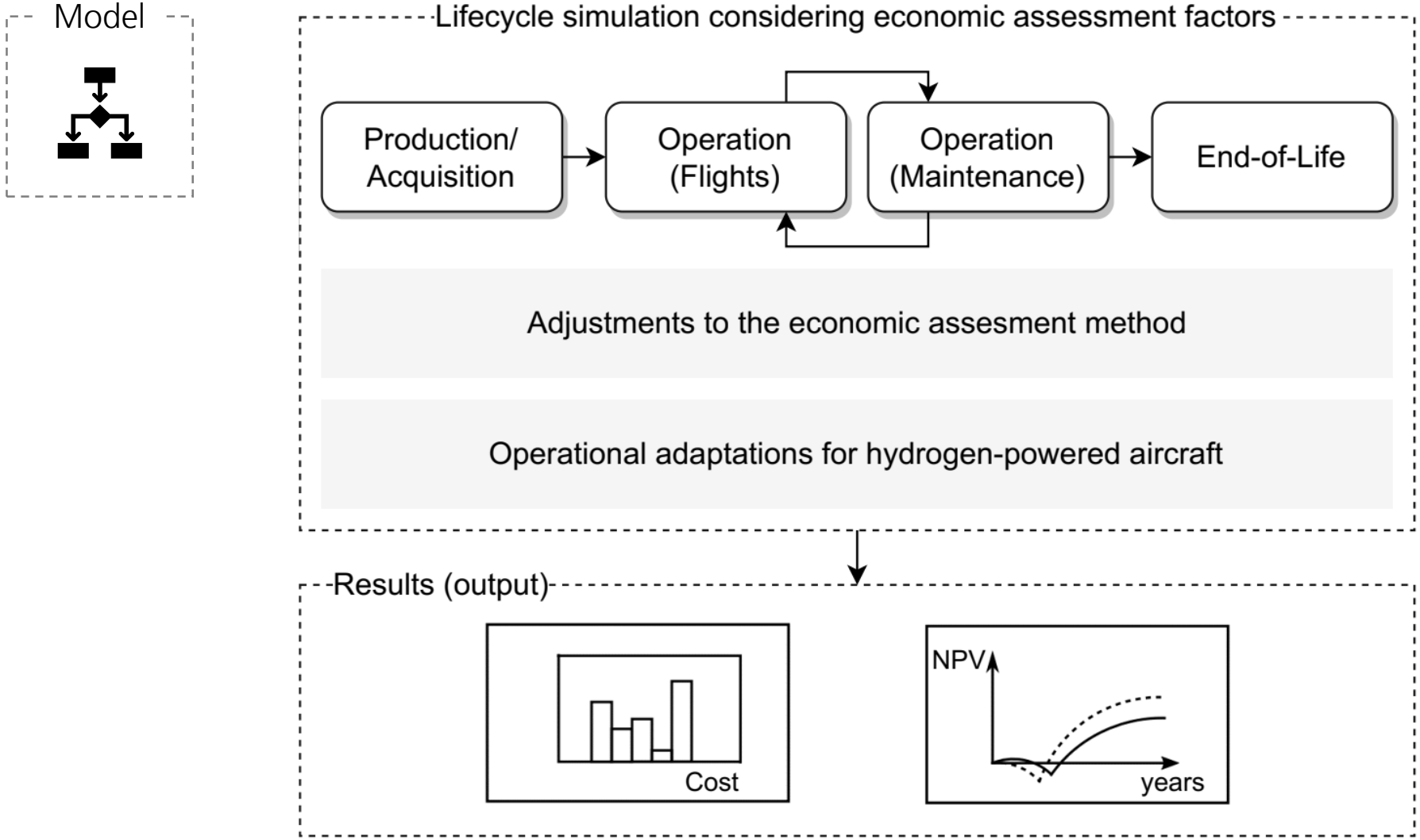
Fuel cell system and LH_2 delivery system

Future

Aircraft concepts from:

Model for life cycle cost estimation - LYFE

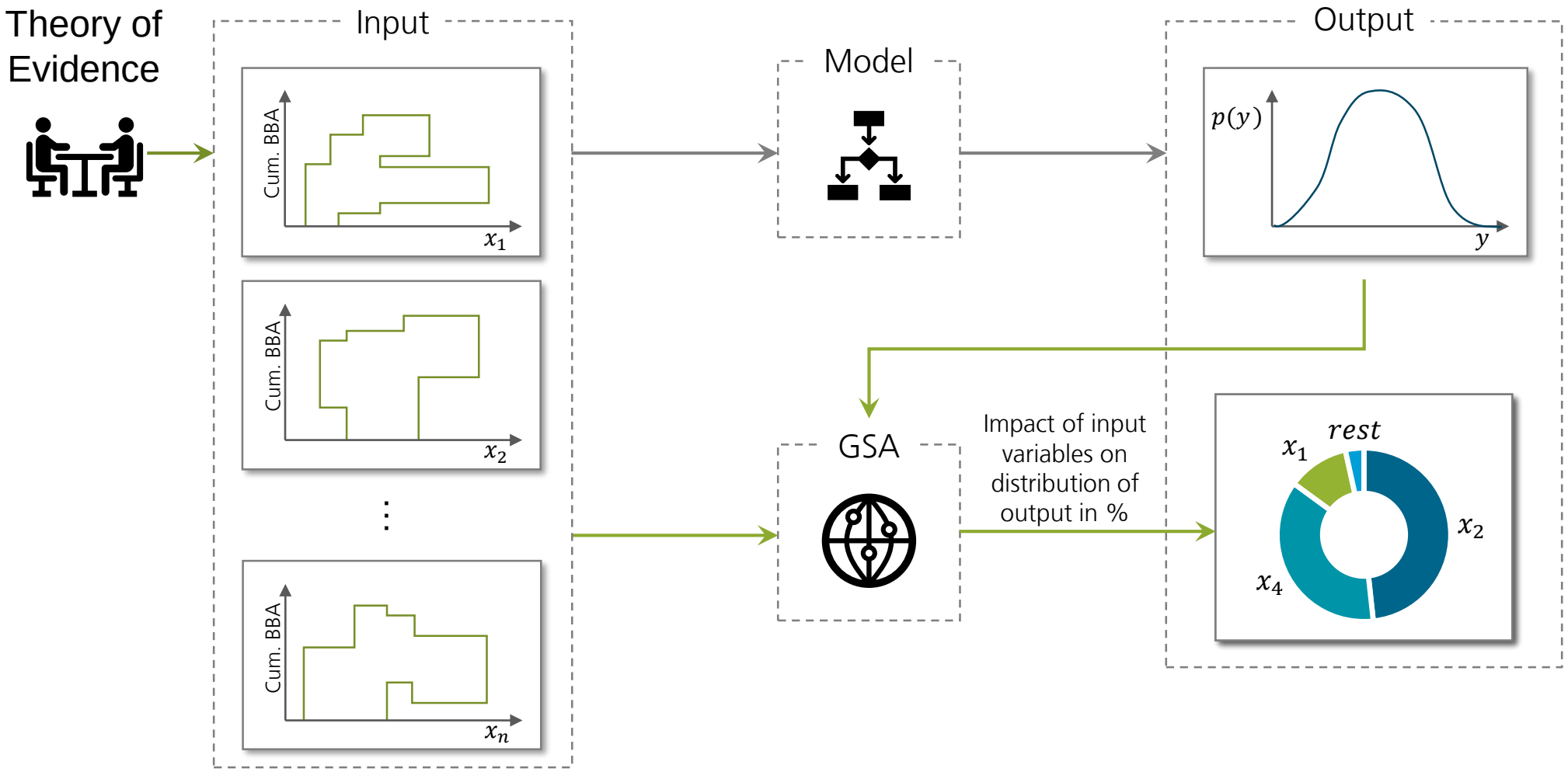
General method – Overview [4]



[4] Ramm et al. - Assessing the Feasibility of Hydrogen-Powered Aircraft: A Comparative Economic and Environmental Analysis, Journal of Aircraft 2024, DOI: 10.2514/1.C037463

Method - Overview

How to integrate uncertainty quantification in assessment within early development phases [3]

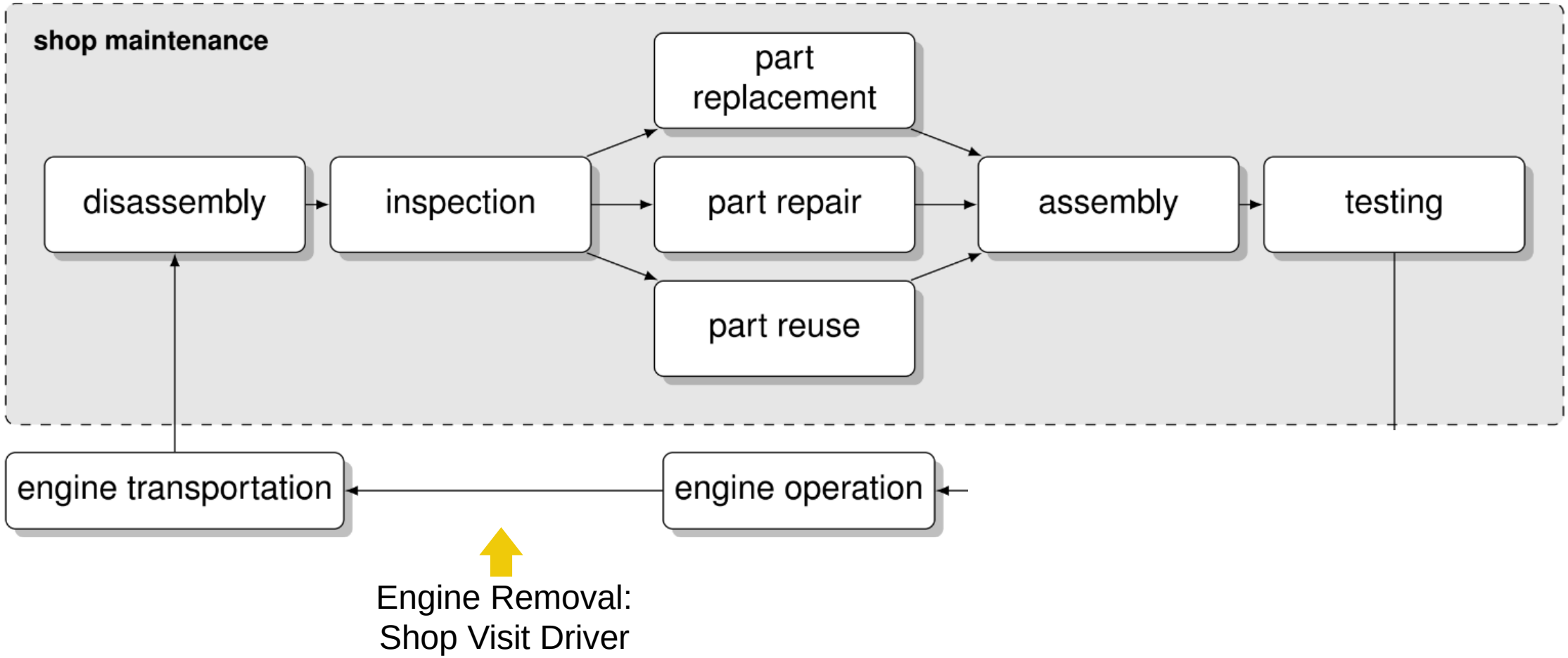


[3] Ramm et al. - Uncertainty quantification in hydrogen tank exchange: Estimating maintenance costs for new aircraft concepts, International Journal of Hydrogen Energy 2024, DOI: 10.1016/j.ijhydene.2024.04.157

TECHNICAL OVERVIEW

Engine Maintenance Overview

Shop Visit Process [1]



[1] Oestreicher et al. - *Sustainable Engine Maintenance: Evaluating the Ecological Impact of Life Limited Part Replacement.* ICAS 2024

Shop Visit Drivers for Kerosene Combustion Engines

Common Engine Failures [2]

Categories of Causes

- **Impact**
  - Foreign Object Damage
  - Weather
  - Sand
  - …
- **Environmental**
  - Polluted air
  - Moisture
  - Acids
  - …
- **Operational**
  - Overheating
  - Vibrations
  - Turbulences
  - …
- **Fatigue**
  - Stress concentrations
  - Life time of part exceeded
  - Surface finish
  - …

Defect/ Damages

- **Material damage**
  - Corrosion
  - Sulfidation
  - Erosion
  - …
- **Wear**
  - Abrasion
  - Groove
  - …
- **Material separation**
  - Chipping
  - Crack
  - …
- **Material deformation**
  - Bent
  - Creep
  - …

Consequences

- **Mechanical damage**
- **Efficiency reduction**

[2] Aust et al. - *Taxonomy of Gas Turbine Blade Defects.* Aerospace 2019 DOI: 10.3390/aerospace6050058

Shop Visit Drivers for Kerosene Combustion Engines

Common Engine Failures [2]

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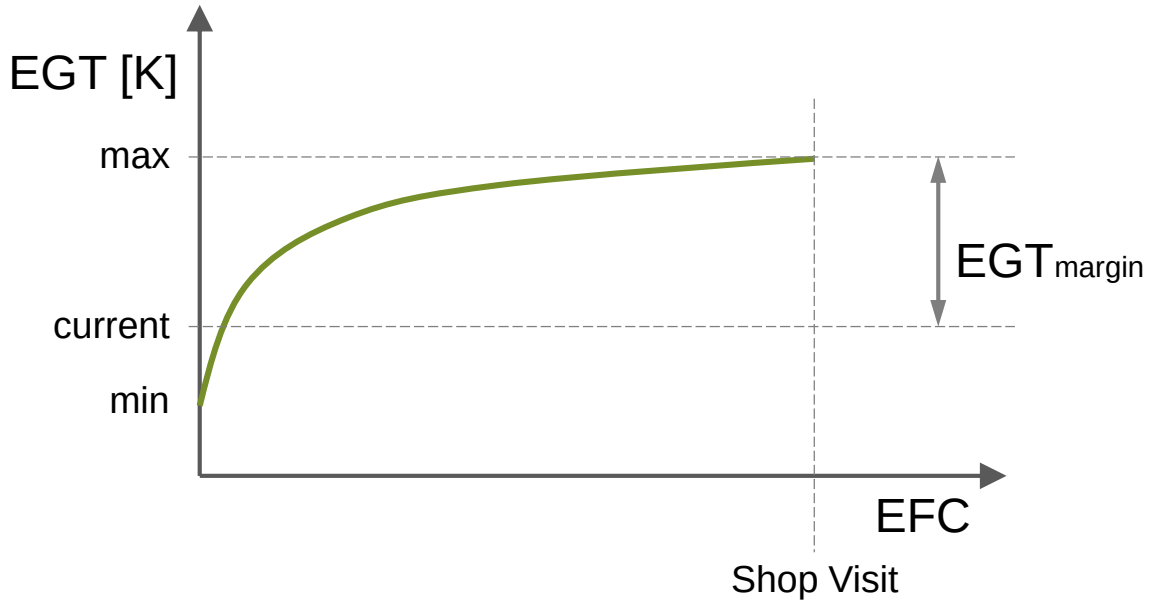
Consequences

- Mechanical damage
- Efficiency reduction

Engine Parameter (monitored)

- Exhaust Gas Temperature Margin



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Shop Visit Drivers for Kerosene Combustion Engines

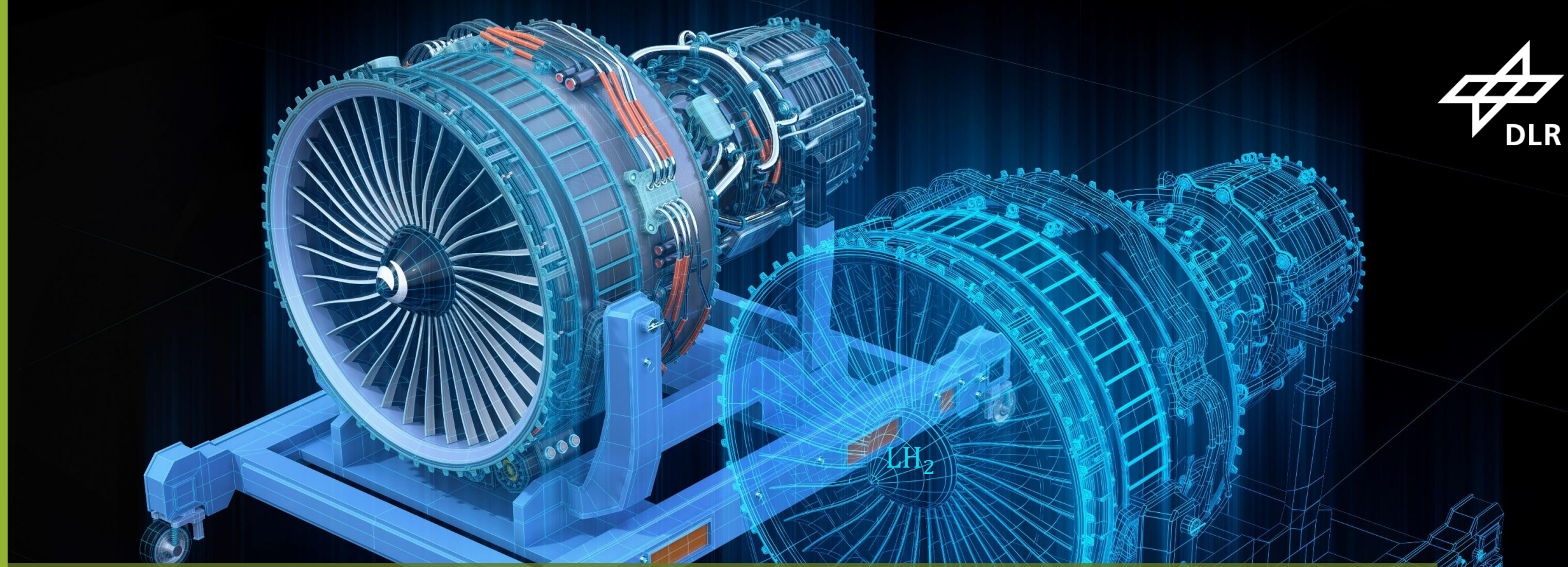
Common Engine Failures [2]

Defect/ Damages		Consequences
Material damage	• Corrosion • Sulfidation • Erosion • …	
Wear	• Abrasion • Groove • …	Mechanical damage
Material separation	• Chipping • Crack • …	Efficiency reduction
Material deformation	• Bent • Creep • …	

Engine Parameter (monitored)

- Exhaust Gas Temperature Margin
- Life Limited Parts
- Spool Speeds
- Fuel supply
- Oil pressure/ temperature
- Vibrations
- Metal particles in the system

[2] Aust et al. - *Taxonomy of Gas Turbine Blade Defects.* Aerospace 2019 DOI: 10.3390/aerospace6050058



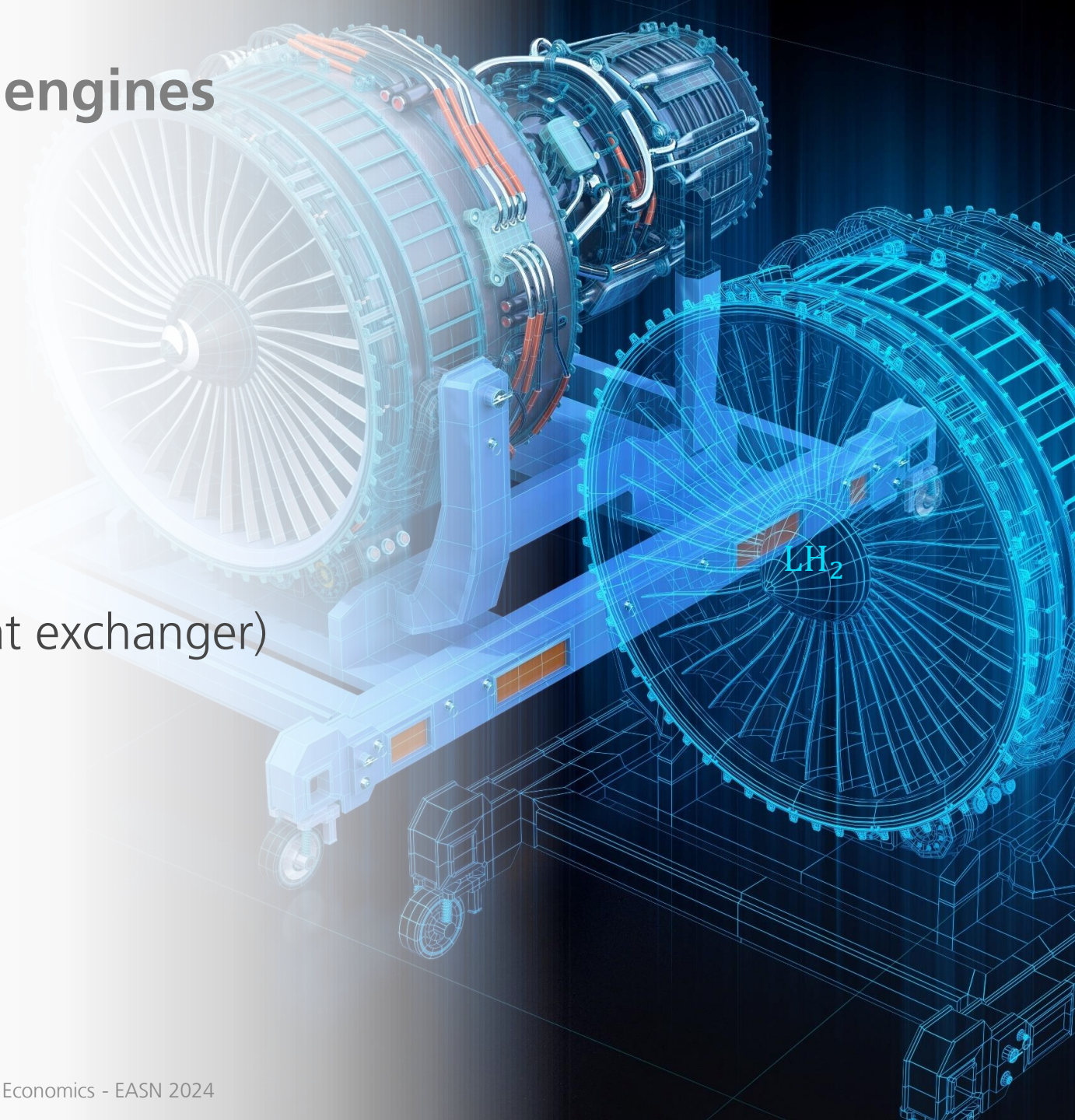
CHANGES FOR LH_2 COMBUSTION ENGINES?

Changes for LH_2 combustion engines

Overview

- Combustion temperature
- Spool speeds
- Water density in exhaust
- Hydrogen pre-conditioning (heat exchanger)

→ EGT margin
→ LLP limits
→ Material cost



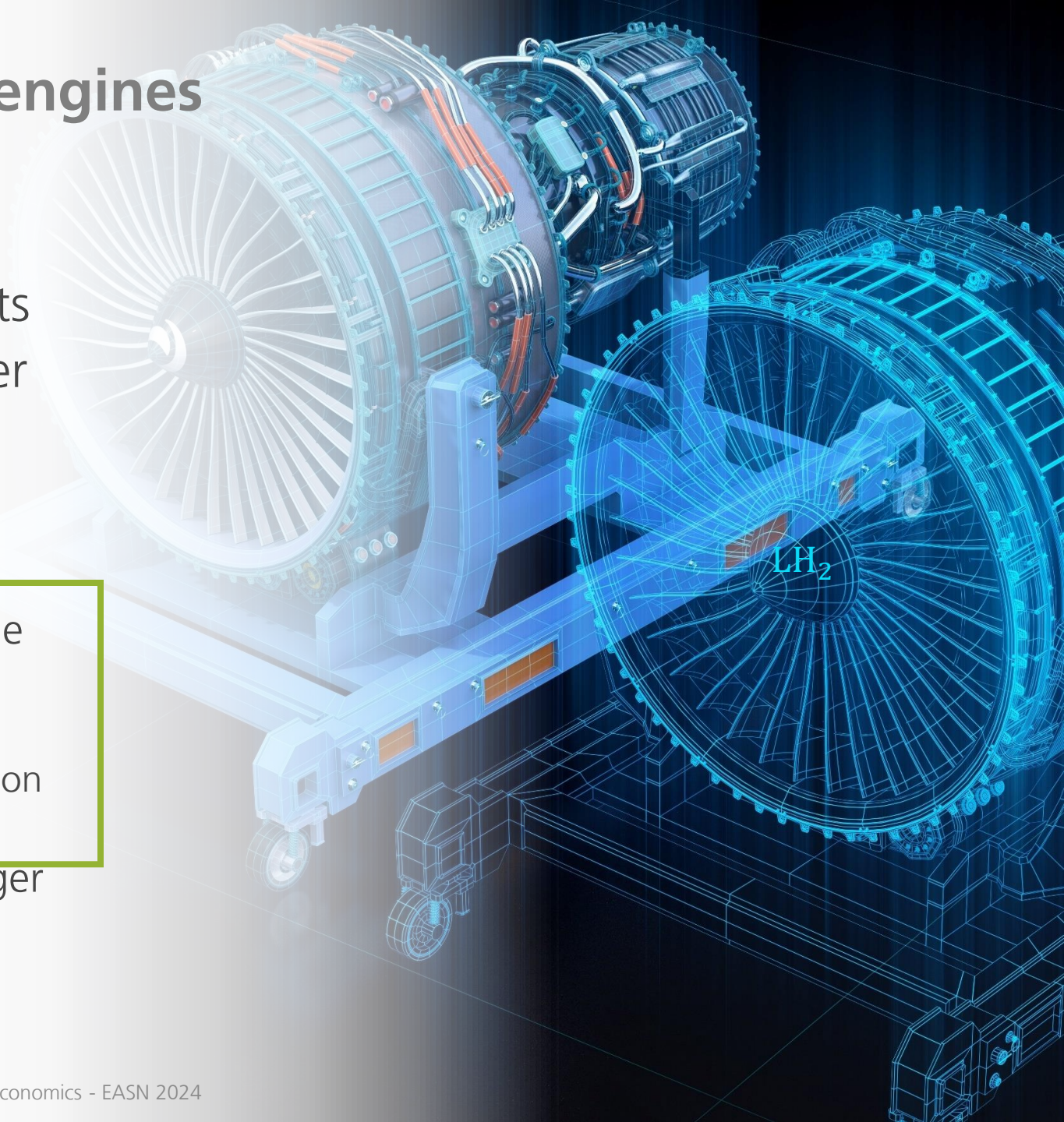
Changes for LH_2 combustion engines

First insights

- Maintenance limits are design targets
- Biggest uncertainty – Heat exchanger

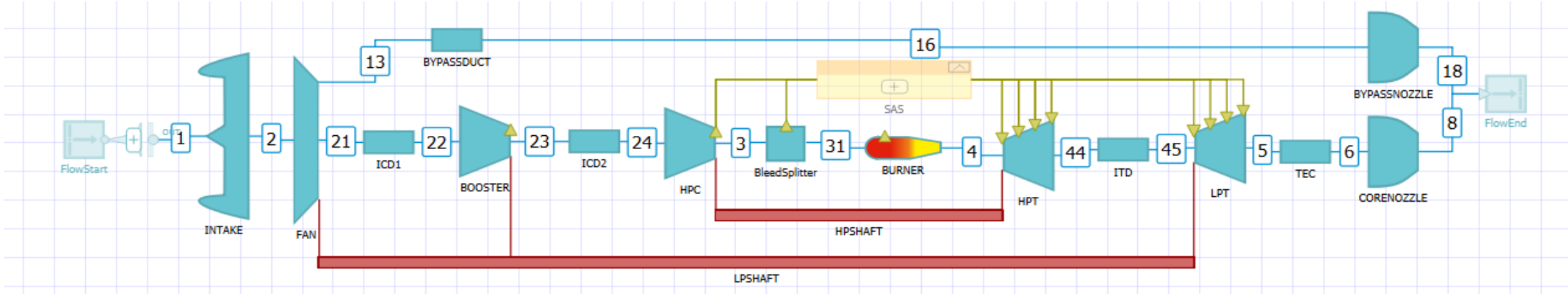
Two folded study:

- Maintenance changes for retrofit engine
  - Different combustion chamber for LH_2 combustion
  - Overview for pot. changes and effects on maintenance
- Maintenance changes for heat exchanger



Engine Parameter – Retrofit Engine

Hydrogen combustion engine vs. kerosene combustion engine



Delta values between hydrogen combustion engine and kerosene engine

		Hydrogen Combustion	
		Cruise	MTO ISA+15K
Compressor Outlet Temperature (T3)	[K]	7.9	6.8
Combustor Outlet Temperature (T4)	[K]	22.3	-51.3
Turbine Rotor Inlet Temperature (41)	[K]	-17.4	-42.8
High Pressure Turbine Outlet Temperature (T45)	[K]	-8.1	-23.7
Exhaust Gas Temperature (T5)	[K]	-9.2	-20.5
HPSHAFT N (Spool Speed)	[%]	1.37	1.38
LPSHAFT N (Spool Speed)	[%]	3.1	1.6
W21 (Core Mass Flow)	[%]	5.82	2.63

[3] Görtz et al. - Step-by-Step Evaluation of the Fuel Switch From Kerosene to Hydrogen on the Thermodynamic Cycle in Gas Turbine Engines. ASME 2024 DOI:10.1115/1.4065926

STUDY SURVEY:

Potential show stoppers and challenges of LH_2 aircraft need to be identified!

→ Maintenance and safety aspects can have a big impact!

Thanks For Your Attention!

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Product Lifecycle Management