23–27 JANUARY 2023

Clean Aviation Special Session: Innovative Aircraft Concepts and Novel Configurations

AGENDA

Presentations

Overview of CHYLA and GLOWOPT Projects: Methods for Sustainable Aircraft Design

Dr. Maurice Hoogreef*, *Pieter-Jan Proesmans, *Delft University of Technology*

From Design to Final Validation of a Full-Scale Morphing Droop Nose Demonstrator

Alessandro De Gaspari, *Politecnico di Milano*

SPEAKERS

Dr. Maurice Hoogreef

Assistant Professor, Faculty of Aerospace Engineering

Delft University of Technology

Pieter-Jan Proesmans

Faculty of Aerospace Engineering

Delft University of Technology

Alessandro De Gaspari

Assistant Professor

Politecnico di Milano

THANK YOU!

CLEAN AVIATION

CHYLA

Credible **HY**brid e**L**ectric **A**ircraft

Presenter:

Dr.ir. M.F.M. (Maurice) Hoogreef – TU Delft

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CHYLA – CREDIBLE HYBRID ELECTRIC AIRCRAFT

- CHYLA: Credible Hybrid Electric Aircraft
  - **THEMATIC TOPIC – 2020 - 2023**
- Landscape of opportunities, challenges and limitations for application of key radical technologies in terms of **scalability** across different classes:
  - **GA, COMMUTER, REGIONAL, SMR AND LPA**
- Credibility (uncertainty) of underlying technology assumptions as explicit factor in MDO approach
- Analysis of the infrastructure, operational, & economical aspects.

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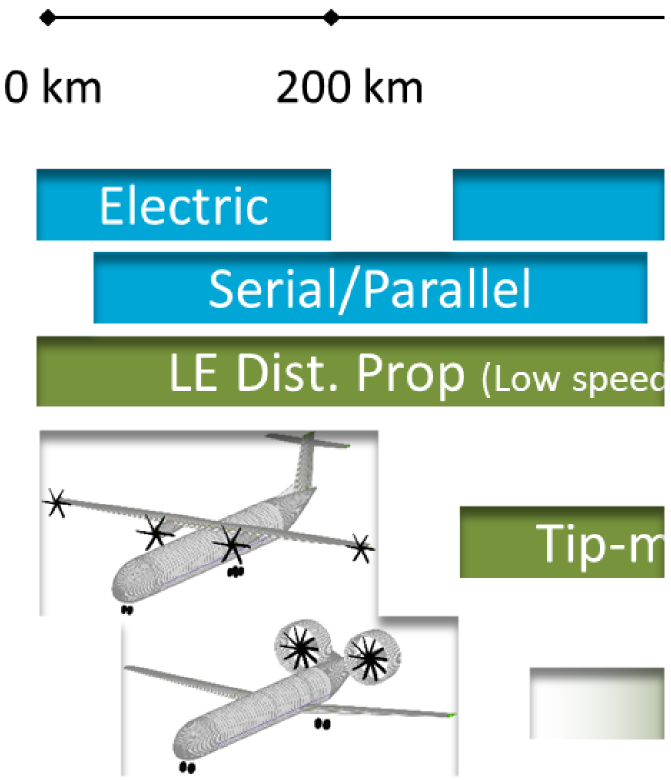
APPROACH TO ASSESS SCALABILITY



- ✓ Integrating novel airframe technologies with hybrid electric energy network.
  - ☐ AVIATION 2022 10.2514/6.2022-3741
- ✓ Integrated aircraft design with physics-based subsystem design.
  - ☐ CEAS AERONAUTICAL JOURNAL 10.1007/s13272-022-00601-6; ICAS2022_0248; ICAS2022_0481; SCITECH 2023 10.2514/6.2023-2098
- ✓ Credible hybrid electric aircraft design through MDO. → “Credibility-based MDO”
  - ☐ ICAS2022_0850 & SCITECH 2023 10.2514/6.2023-1847
- ➢ Analysis of the infrastructure, operational, economical, safety, reliability and regulatory aspects.
  - ☐ Submitted to AIAA/EATS 2023

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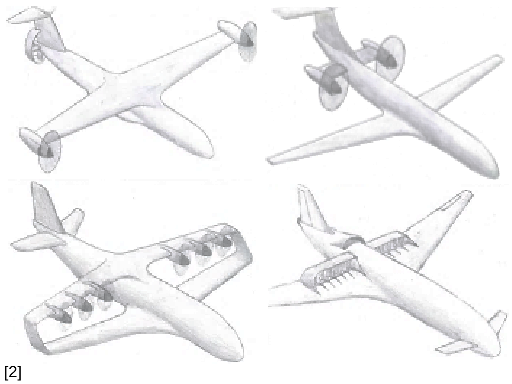
CLEAN AVIATION

CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

SUSTAINABLE AIRCRAFT DESIGN?

Vast literature involving:
- different scales
- different technologies
- different aircraft configurations
- different design tools



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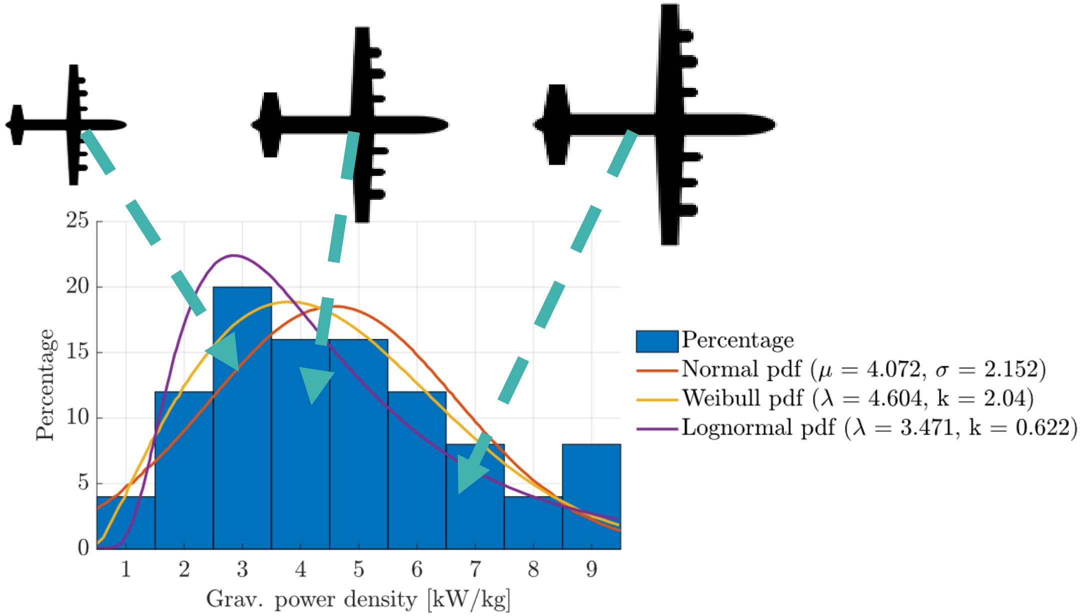
[3] CC-BY-SA-3.0

- Which technologies can be applied ?
- At which scales can they be applied ?
- What is the credibility of the technological assumptions made?

COM → REG → SMR



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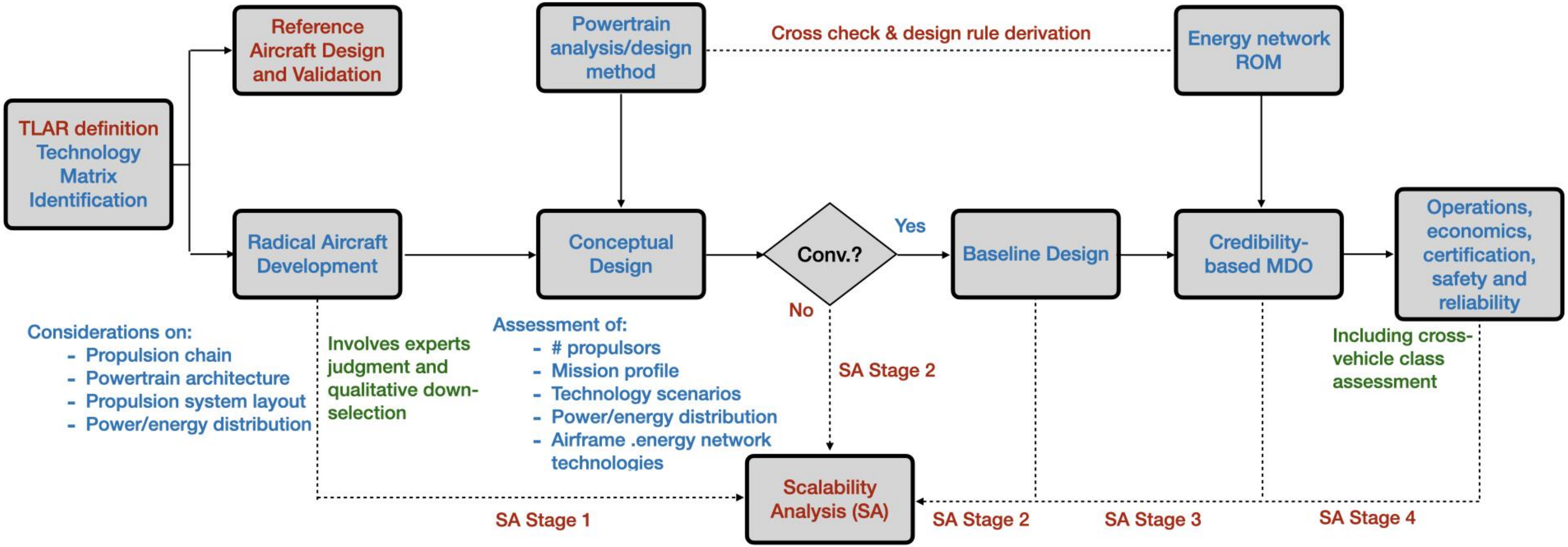
PROJECT OUTLINE

Per vehicle class; all designs/optimizations are manually analysed for performance and compared to references



TLAR definition
Technology Matrix Identification

Reference Aircraft Design and Validation

Radical Aircraft Development

Considerations on:
- Propulsion chain
- Powertrain architecture
- Propulsion system layout
- Power/energy distribution

Involves experts judgment and qualitative down-selection

Powertrain analysis/design method

Cross check & design rule derivation

Energy network ROM

Conceptual Design

Assessment of:
- # propulsors
- Mission profile
- Technology scenarios
- Power/energy distribution
- Airframe .energy network technologies

Conv.?

Yes

No

Baseline Design

Credibility-based MDO

Operations, economics, certification, safety and reliability

Including cross-vehicle class assessment

Scalability Analysis (SA)

SA Stage 1

SA Stage 2

SA Stage 2

SA Stage 3

SA Stage 4

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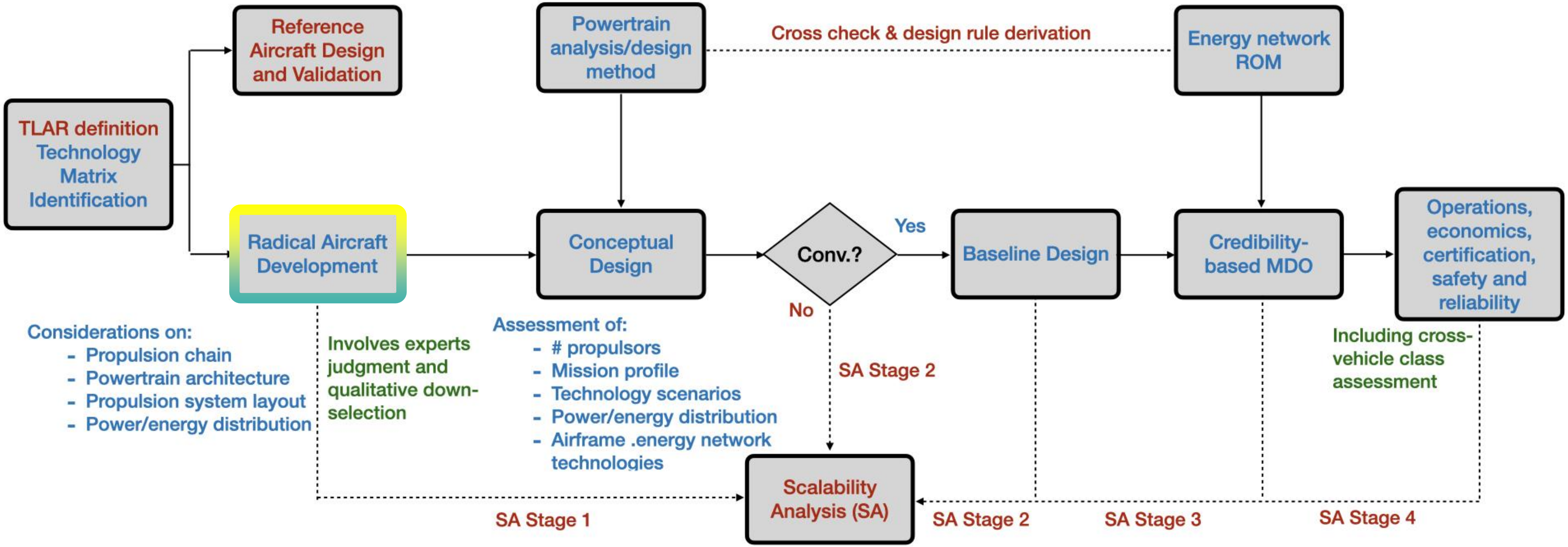
Per vehicle class; all designs/optimizations are manually analysed for performance and compared to references



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CLEAN AVIATION

CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

REFERENCE AIRCRAFT & TLARS

reference aircrafts (conventional)		Long Range (~A350-900) CS-25	Medium Range (~ A320-NEO) CS-25	Regional (~ ATR72-600) CS-25	Commuter CS-23	General Aviation CS-23
mission requirements	pax	315	150	70	19	4
	payload [t]	53,5	20	7,5	2,3	0,35
	range [nm / km]	5 830 / 10 800	2 560 / 4 555	500 / 926	270 / 500	230 / 426,5
	cruise Mach	0,85	0,78	0,4	0,316 (200 kt)	0,187 (125 kt)
	cruise alt [ft / m]	40 000 / 12 192	37 000 / 11 278	23 000 / 7 010	12 000 / 3657	8 000 / 2 438

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CLEAN AVIATION

CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

DESIGN SPACE

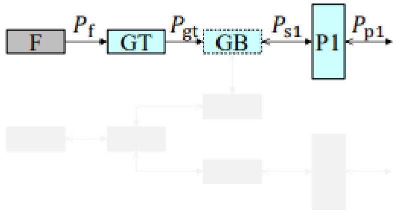
Fuel (Jet-A)

Fuel (H2)

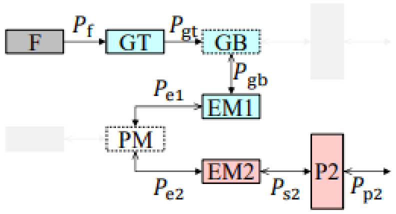
battery

H2 + Fuel Cell

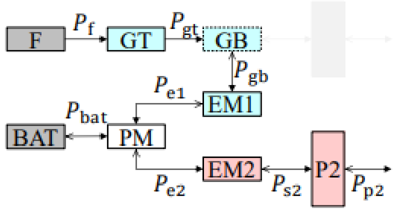
1. Conventional



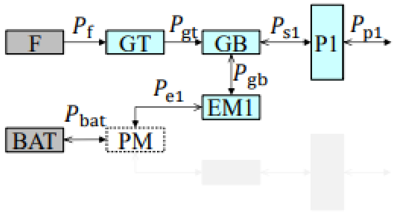
2. Turboelectric



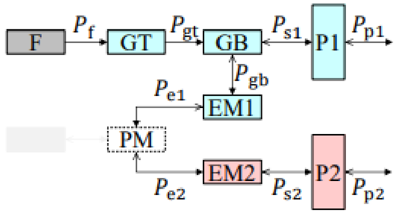
3. Serial



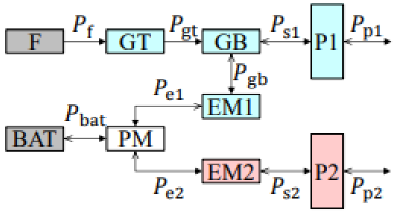
4. Parallel

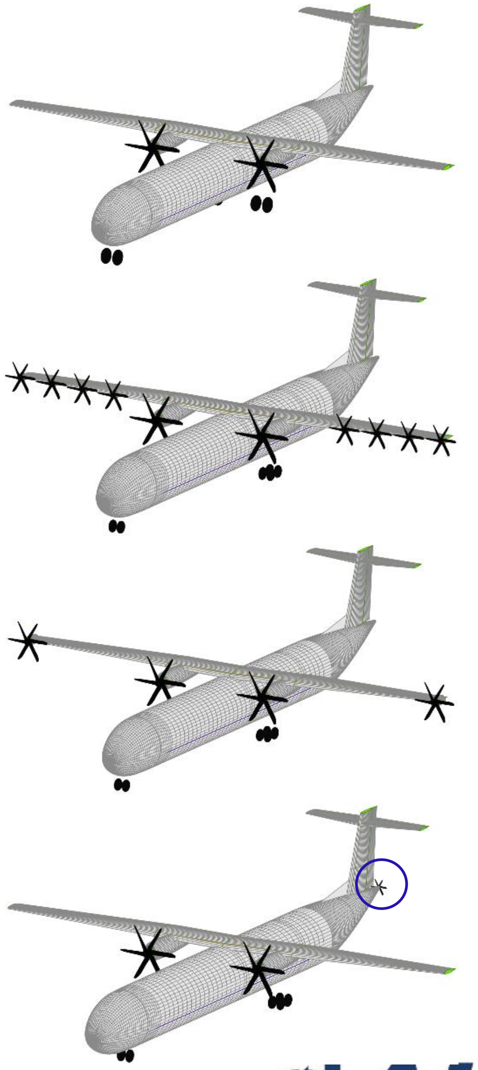


5. Partial turboelectric



6. Serial/parallel partial hybrid





mission requirements / energy storage source /
powertrain architecture / propulsion layout

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CLEAN AVIATION

CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

MATRIX OF TECHNOLOGIES

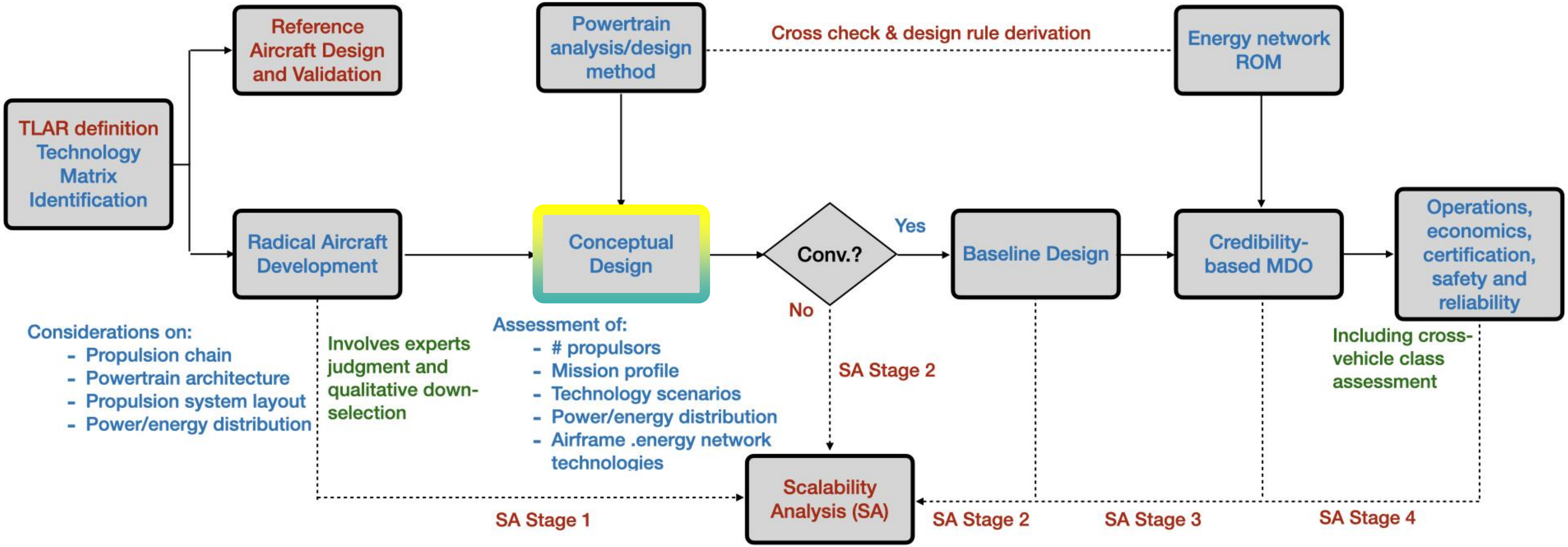
	Conventional H2 direct burn	Partial Turbo Electric	Parallel	Serial Parallel Partial Hybrid	Serial	Full-electric
Fuel (H2 or JetA1)			▨	▨	▨	▨
Fuel (JetA1) + Battery	▨	▨				▨
Fuel Cell + Battery	▨	▨	▨	▨		▨
Battery	▨	▨	▨	▨	▨	

CLEAN AVIATION

CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

SCALABILITY ASSESSMENT STAGE 1

	Conventional H2 direct burn	Partial Turbo Electric	Parallel	Serial Parallel Partial Hybrid	Serial	Full-electric
Fuel (H2 or JetA1)	P1: TF. P2: NA LPA; SMR P1: TP. P2: NA Reg	P1: TF. P2: BLI-fan LPA; SMR P1: TP. P2: BLI-fan Reg P1: TP. P2: WtipMP Reg				
Fuel (JetA1) + Battery			P1: boosted TF. P2: NA SMR P1: boosted TP. P2: NA Reg	P1: TP. P2: BLI-fan Reg P1: TP. P2: WtipMP Reg P1: TP. P2: LEDP Com	P1: NA. P2: WtipMP Com P1: NA. P2: LEDP Com	
Fuel Cell + Battery					P1: elec fan Reg P1: WtipMP Com P1: LEDP Com	
Battery						P1: WMP. P2: WtipMP GA P1: -. P2: LEDP Com; GA



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Energy network ROM

Conceptual Design

Conv.?

Yes

No

Baseline Design

Credibility-based MDO

Operations, economics, certification, safety and reliability

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SA Stage 2

Including cross-vehicle class assessment

Scalability Analysis (SA)

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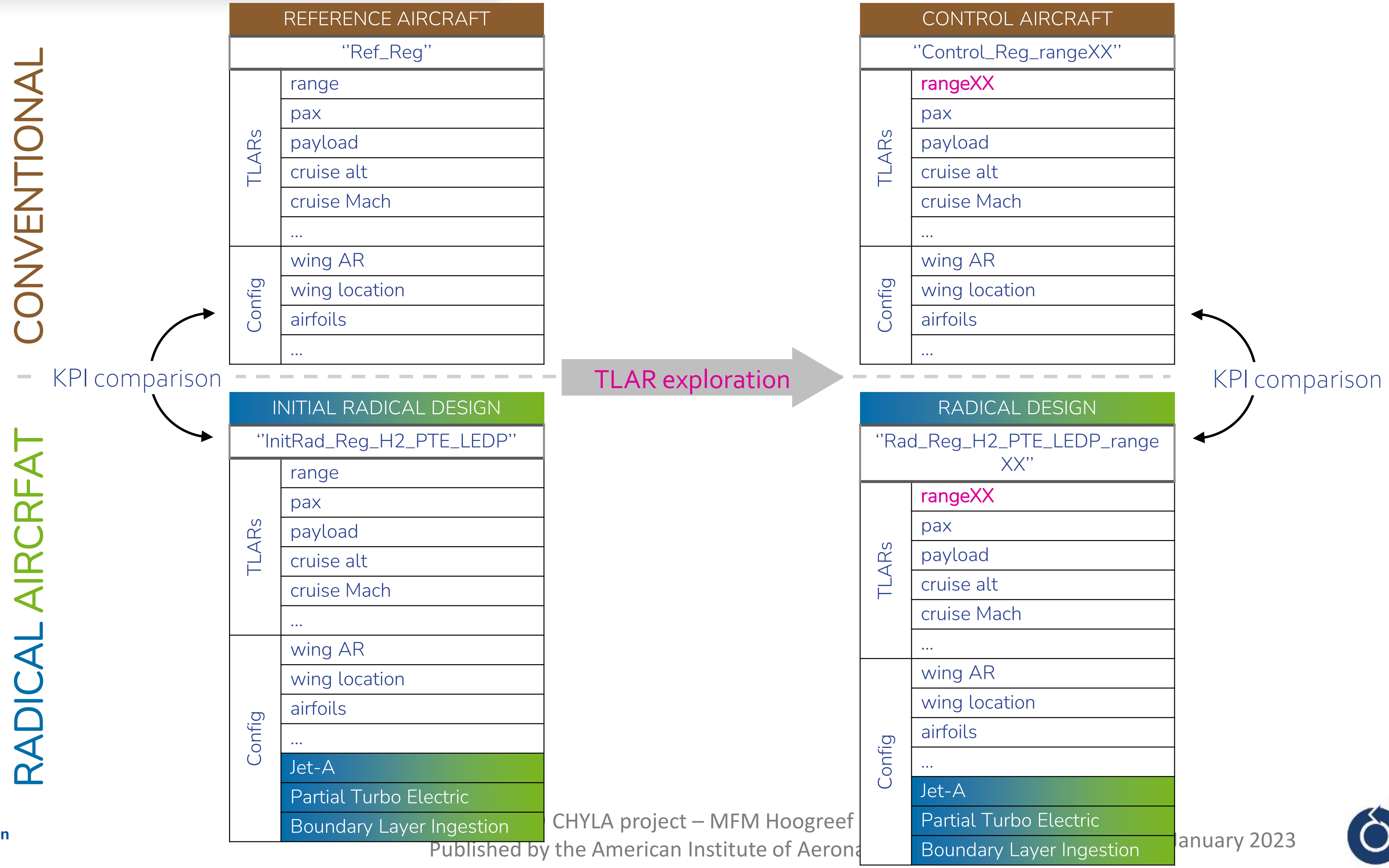
SA Stage 2

SA Stage 3

SA Stage 4

SENSITIVITY ANALYSIS



CONVENTIONAL

RADICAL AIRCRFAT

REFERENCE AIRCRAFT	
"Ref_Reg"	
TLARs	range
	pax
	payload
	cruise alt
	cruise Mach
	…
Config	wing AR
	wing location
	airfoils
	…

CONTROL AIRCRAFT	
"Control_Reg_rangeXX"	
TLARs	rangeXX
	pax
	payload
	cruise alt
	cruise Mach
	…
Config	wing AR
	wing location
	airfoils
	…

KPI comparison

TLAR exploration

KPI comparison

INITIAL RADICAL DESIGN	
"InitRad_Reg_H2_PTE_LEDP"	
TLARs	range
	pax
	payload
	cruise alt
	cruise Mach
	…
Config	wing AR
	wing location
	airfoils
	…
	Jet-A
	Partial Turbo Electric
	Boundary Layer Ingestion

RADICAL DESIGN	
"Rad_Reg_H2_PTE_LEDP_range XX"	
TLARs	rangeXX
	pax
	payload
	cruise alt
	cruise Mach
	…
Config	wing AR
	wing location
	airfoils
	…
	Jet-A
	Partial Turbo Electric
	Boundary Layer Ingestion

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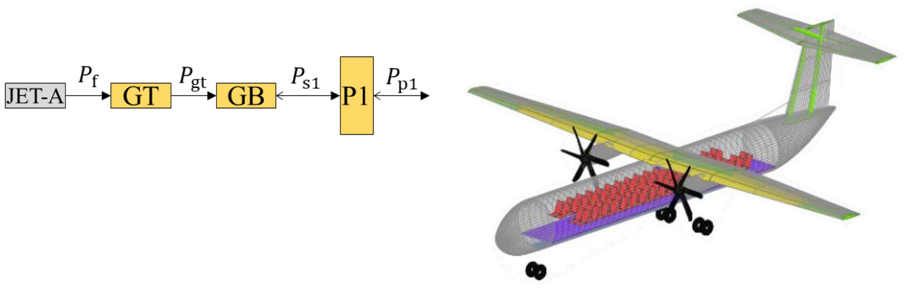
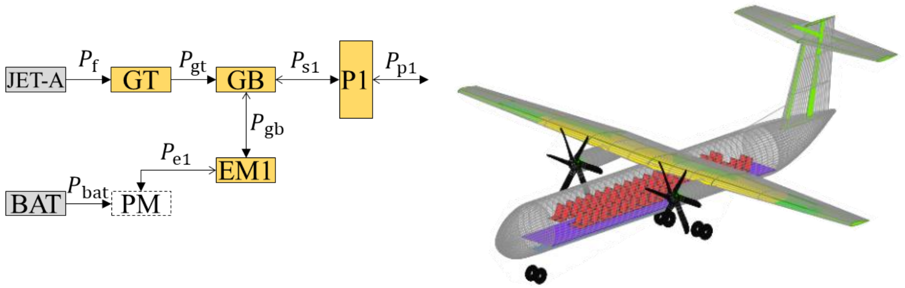
conventional

REG-baseline



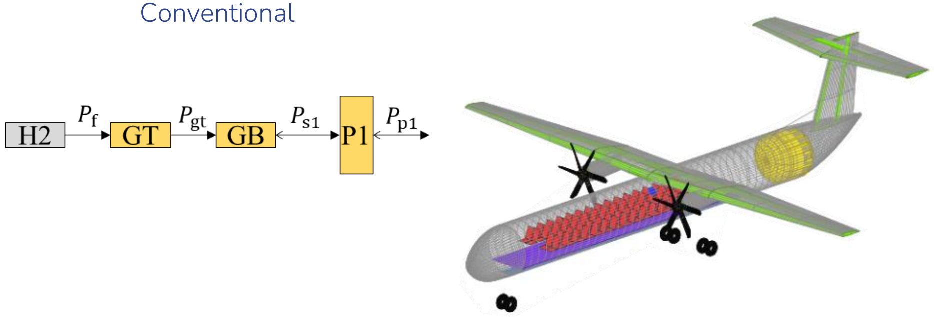
Parallel

REG-boostedTP



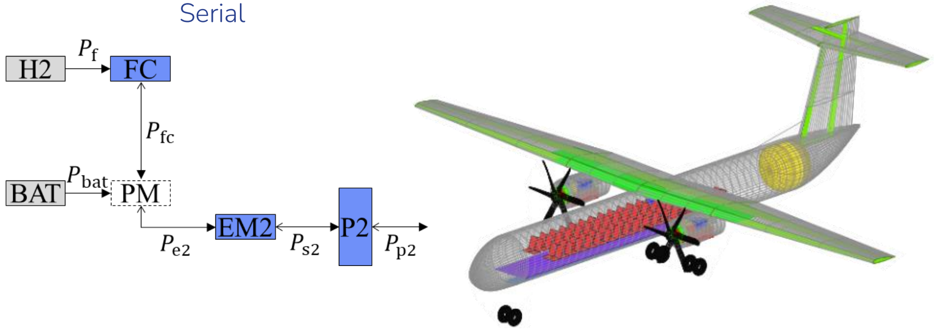
Conventional

REG-LH2



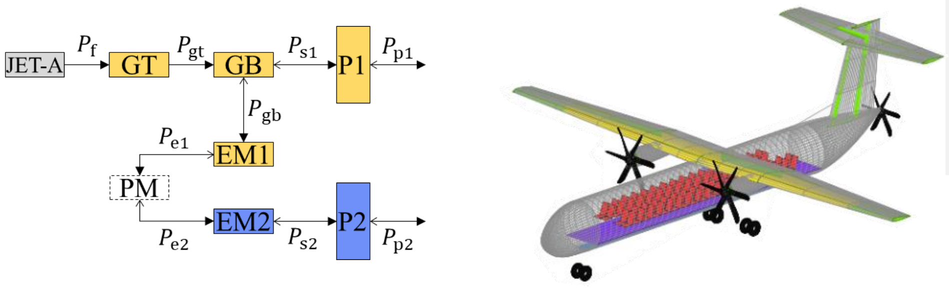
Serial

REG-FC



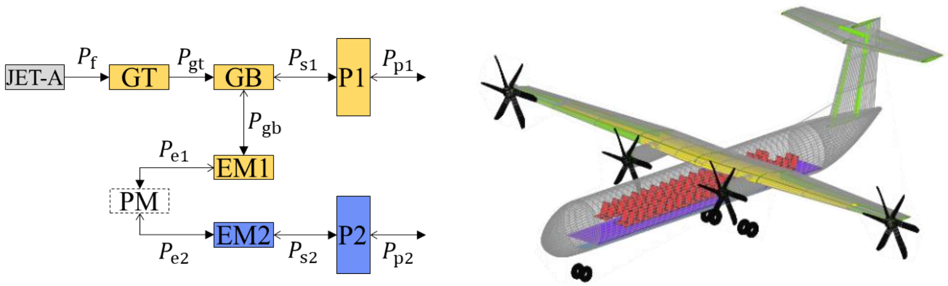
Partial TurboElectric

REG-PTE-BLI



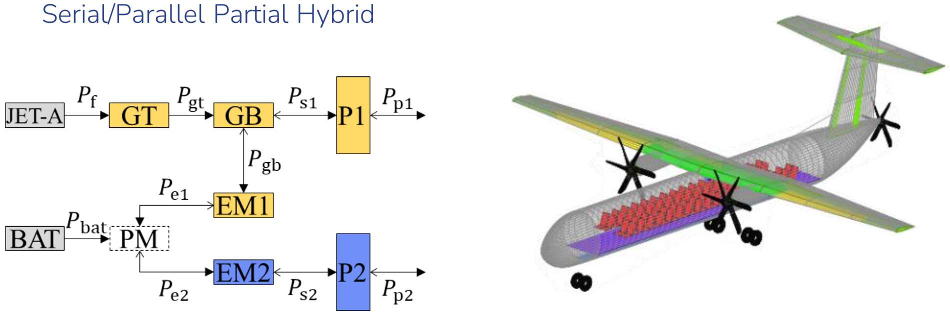
Partial TurboElectric

REG-PTE-WtipMP



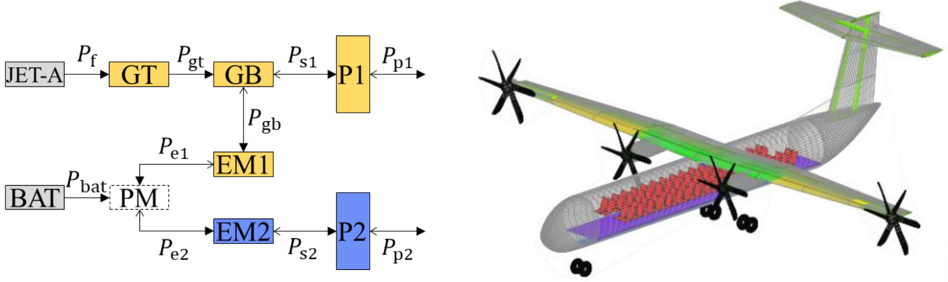
Serial/Parallel Partial Hybrid

REG-SPPH-BLI



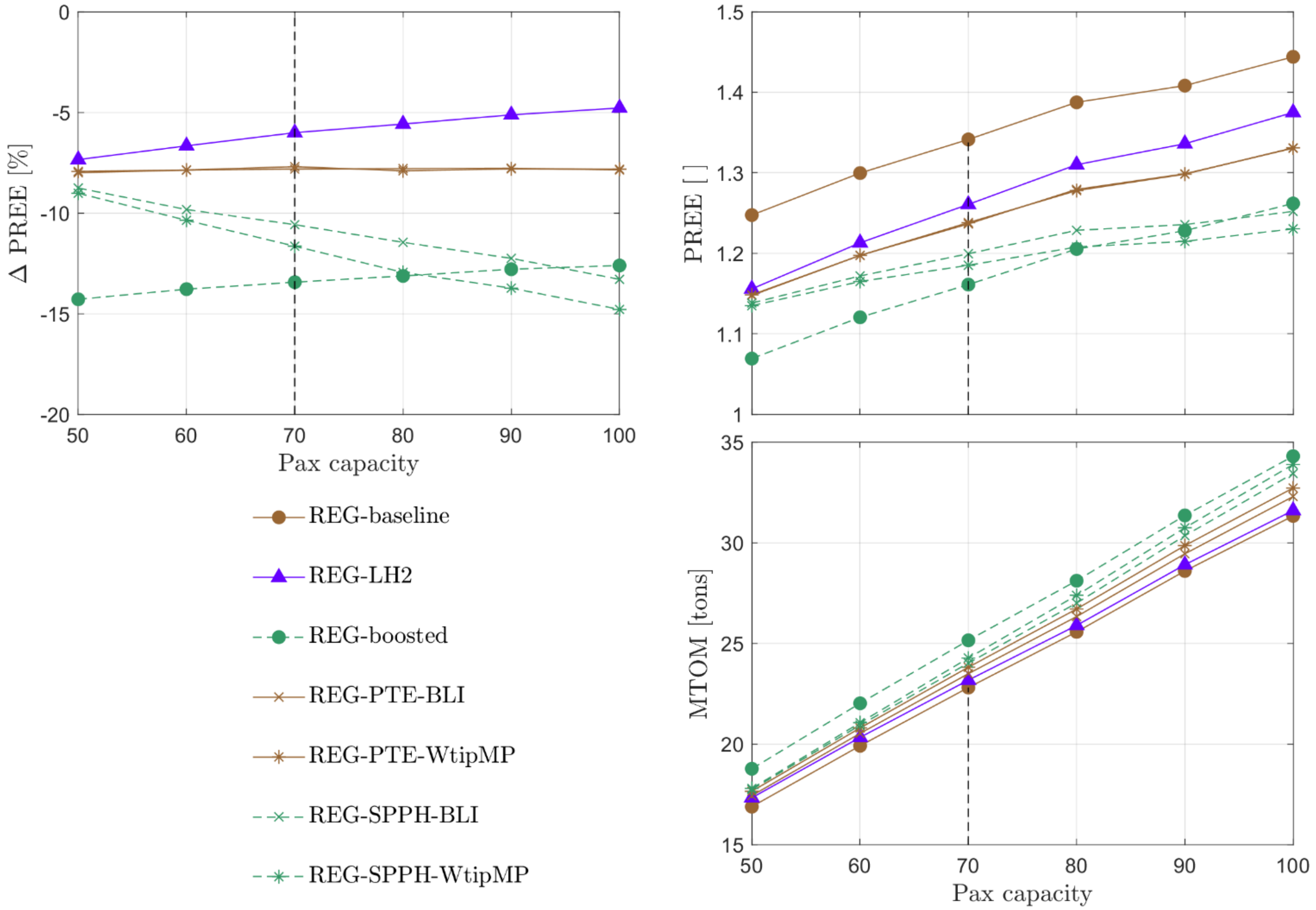
Serial/Parallel Partial Hybrid

REG-SPPH-WtipMP



SENSITIVITY ANALYSIS: SCALABILITY ASSESSMENT STAGE 2

Variation in passenger capacity for aircraft of the regional class



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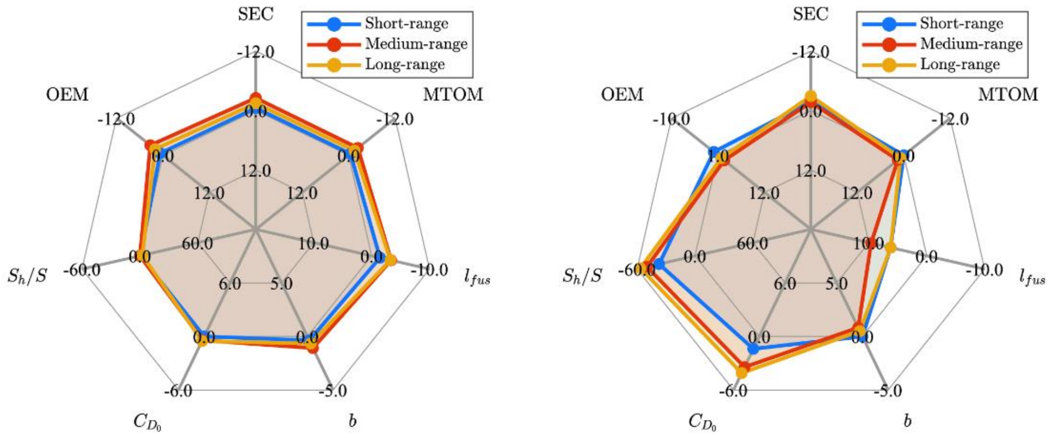
EXAMPLE: SCALABILITY EFFECTS OF LH2 FUEL TANK INTEGRATION

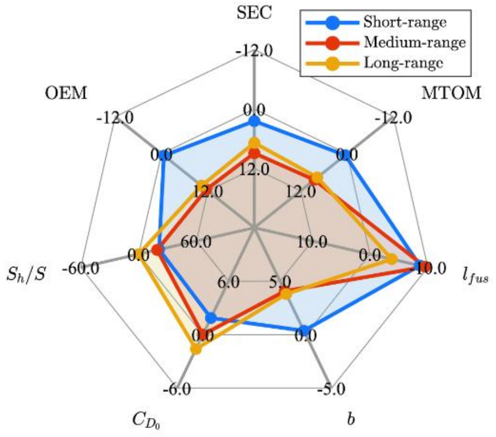
CEAS Aeronautical Journal, September 2022, DOI 10.1007/s13272-022-00601-6

- Integral vs non-integral tank: (a)
  - Benefits increase aircraft category
- Aft-and-forward rather vs aft tank layout (b)
  - SMR & LPA; improved specific energy consumption, worse OEM/MTOM
- Increasing fuselage diameter by adding one seat abreast (c)
  - SMR suffers most due to extra aisle
  - LPA smallest penalty
  - Reg rather unaffected
- Double-deck cabin beneficial for LPA, without large performance degradation (80x80m box)



(a) Integral rather than non-integral tank.

(b) Aft & fwd rather than aft layout.



(c) One extra seat abreast.

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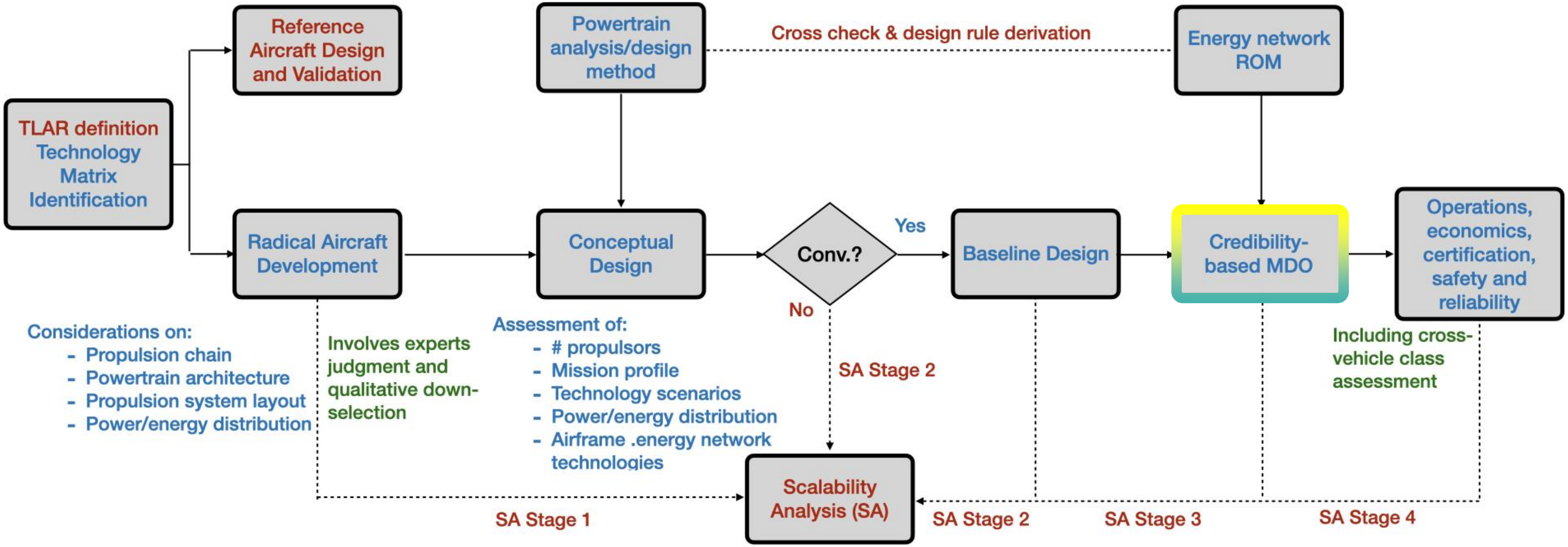

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Conv.?

Yes

No

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SA Stage 2

Including cross-vehicle class assessment

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SA Stage 1

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TECHNOLOGY ASSUMPTIONS

For a given design parameter, what is the credibility of a given target value by 2035?

(Eg: what is the credibility of battery gravimetric energy density of 500 Wh/kg)

- Future predictions always uncertain

→ Estimation of mean and standard deviation at a given date

➢ Prediction of a future Probability Density Function (PDF) for a design parameter

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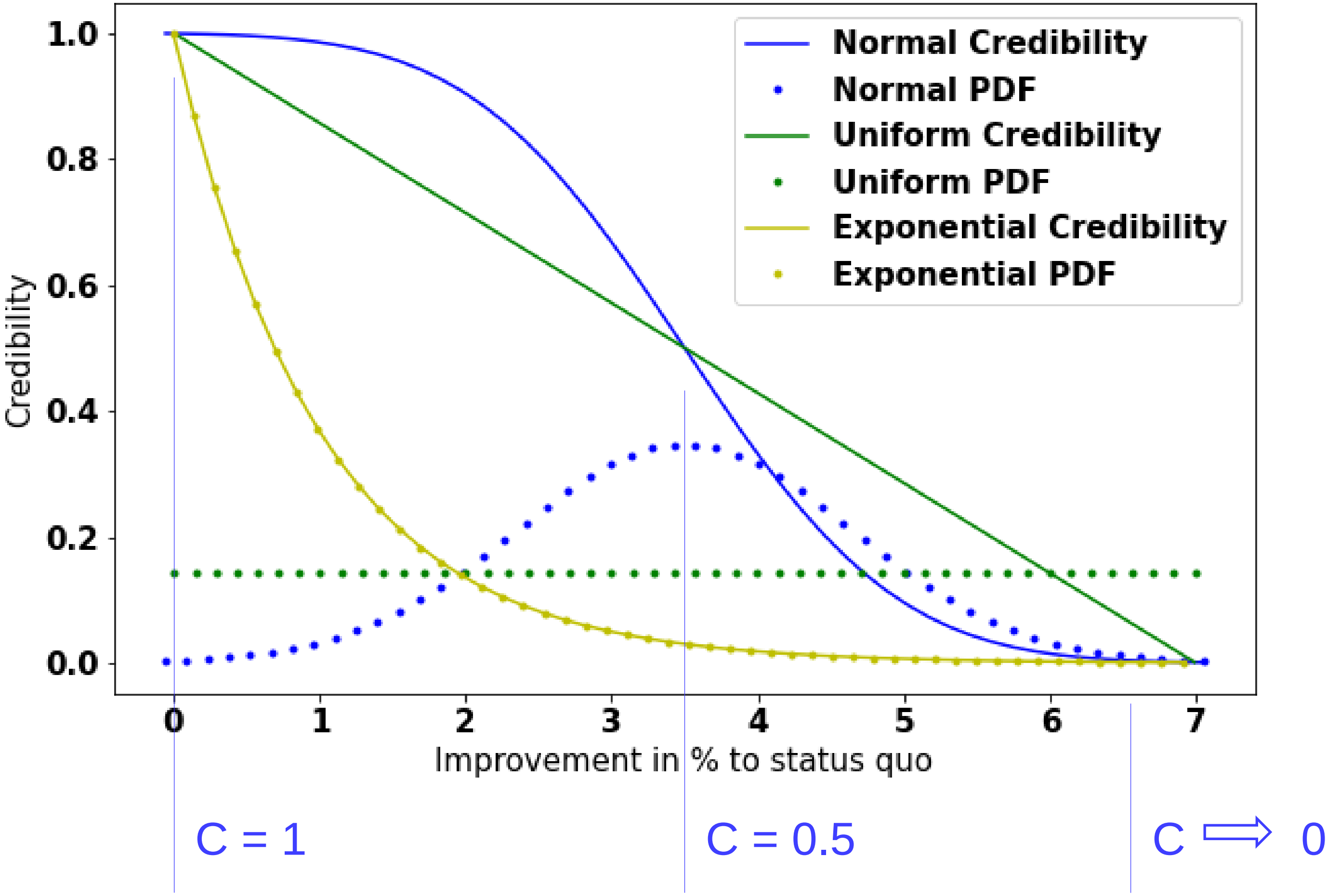
CREDIBILITY AS A FUNCTION

- Probability that at time X technology Y has reached at least maturity Z
- *Credibility is large when probability that technology can exceed the value is large*
- C = P(X>x) = 1 - P(x≤X) = 1 -CDF



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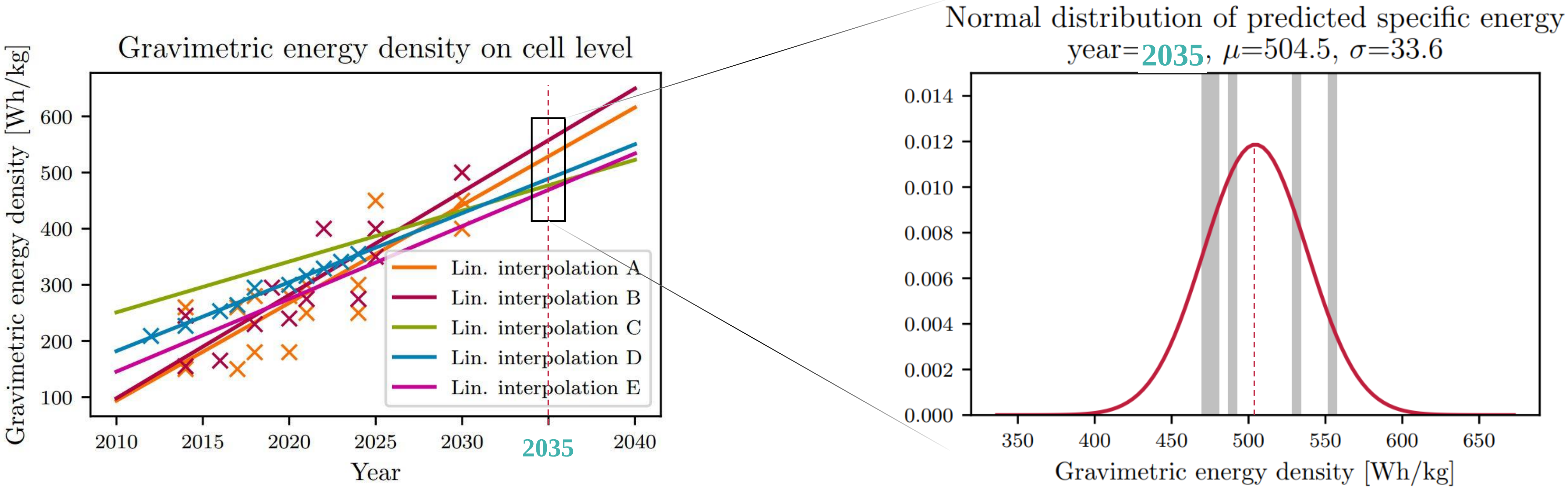
EXAMPLE: BATTERY GRAVIMETRIC DENSITY

Future performance predictions
- wide range of literature
- range of applications for more robust results

Time-based regression over datapoints
- linear interpolation for mean
- normal distribution for credibility



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CREDIBILITY-BASED MDO

Initial guess: radical aircraft from SA2 {energy carrier / powertrain architecture / propulsion layout}

⇓

$$min \quad \int W_f \, dx$$

$$s.t. \quad C_i \geq C_{i,l} \quad \forall i = 1,..,n$$

$$\prod C_i \geq \prod C_{i,l}$$

Objective functions

- Eg: Fuel mass, Range, PREE, Emissions, Credibility

Constraints

- component i level credibility C_i
- aircraft-level ‘composite’ credibility $\prod C_i$
- fixed design point W/P, W/S

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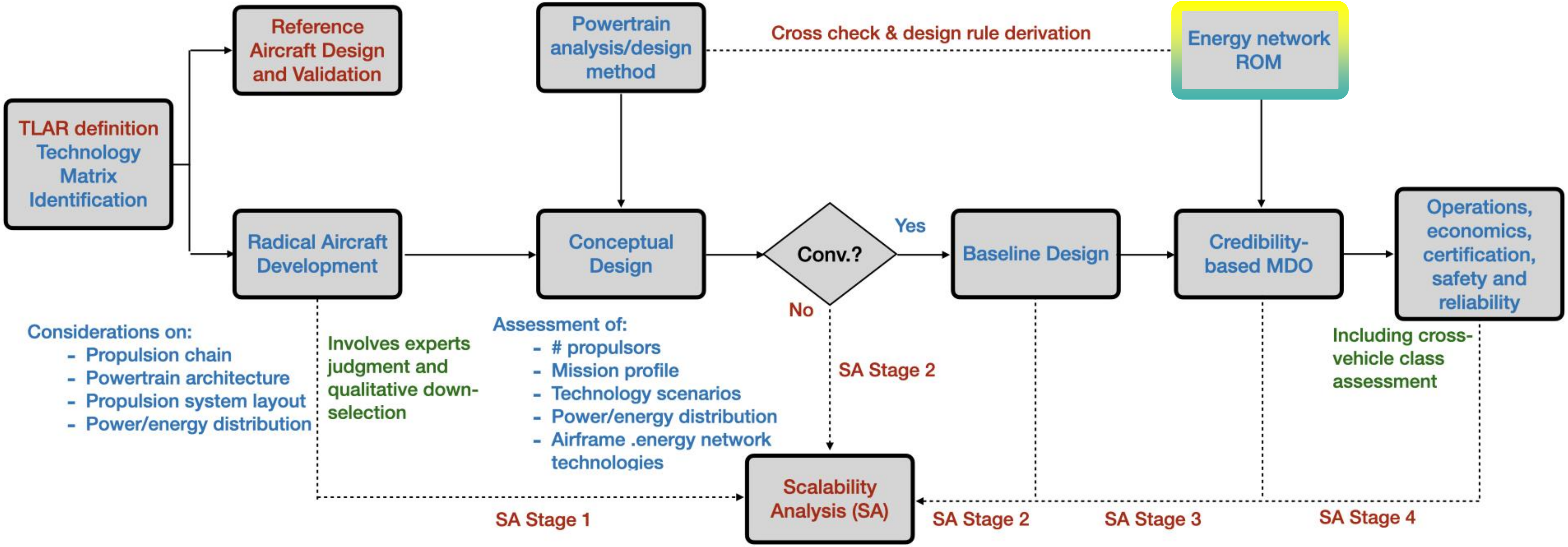

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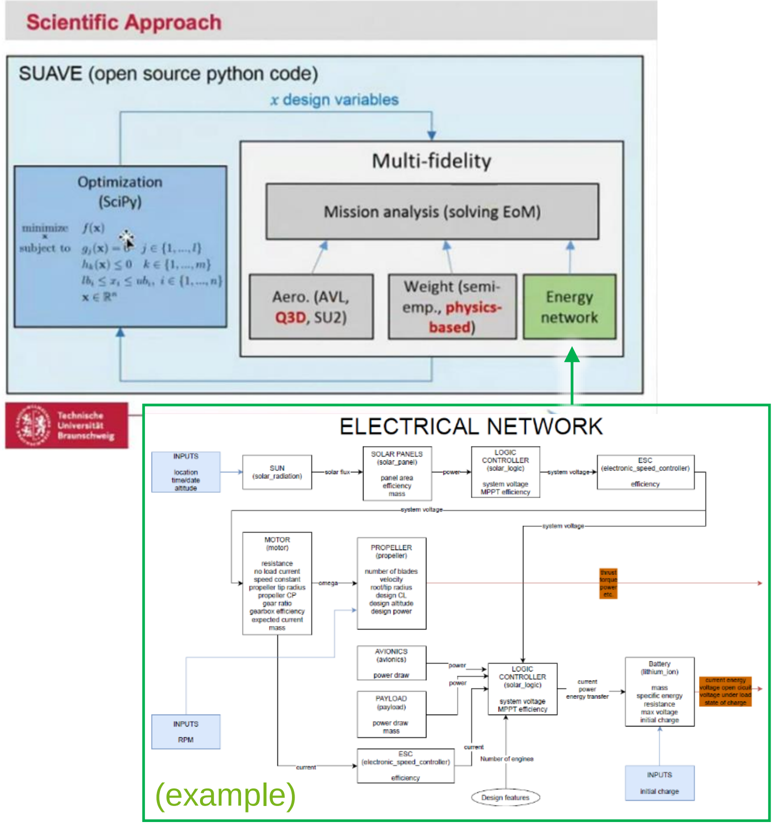
CLEAN AVIATION

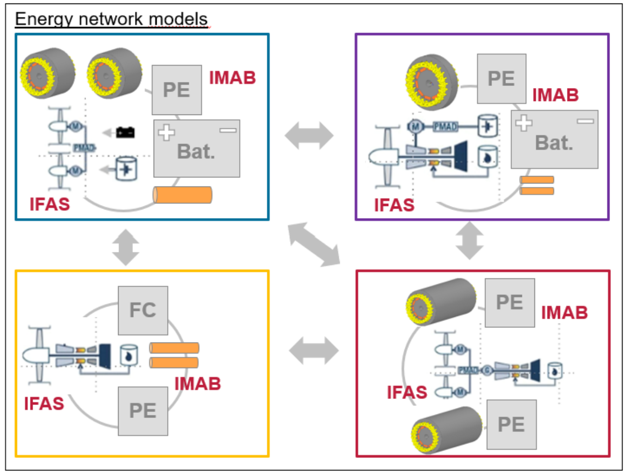
CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

ENERGY NETWORK MODELLING

SUAVE workflow and exemplary energy network



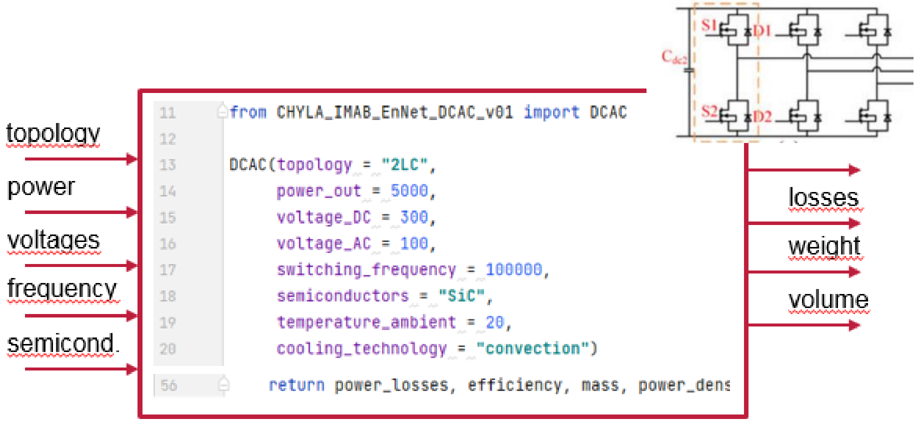
Different energy networks using different tables, functions, models, … which will be provided.



Different energy networks with different technologies/ technology combinations:

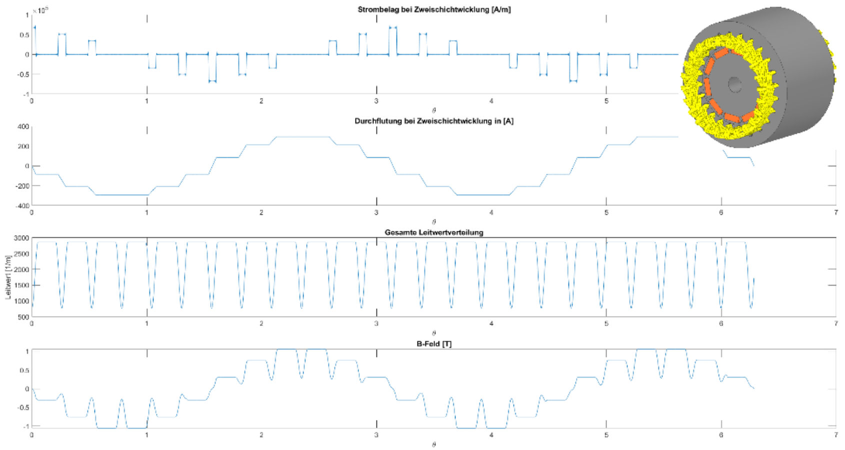
- energy network 2
- energy network 3
- energy network 4

Energy network consisting of interconnected "**function blocks**"



```
from CHYLA_IMAB_EnNet_DCAC_v01 import DCAC

DCAC(topology = "2LC",
     power_out = 5000,
     voltage_DC = 300,
     voltage_AC = 100,
     switching_frequency = 100000,
     semiconductors = "SiC",
     temperature_ambient = 20,
     cooling_technology = "convection")
    return power_losses, efficiency, mass, power_dens
```



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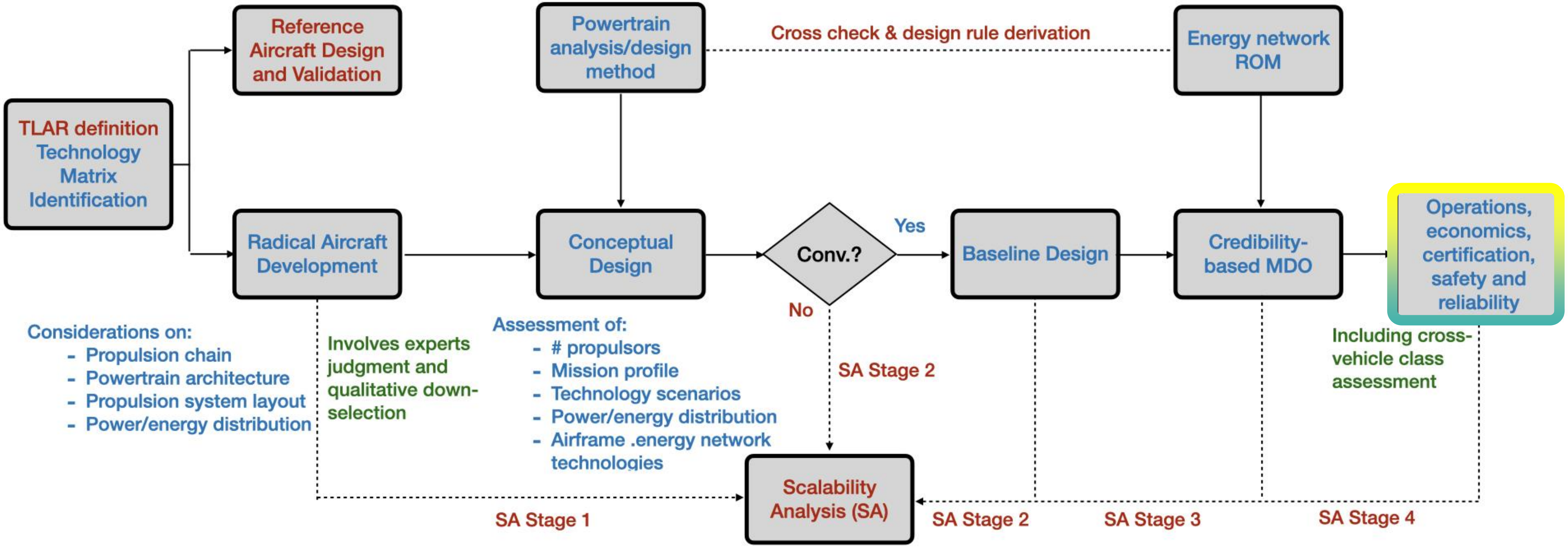

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SA Stage 3

SA Stage 4

CLEAN AVIATION

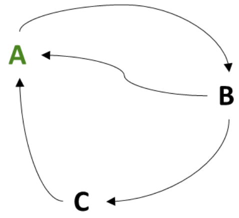
CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

NETWORK AND FLEET MODEL

Existing network and fleet models, adapted to include HEA operations

Max range

Charging locations and time



Aircraft routing

Objective function:

MAX Revenue − (Costs + CO_2 Emission taxes)

Subject to (constraints):

Demand

Capacity

Aircraft range

Continuity

Time

Decision variables:

- # of aircraft (per type)
- Frequencies
- Direct passengers
- Transfer passengers

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26 January 2023

AIAA
SHAPING THE FUTURE OF AEROSPACE

CLEAN AVIATION

CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

COUPLED HYBRID & ELECTRIC AIRCRAFT DESIGN AND STRATEGIC AIRLINE PLANNING

Current developments:

CHYLA collaboration with GLOWOPT

- Strategic airline planning: fleet planning and network development
- Coupled with in-the-loop climate optimized aircraft design
- First results submitted to AIAA/EATS 2023

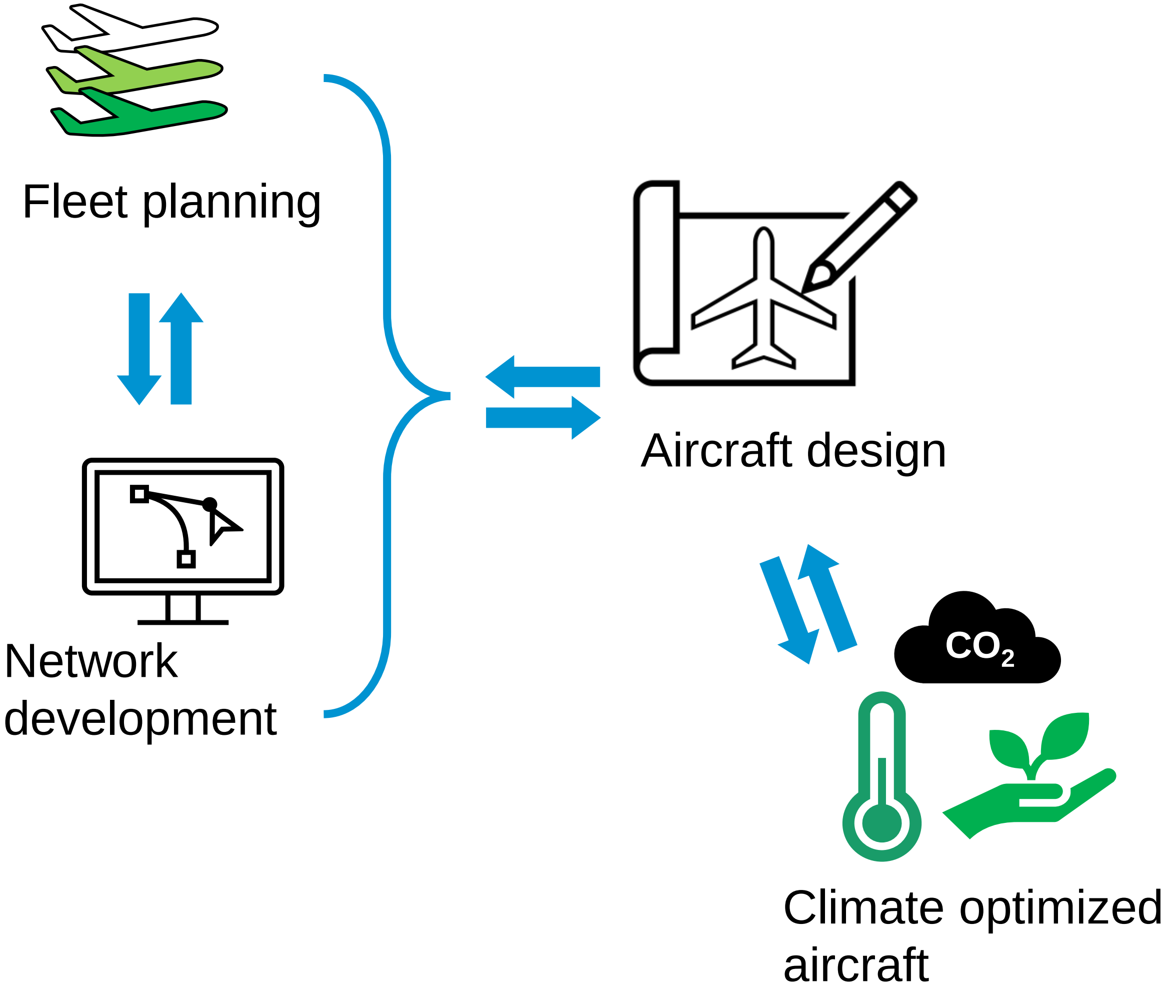
- Goal:
  - Integrate aircraft fleet and network analysis with aircraft design to design aircraft for a regional airline network with reduced climate impact

CHYLA
CREDIBLE HYBRID ELECTRIC AIRCRAFT

GLOWOPT

To be continued in HERA project

CLEAN AVIATION



Fleet planning

Network development

Aircraft design

Climate optimized aircraft

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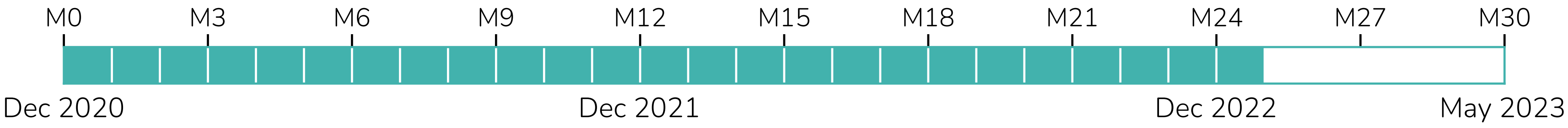
Credible HYbrid eLectric Aircraft



THANK YOU

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European Commission | Horizon 2020

Clean Sky 2

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26 January 2023

CLEAN AVIATION

GLOWOPT

GLOBAL-WARMING-OPTIMIZED AIRCRAFT DESIGN

Presenter:

Ir. Pieter-Jan Proesmans – TU Delft

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INTRODUCTION

- Minimizing global-warming impact
  - CO_2 and non-CO_2 effects
  - Altitude dependency
  - Location dependency

- Large computational cost in MDO

GLOWOPT: How to efficiently design aircraft with minimum climate impact?

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CLEAN AVIATION

GLOWOPT

INTRODUCTION

- GLOWOPT Objectives
  - Development of novel CFAD
  - MDO of an aircraft using CFAD

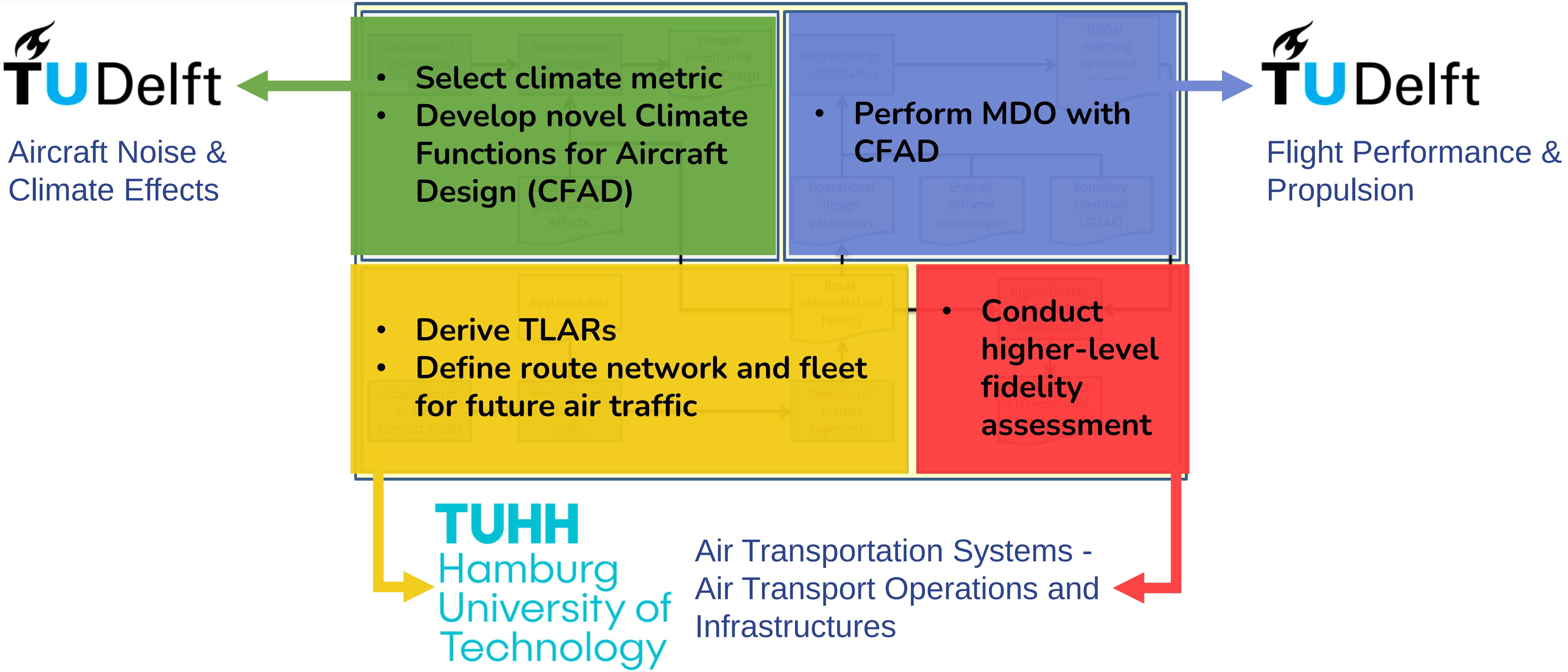
- Consortium of 2 universities
  - TUHH
  - TU Delft
    - Aircraft Noise and Climate Effects
    - Flight Performance and Propulsion

TUHH Hamburg University of Technology

TU Delft

Co-funded by the European Union

INTRODUCTION



TU Delft

Aircraft Noise & Climate Effects

- Select climate metric
- Develop novel Climate Functions for Aircraft Design (CFAD)

- Perform MDO with CFAD

TU Delft

Flight Performance & Propulsion

- Derive TLARs
- Define route network and fleet for future air traffic

- Conduct higher-level fidelity assessment

TUHH Hamburg University of Technology

Air Transportation Systems - Air Transport Operations and Infrastructures

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GLOWOPT

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CFAD

- Climate effects
  - CO_2 and H_2O are greenhouse gases
  - NO_x → O_3 formation, but CH_4 and PMO depletion
  - Contrails and contrail-cirrus

- Climate change functions (Grewe et al., 2014)
  - Impact per unit and type of emissions
  - Dependence on location
    - Altitude
    - Longitude
    - Latitude
  - Dependence on time

CFAD include network and scenario info

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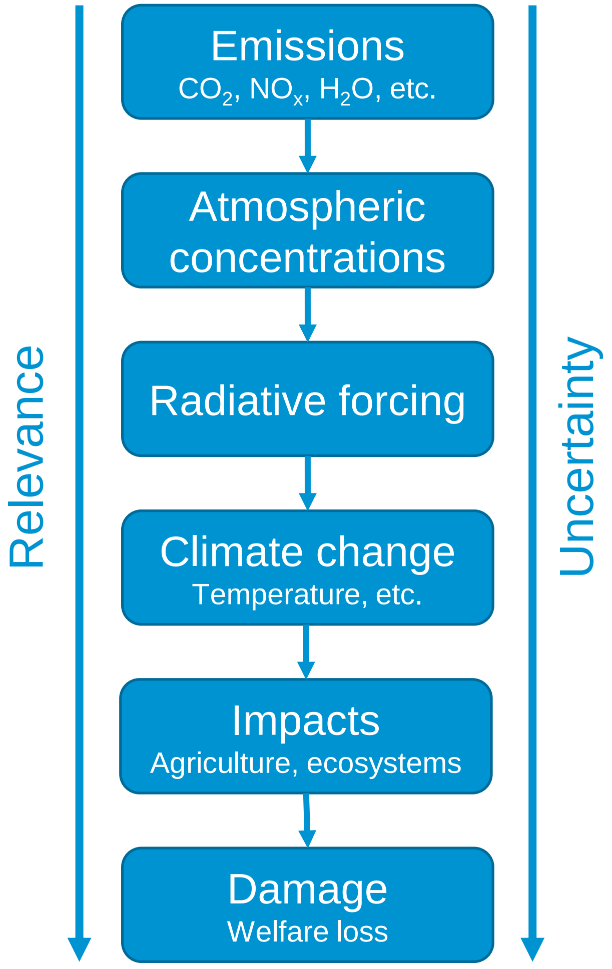
CFAD



(Adapted from Fuglestvedt et al., 2003)

- How to express climate impact?
- Need to find a balance
  - Relevance and uncertainty
  - Short- and long-term effects
- Average temperature response

Temperature response

$$\mathrm{ATR}_{100} = \frac{1}{100}\int_0^{100} \Delta T\, dt$$

100 years

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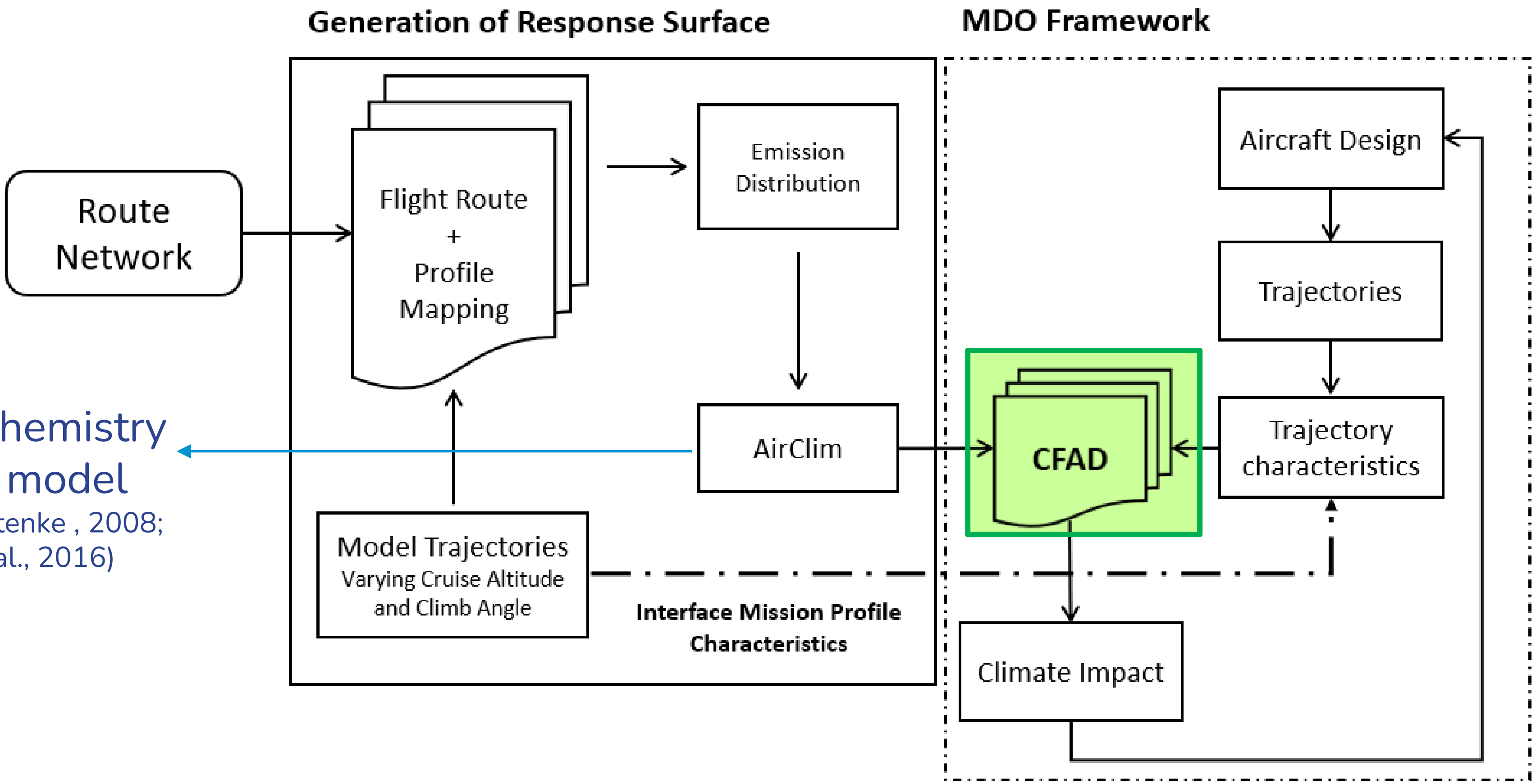
CFAD

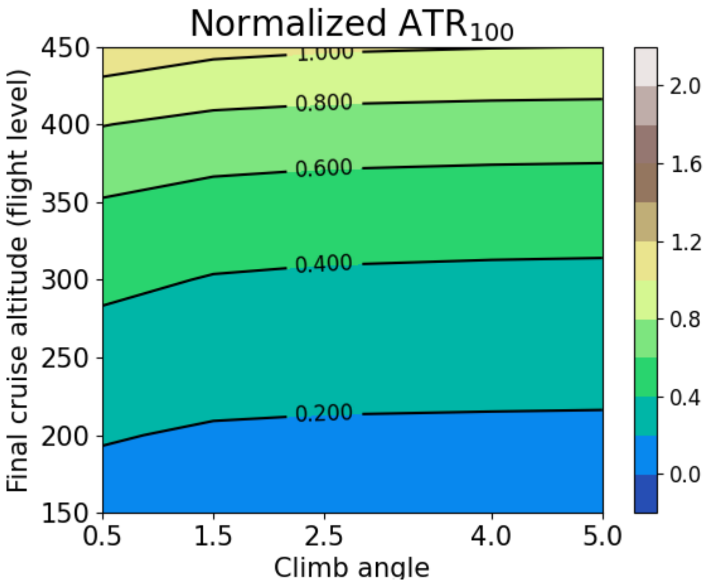


Climate chemistry response model
(Grewe and Stenke , 2008; Dahlmann et al., 2016)

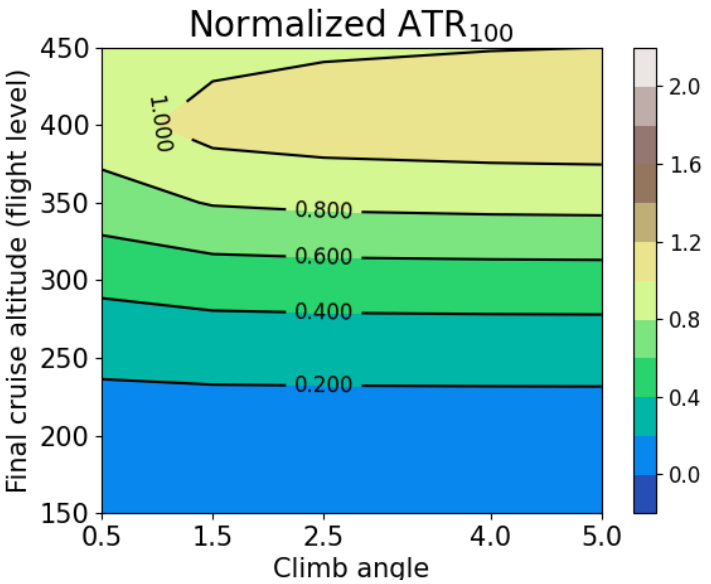
(Radhakrishnan et al., 2022)

- Response surface model

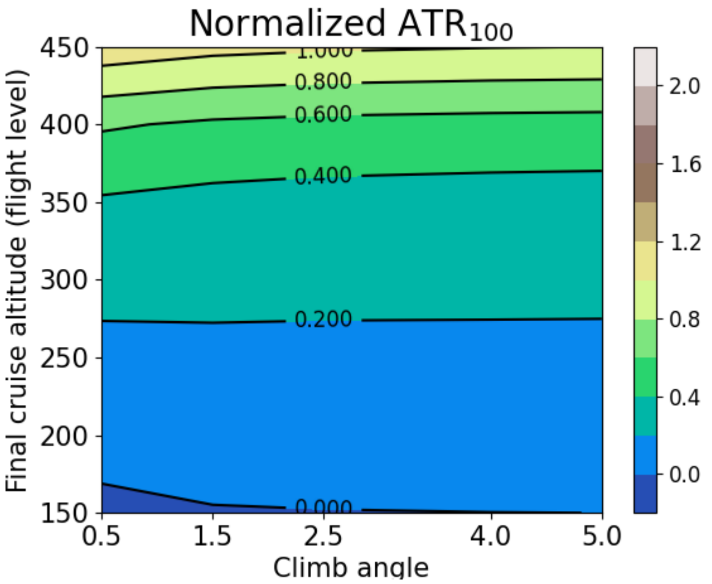
Total



Contrails



NO$_x$



(Radhakrishnan et al., 2022)

CLEAN AVIATION

GLOWOPT

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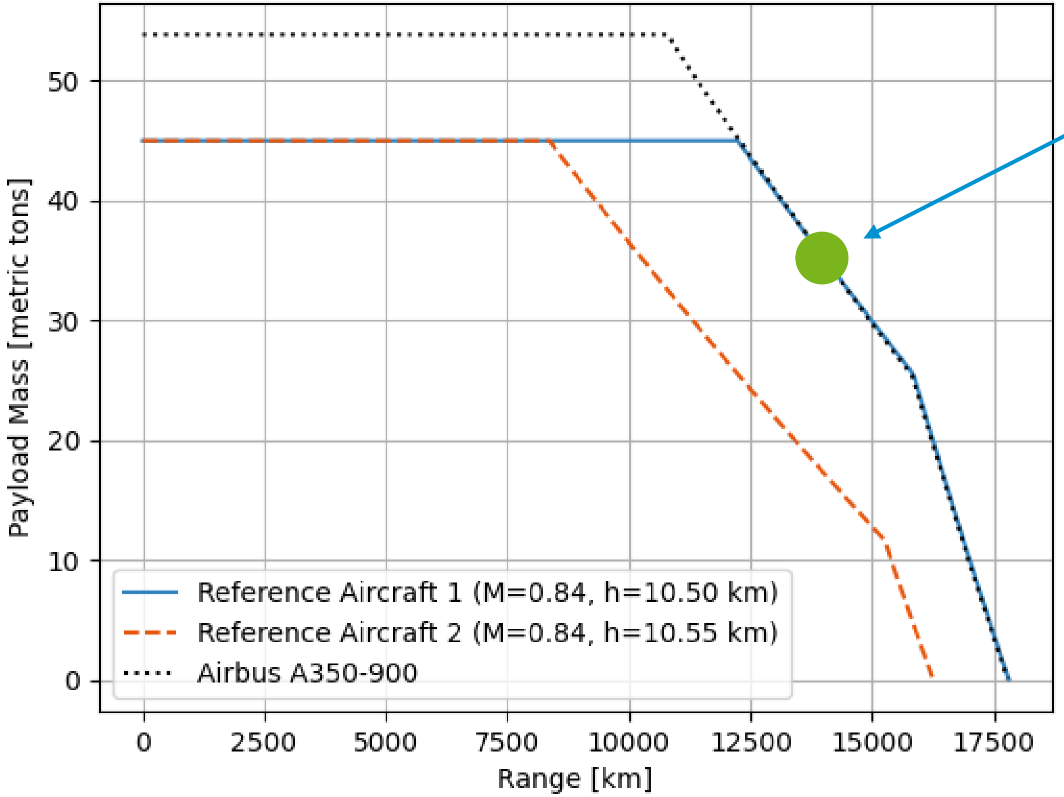
MDO AND TECHNOLOGY EVALUATION

- Long-range, wide-body aircraft
- Similar to Airbus A350-900



Design point aircraft 1
- 350 passengers
- 14150 km

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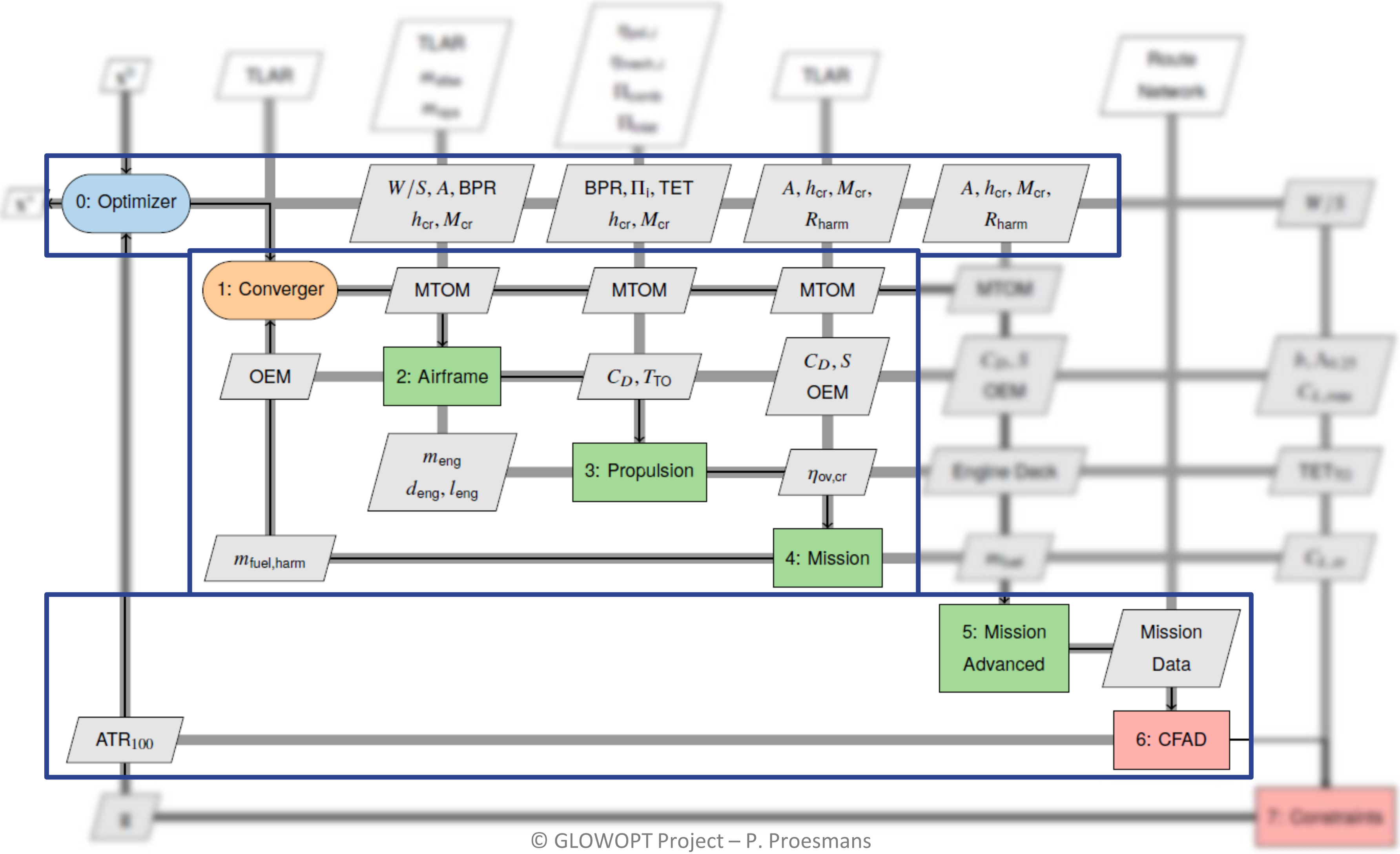
MDO AND TECHNOLOGY EVALUATION



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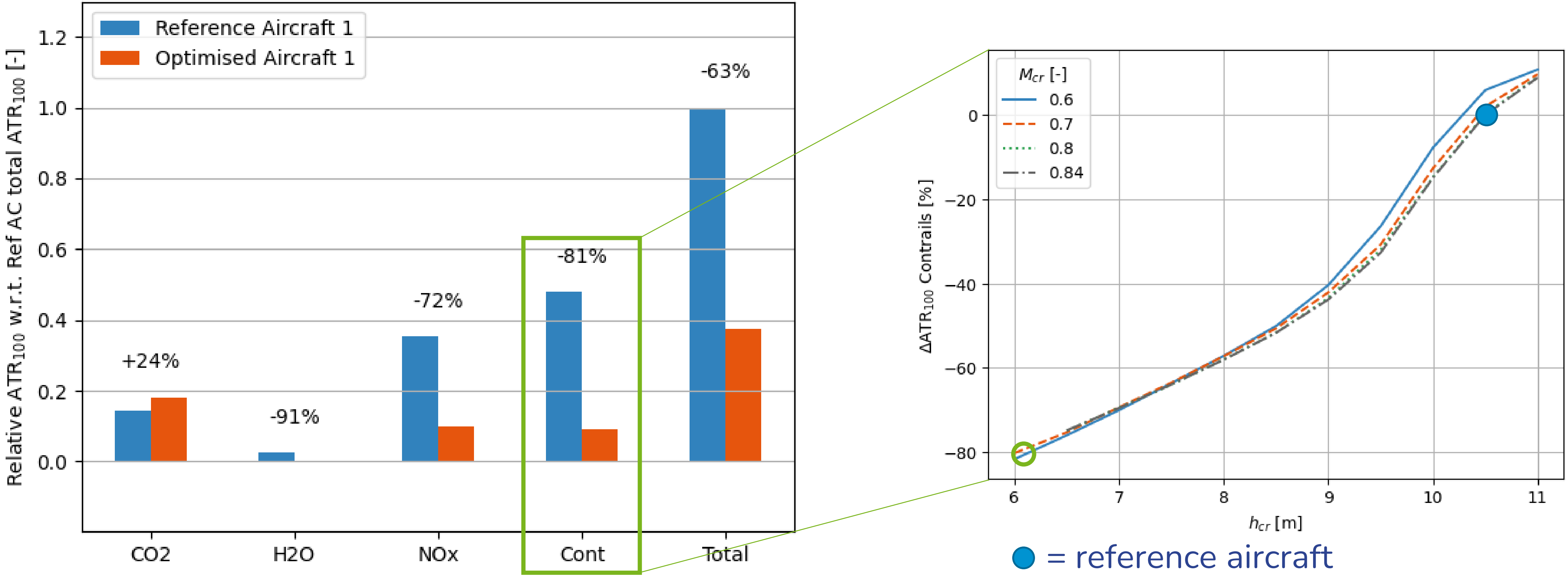
MDO AND TECHNOLOGY EVALUATION

- Total reduction of 63% in ATR_{100}



● = reference aircraft

○ = optimised aircraft

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MDO AND TECHNOLOGY EVALUATION

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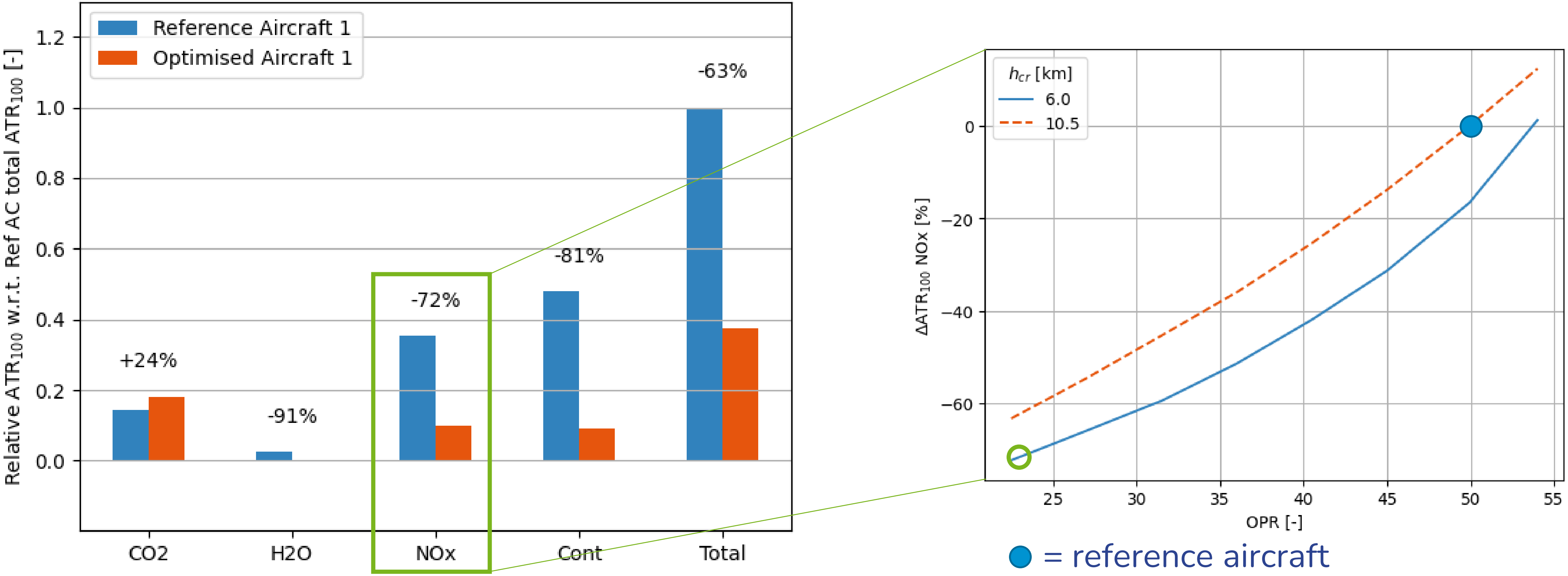

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MDO AND TECHNOLOGY EVALUATION

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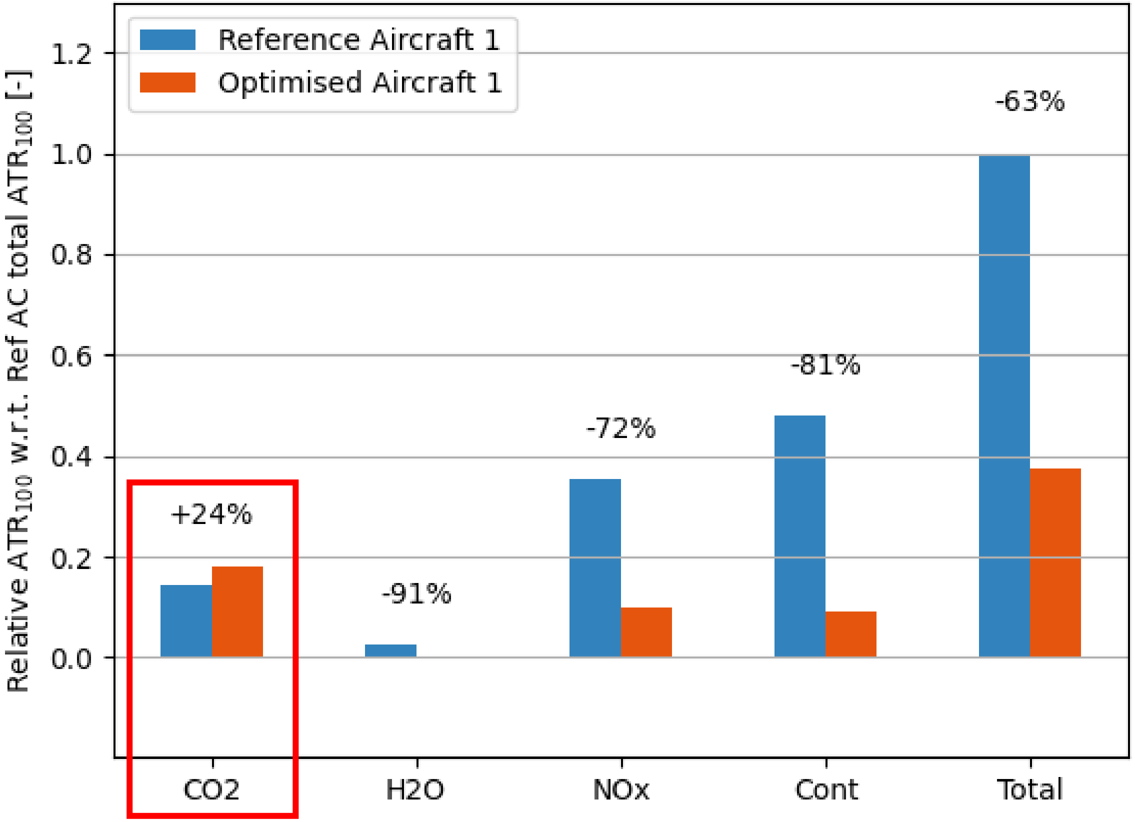

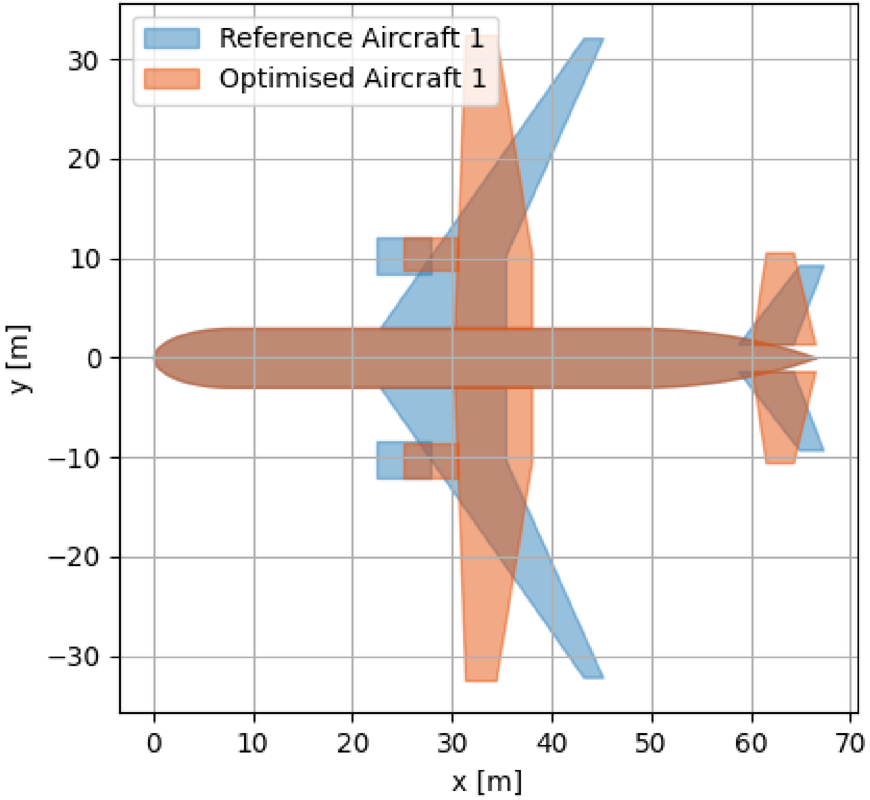

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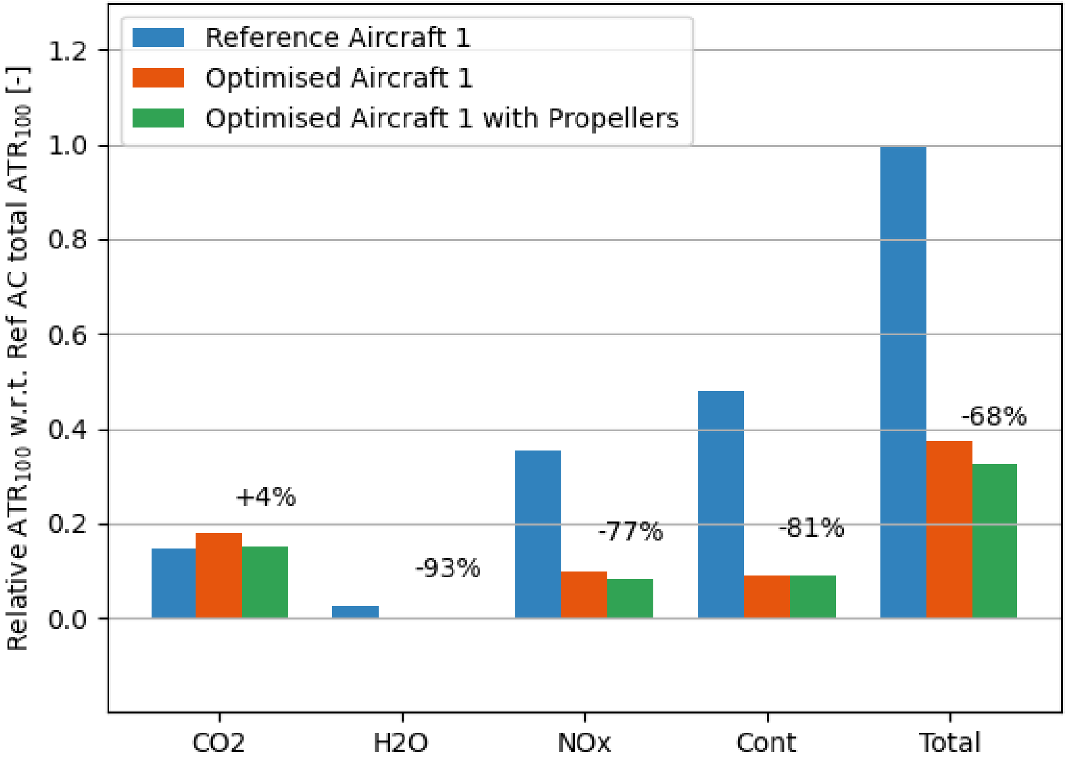
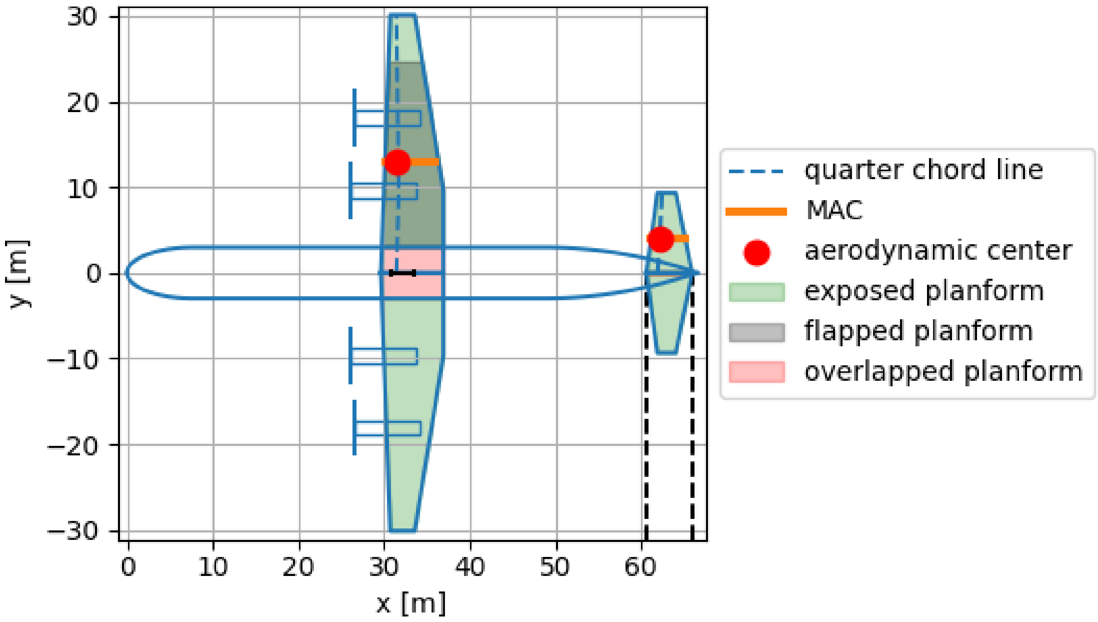
- Propeller-based propulsion





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VALIDATION AND PERFORMANCE

- High-fidelity analysis
  - Total error of CFAD less than 5% for all species

	CO_2	H_2O	Contrails	NO_x
FL 200	3.6%	<0.1%	-3.5%	-0.1%
FL 300	0.9%	-0.2%	-4.2%	3.5%
FL 400	0.5%	-1.5%	3.9%	-2.9%
	1.6%	-0.6%	-1.2%	0.1%

  - Further uncertainties within the climate modelling need to considered

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VALIDATION AND PERFORMANCE

- Cash and direct operating costs increase
  - Higher fuel consumption
  - Longer flight time

For Design Mission – 14150 Km

Aircraft	Fuel	Flight Time	COC	DOC
Reference	1	1	1	1
Optimized	1.11	1.27	1.14	1.20
Delta	11%	27%	14%	20%

For entire route network

Aircraft	Fuel	Flight Time	COC	DOC
Reference	1	1	1	1
Optimized	1.11	1.23	1.13	1.17
Delta	11%	23%	13%	17%

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CONCLUSIONS

- Development of CFAD
    - Considering CO_2 and non-CO_2 effects
    - Global route network
    - Fast computation of ATR_{100}

- MDO with CFAD
    - 63% reduction in ATR_{100} for wide-body aircraft
    - Lower cruise altitude and reduced OPR
    - New technologies to reduce CO_2 penalty

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CONCLUSIONS

- Recommendations for future research
  - Robust aircraft design w.r.t. climate metric
  - Improved modelling of NO_x, nVPM, and contrails
  - Similar CFAD approach for
    - Future aviation fuels
    - Different market segments

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Thank you for your attention!

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