CHYLA workshop

SOUTHAMPTON, 15 FEBRUARY 2023

TU Delft | Technische Universität Braunschweig | University of Southampton

CHYLA

CREDIBLE HYBRID ELECTRIC AIRCRAFT

Clean Sky 2

Welcome to Southampton!

Workshop Agenda

Start	End	Duration	Topic
9:00	9:15	15	Welcome
9:15	9:30	15	Introduction to workshop and agenda
9:30	10:00	30	Keynote
10:00	10:30	30	Project synopsis, baseline designs
10:30	10:45	15	Coffee Break
10:45	11:30	45	Credibility-based MDO methodology
11:30	12:30	60	Sensitvity study and MDO study results
12:30	13:30	60	Lunch
13:30	14:15	45	Regional operative scenario
14:15	14:45	30	SIENA project
14:45	15:15	30	FUTPRINT50 project
15:15	15:30	15	Coffee Break
15:30	16:30	60	Open discussion on scalability/challenges/switching points of HEP applications
16:30	17:15	45	Discussion on FUTPRINT50 roadmap and connection to SIENA/CHYLA activities
17:15	17:30	15	Concluding remarks/end of workshop
19:00			Dinner

Workshop Objectives

- Support reflection on results and studies to aid final scalability assessment
  - Review and validate sensitivity studies and optimization results
  - Integrate expert vision on solutions and challenges
  - Support both CHYLA and SIENA projects
- Showcase FUTPRINT50 roadmap and collect input
- Note: minor update can be accomodated for CHYLA, no major considerations due to project end date (*Final Review on 31 May*)

Feedback forms

- To collect feedback/comments/suggestions during presentations:
  - Feedback forms
  - Will be processed prior to open discussion in the afternoon & reviewed after meeting to support scalability assessment
  - Analog (distributed in the room)
  - Digitally:
    - https://forms.office.com/e/M5DtwVtyGM
    - short: http://tiny.cc/CHYLA
    - (link als on the bottom of the page, QR code in top right cor

Project synopsis

Call history, objectives and setup

Background

- JTI-CS2-2020-CFP11-THT-14:

  Scalability and limitations of Hybrid Electric concepts up to large commercial aircraft

- Switching points:
  - Technologies better suited to one or another class (or CS23/25)
  - Influence:
    - TLAR
    - Propulsion system architecture
    - Economics

- Two parallel projects:

HEP – some challenges

HEP → *Enables/ facilitates* → **Distributed Propulsion, BLI**

Challenges?

- Weight & Complexity
- TRL of high-power electrical systems
- Cooling systems
- Airport infrastructure
- Safety & Certification

Challenges?

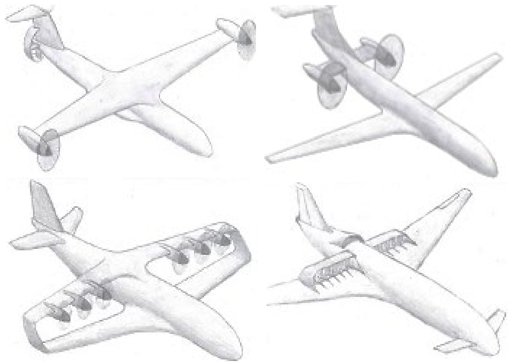
Quantification of the effect on:

- Propulsive efficiency
- Lift-to-drag ratio

Sustainable Aircraft Design?

Vast literature involving:

- different scales
- different technologies
- different aircraft configurations
- different design tools



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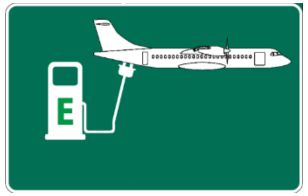

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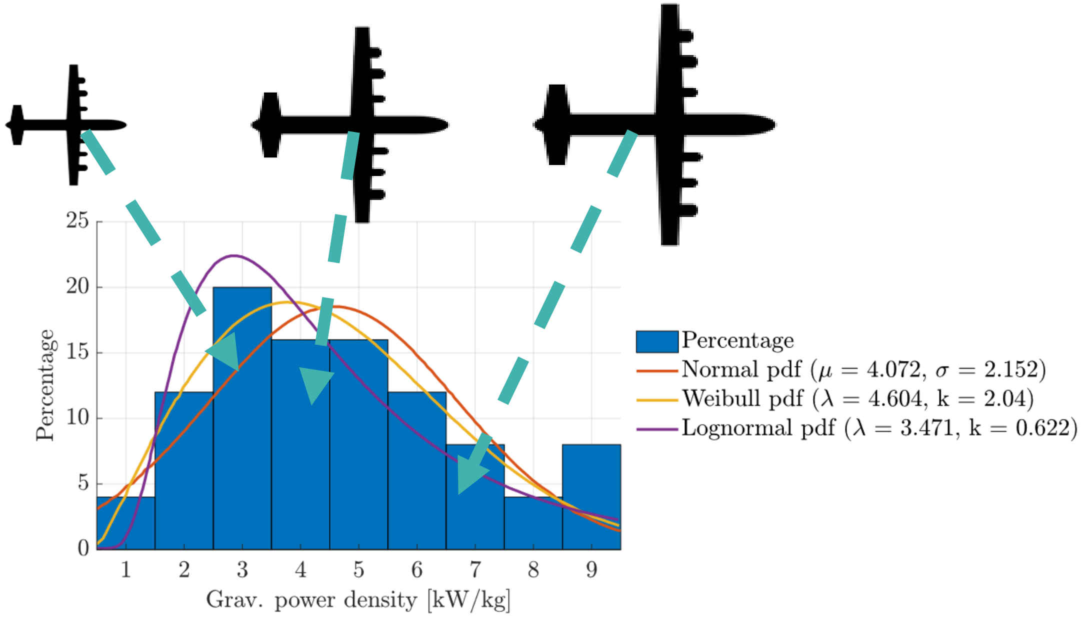
- Which technologies can be applied ?
- At which scales can they be applied ?
- How credible are the technological assumptions?

COM → REG → SMR



CHYLA – Credible Hybrid Electric Aircraft

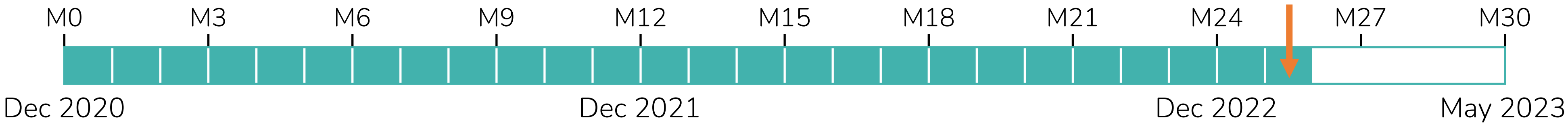
TU Delft

Technische Universität Braunschweig

University of Southampton

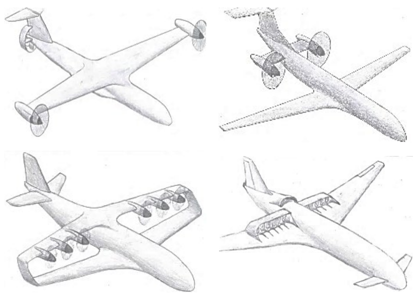
Clean Sky 2

- 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.



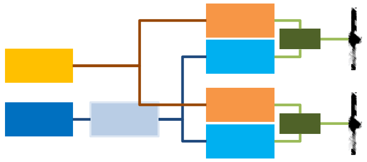
Design approach

Qualitative Conceptual trade-off



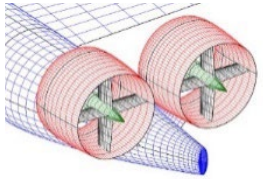
Configurations

Subsystem analysis: powertrain



Energy network 10.2514/6.2022-3741

Subsystem analysis: propulsor integration



Integration of aero-propulsive interactions
10.2514/1.C035388

Conceptual designs

10.1007/s13272-022-00601-6
+ LH_2 aircraft

ICAS2022 #248

Sensitivity studies
ICAS2022 #481 & 10.2514/6.2023-2098

MDO

ICAS2022 #850 & 10.2514/6.2023-1847

Scalability Assessment

Scalability

"FEASIBILITY OF NEXT GENERATION KEY TECHNOLOGIES WHEN APPLIED TO DIFFERENT VEHICLE CLASSES"

- Identification of switching points.
- Opportunities/Limitations/Challenges for different technology applications (to different scale/classes of aircraft).

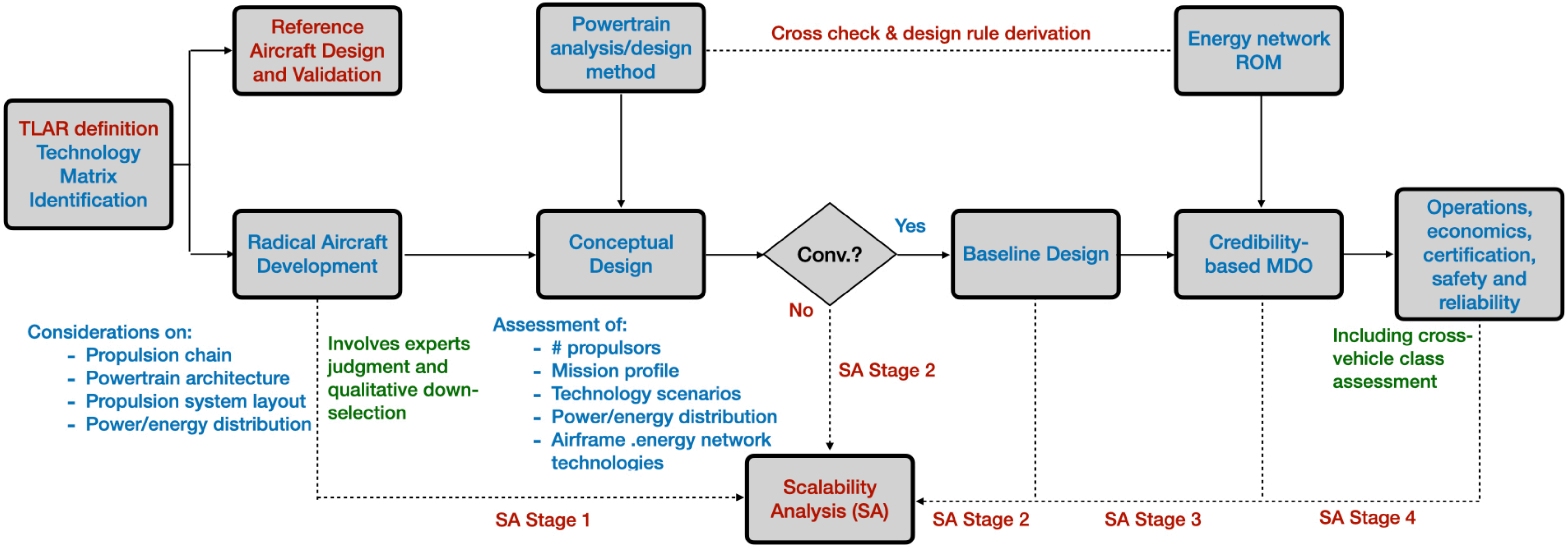
Scalability Assessment – 4 stages

1. Qualitative – expert opinion: “Matrix of Technologies”
   - Advisory board feedback
   - Literature/workshop/conference cross-checks

   → Defines design space
2. Baseline designs: “Areas of Interest”
3. Credibility-based MDO & design sensitivities
4. Operations and economics

→ Cross-vehicle class scalability assessment

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



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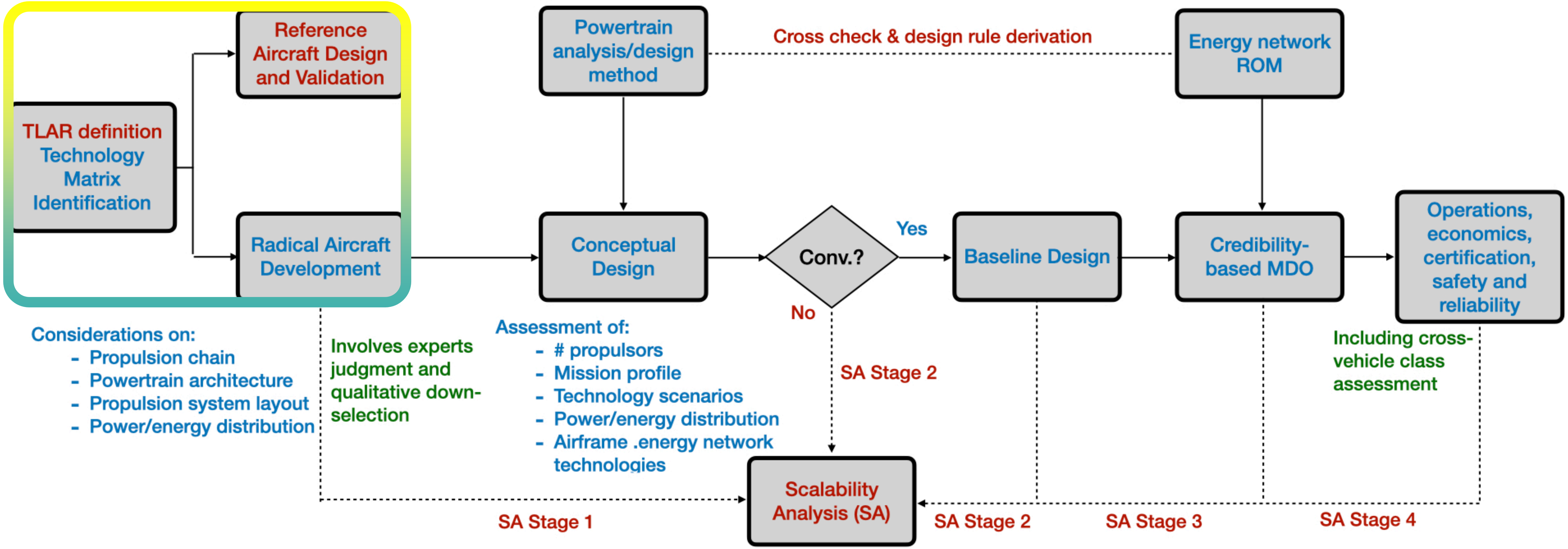


reference aircrafts (conventional)		Long Range (~A350-900) CS-25	Medium Range (~ A320-NEO) CS-25	Regional (~ ATR72-600) CS-25	Commuter CS-23	General Aviation CS-23
mission requirements	pax	315	150	70	19	4
	payload [t]	53,5	20	7,5	2,3	0,35
	range [nm / km]	5 830 / 10 800	2 560 / 4 555	500 / 926	270 / 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

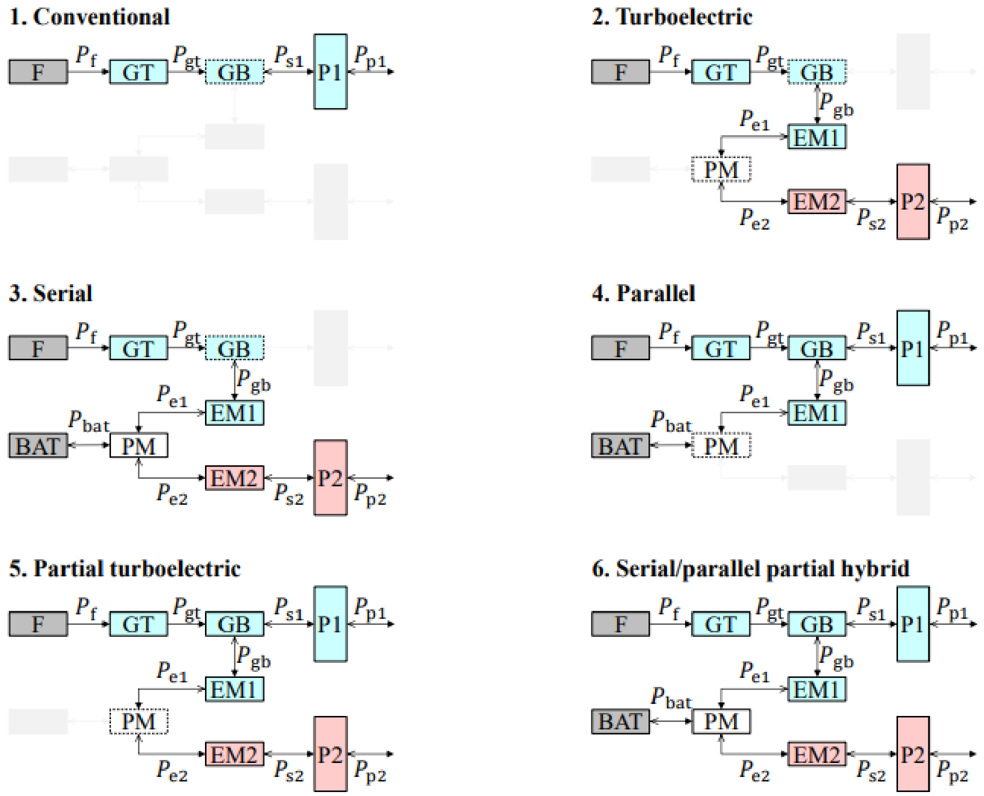
mission requirements / energy storage source / powertrain architecture / propulsion layout

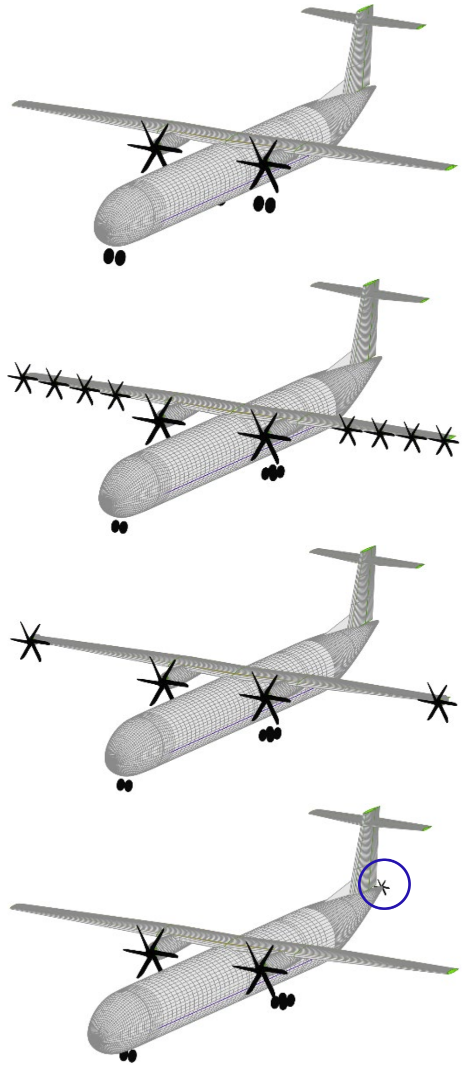
Fuel (Jet-A)

Fuel (H2)

battery

(H2 + Fuel Cell)





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

Conclusions from earlier studies

- If field performance is limiting: enhance **low-speed performance** (e.g. LEDP)
- For long-range aircraft: aero-propulsive benefit of propulsion systems which enhance **cruise performance**
- Expand turboelectric “regional prop” market to longer ranges

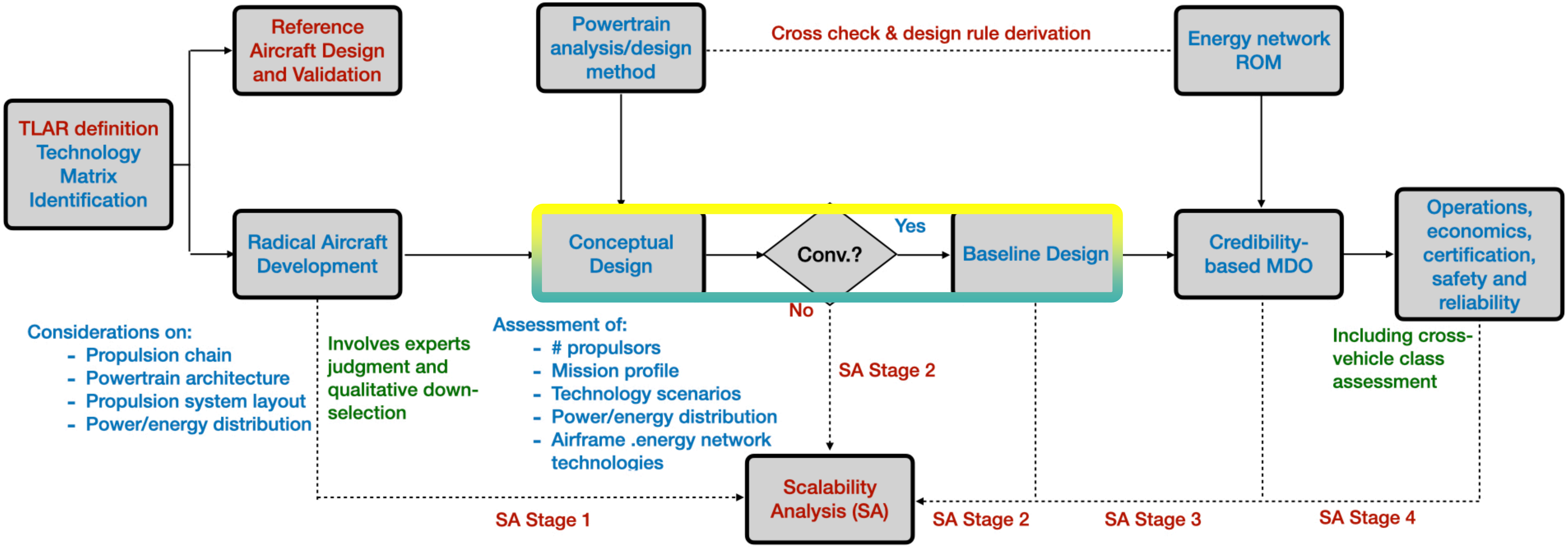
- Leading-edge distributed propulsion for high speed application (M> 0.6)
- Serial, fully-electric, or fully-turboelectric powertrains for SMR, LPA

	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	
Battery						P1: WMP. P2: WtipMP GA P1: -. P2: LEDP Com; GA

Baseline designs

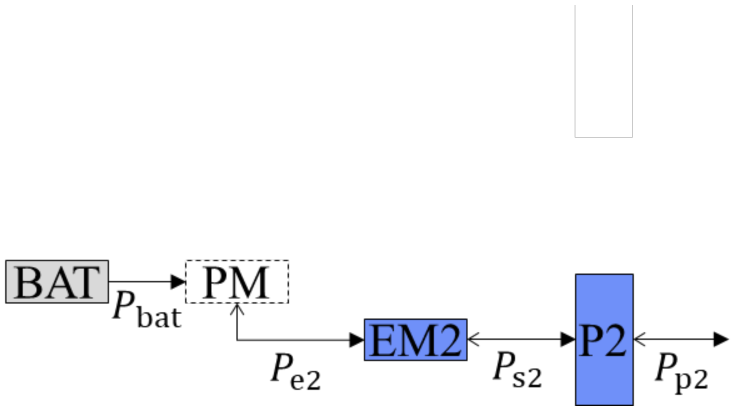
Scalability assessment stage 2

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



General aviation

- Candidate for full electric powertrain
- Combined with LEDP



- LEDP enables higher wing loading
  - Smaller wing per unit weight
- Equivalent PREE to reference
  - Despite MTOM penalty
  - ~900kg battery required for equivalent 33kg fuel
  - Benefits from high EM efficiency
- Scalable to commuter class

Commuter aircraft - summary

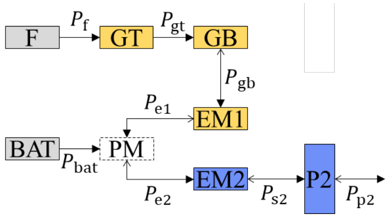
- Full-e LEDP
- Serial LEDP & WTMP
- SPPH (main + LEDP)

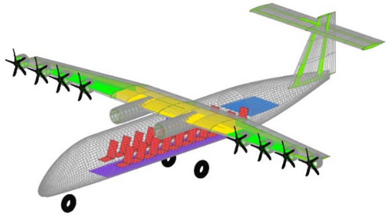
- Hybrids within CS-23
- Full-e exceeds CS-23 (150%)
- Serial WTMP can achieve FM benefit at similar PREE
- Significant increase in masses and dimensions

Commuter - detail

Serial LEDP

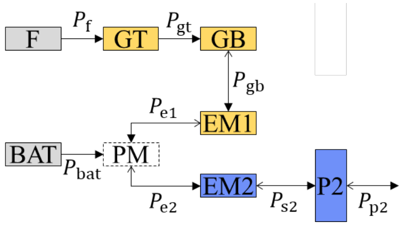
- At CS-23 limit
- Battery power supply increases GT powerloading
- Increased wingloading (33%)
- PREE decrease
- Power conversion losses and battery mass penalize cruise L/D improvement

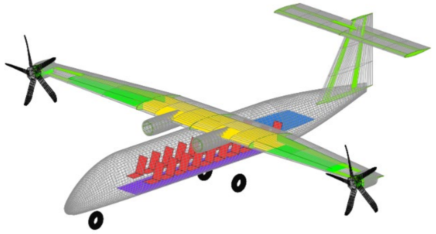




Serial WTMP

- Within CS-23
- Battery power supply increases GT powerloading
- High aero-prop efficiency
- Equivalent PREE and fuel burn reduction
- Potential for more improvement sizing battery for energy

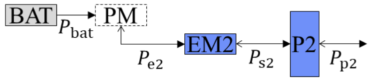


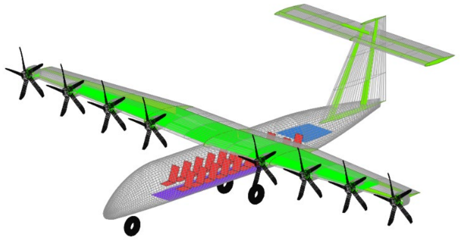


Commuter - detail

Full-E LEDP

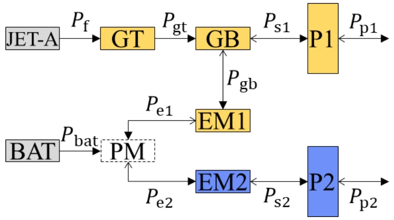
- CS-23 MTOM exceeded
- Increased wingloading (17,5%, serial LEDP at 33%)
- Significant PREE improvement

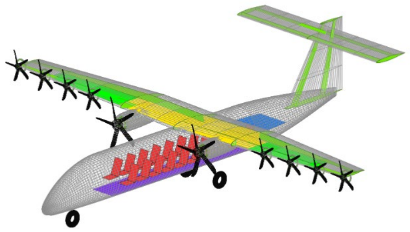




SPPH-LEDP

- Within CS-23
- Battery power supply increases GT powerloading
- Design wingloading sensitive to φ (supplied power ratio)
- PREE decrease, FM increase



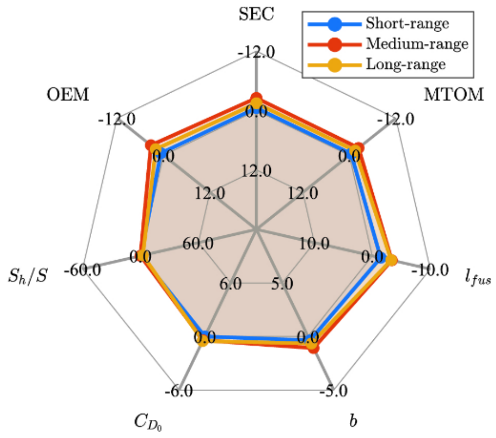


Supplementary studies

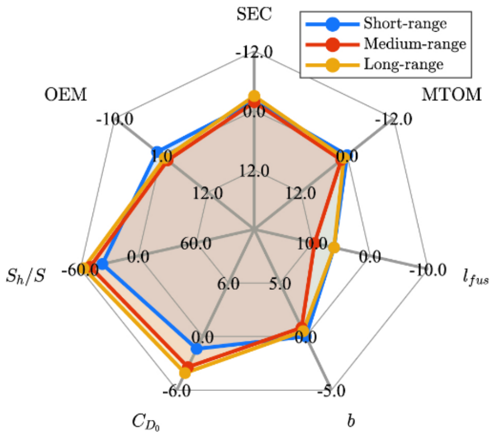
Liquid Hydrogen Tank integration

Effects of LH2 fuel tank integration

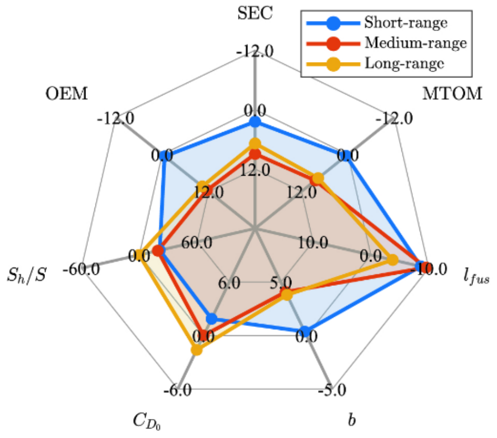
- Integral vs non-integral tank: (a)
  - Benefits increase aircraft category
- Aft-and-forward rather vs aft tank layout (b)
  - SMR & LPA; improved specific energy consumption, worse OEM/MTOM
- Increasing fuselage diameter by adding one seat abreast (c)
  - SMR suffers most due to extra aisle
  - LPA 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.

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

Regional aircraft - summary

- Largest design space exploration
- LH2 combustion
- WTMP, BLI or LEDP

- LH2 most FM reduction
- LEDP offers potential when gate-size constrained
  - Battery volume (in wing) becomes constraining
- Sensitivity studies indicate potential for FM benefits

- Mass penalty must be carefully overcome by power-control parameter selection
- Power conversion losses can be penalizing

Short/medium range aircraft

- Boosted turbofan
- BLI fan
- LH2 combustion

- Only LH2 combustion shows potential to lower FM
  - Fuselage length/mass penalize PREE
- Boosted turbofan suffers from debilitating mass penalties, even at low supplied power
- BLI fan sensitive to OEM increases

Large passenger aircraft

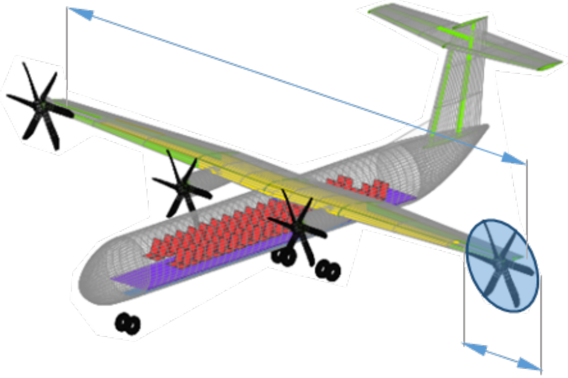
- BLI fan
- LH2 combustion

- No possibility to scale up boosted turbofan from SMR

- Effects from SMR scale up directly
- Extreme fuselage length increase for LH2
  - Challenge to fit in 80x80m box
  - Double deck configuration may be of interest
- BLI fan shows similar effects to SMR, potentially better at LPA

Scalability assessment stage 2 - summary

- Full-e up to 19 pax commuter, if CS-23 limit ignored
- LEDP enables HEP span-constraint regional or large commuter aircraft to fit within gate limits
  - FM reduction possible
  - Wing volume becomes constraining
- WTMP seems better suited to commuter aircraft
- Serial power train for commuter/regional, SPPH for dual powertrain suffers from power conversion losses
- Beyond regional, only LH2 combustion
- Hybridization up to SMR, boosted turbofan



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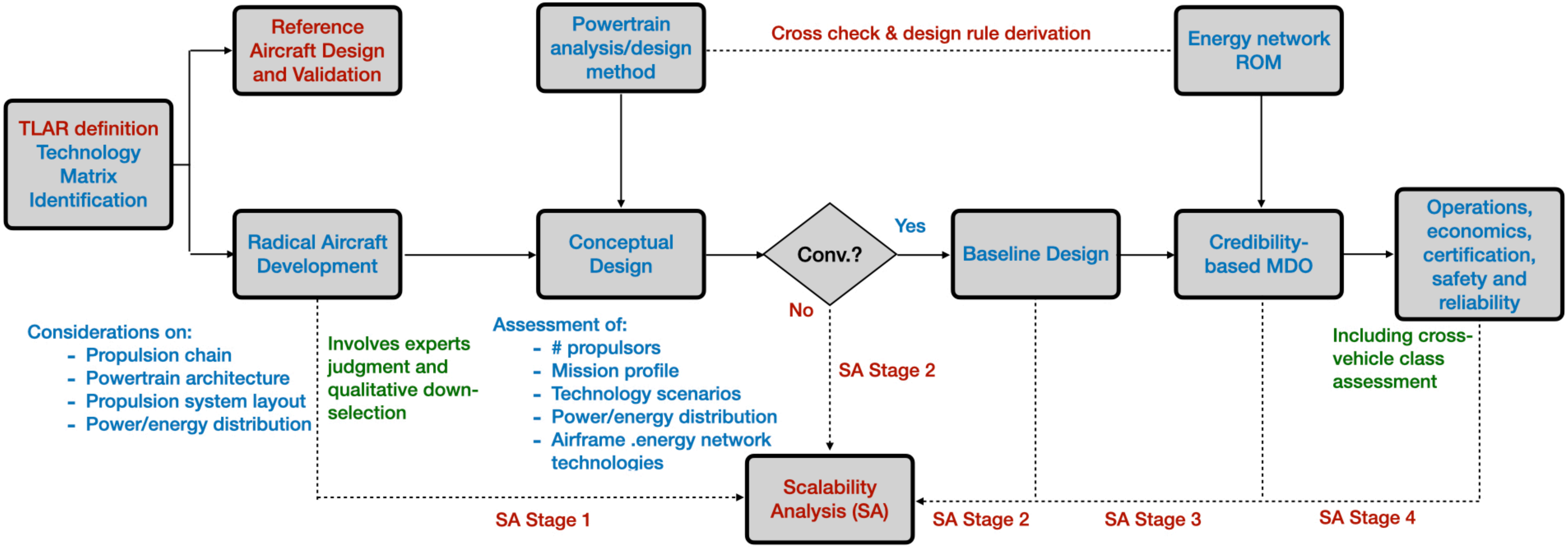
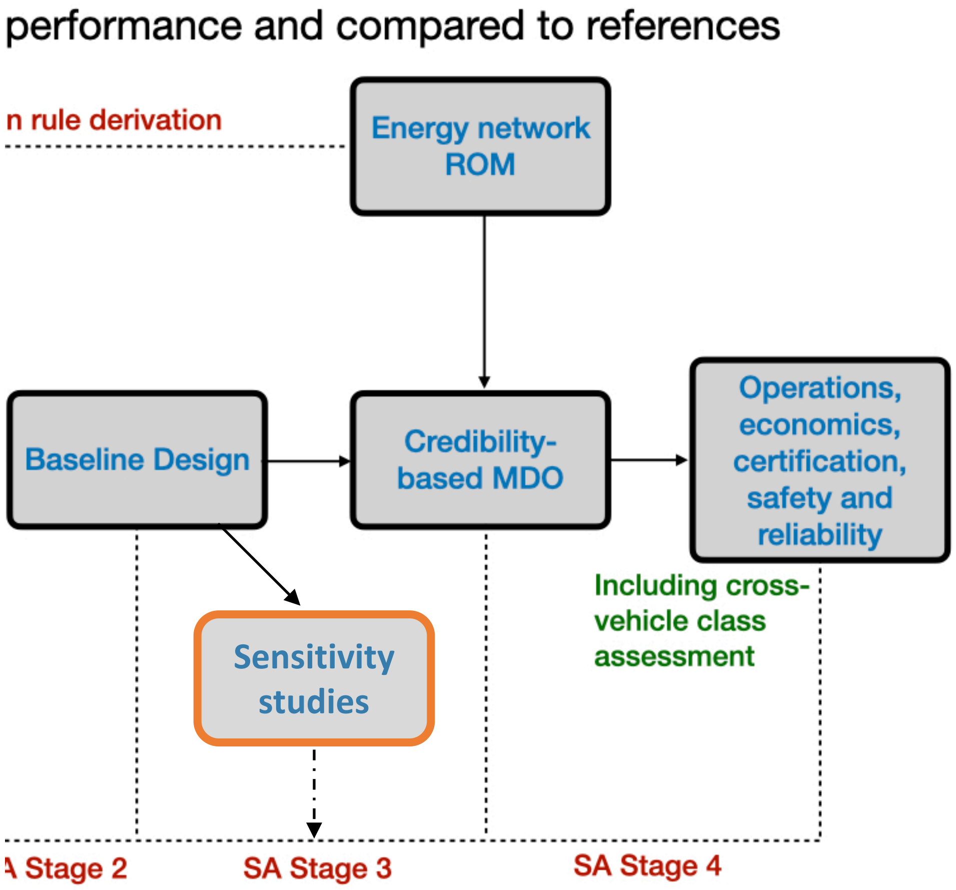


Scalability Assessment Stage 3 & 4

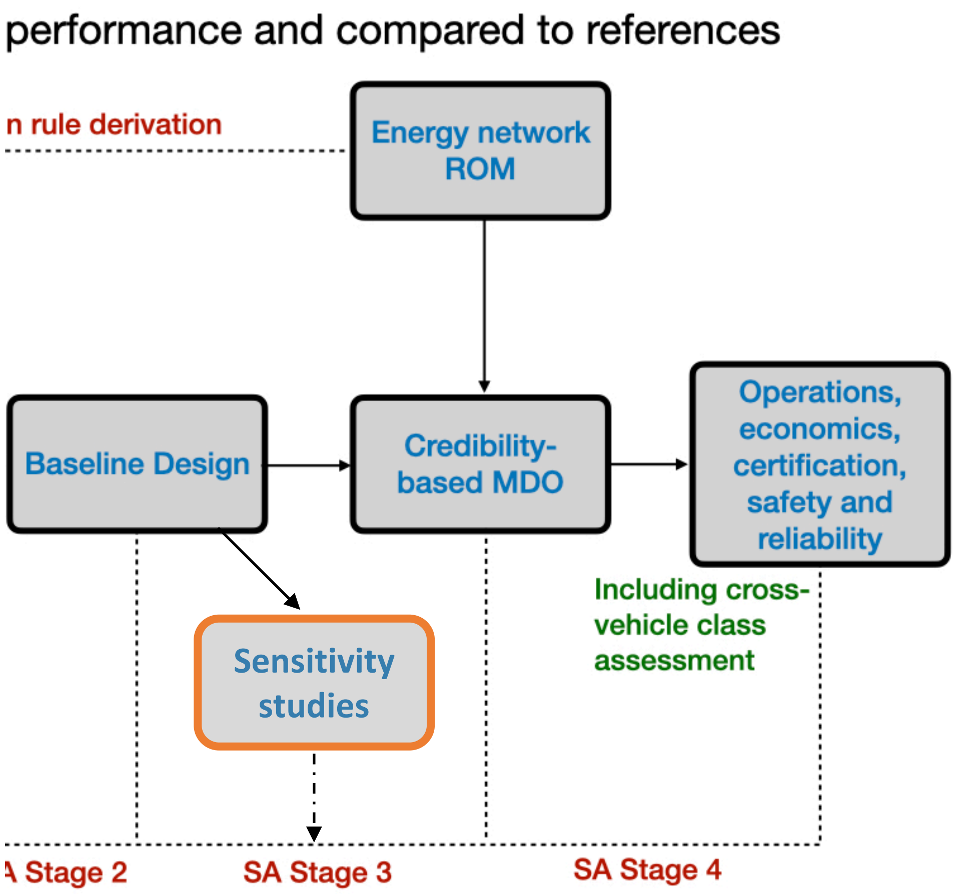
- Stage 3:
  - Selected aircraft for credibility-based MDO; with higher fidelity analysis
  - Supported by additional sensitivity studies with state-of-the-art conceptual aircraft design methods
- Stage 4:
  - Regional Airline Network
  - Airport integration



CHYLA advancements beyond SotA

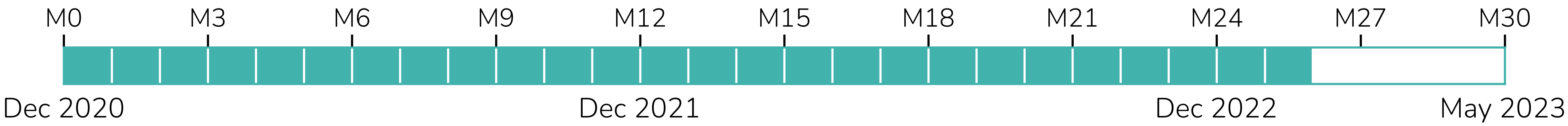
Development of:

- Credibility-based MDO method
- (Hybrid) Electric Energy Network
- Regional airline network



- Scope for next presentations
- Provide key exploitable results beyond CHYLA project

Credible HYbrid eLectric Aircraft



Thank You

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European Commission | Horizon 2020

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