Exploration of Hybrid Electric Propulsion in Regional Aircraft

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Publication date
2016

Document Version
Final published version

Citation (APA)
Veldhuis, L., & Voskuijl, M. (2016). *Exploration of Hybrid Electric Propulsion in Regional Aircraft*. The Electric and Hybrid Aerospace Technology Symposium 2016, Cologe (Koln), Germany.

Exploration of Hybrid Electric Propulsion in Regional Aircraft

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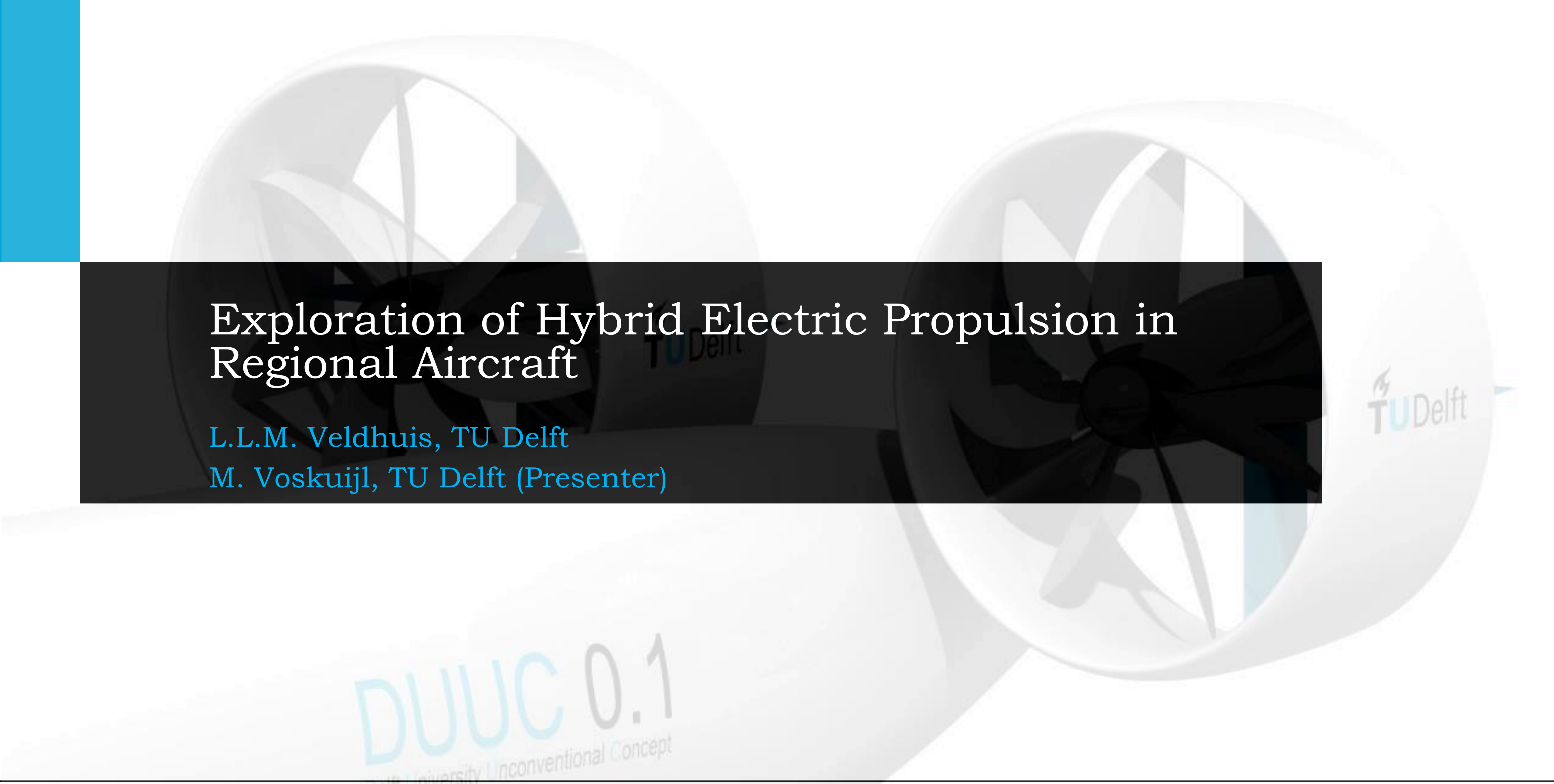
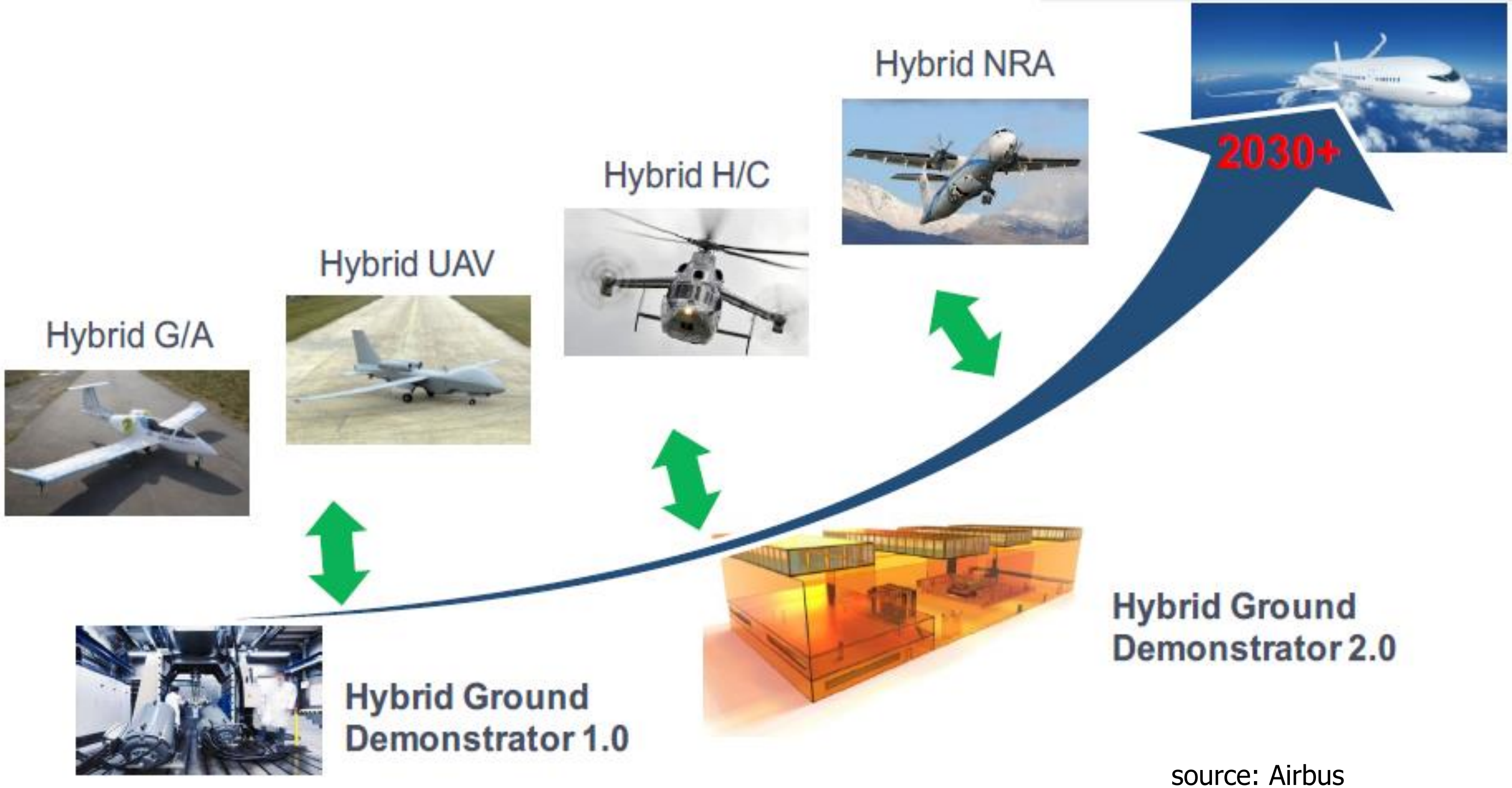


Contents

- Feasibility of hybrid-electric aircraft
- 3 Recent studies (S1,S2,S3)
- Project NOVAIR
- DUUC initiative
- Conclusions

Technology advancement

Technology demonstrators to validate basic assumptions and to drive technology maturations



source: Airbus

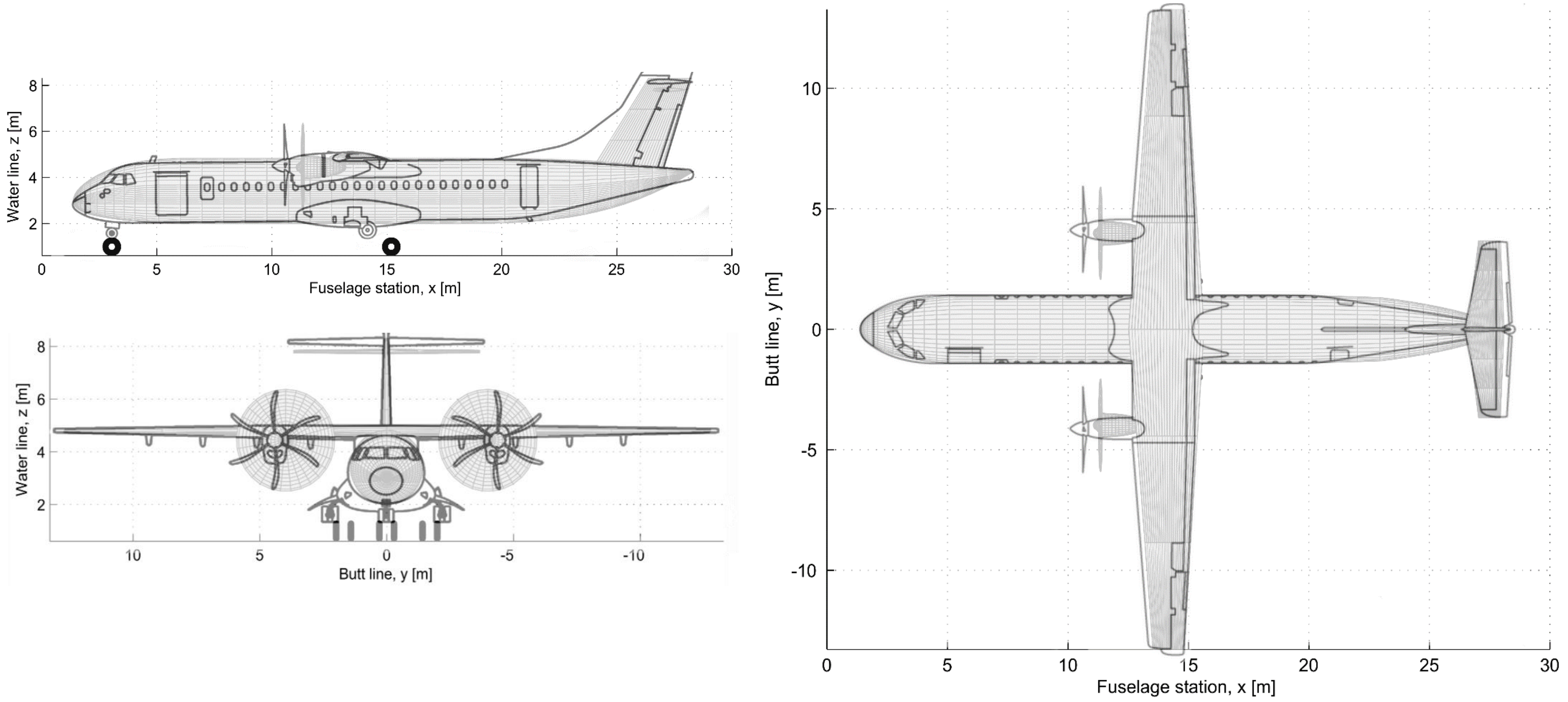
S1: Analysis & design of a hybrid electric regional aircraft

Objective

- Assess the potential **fuel consumption reduction** of **hybrid-electric regional aircraft**, compared to a **reference aircraft** by **2035**
- Fuel is replaced partly by batteries as **energy source**
- Explore design space

S1: Reference Aircraft

Comparison between reference aircraft design and ATR-72-600:



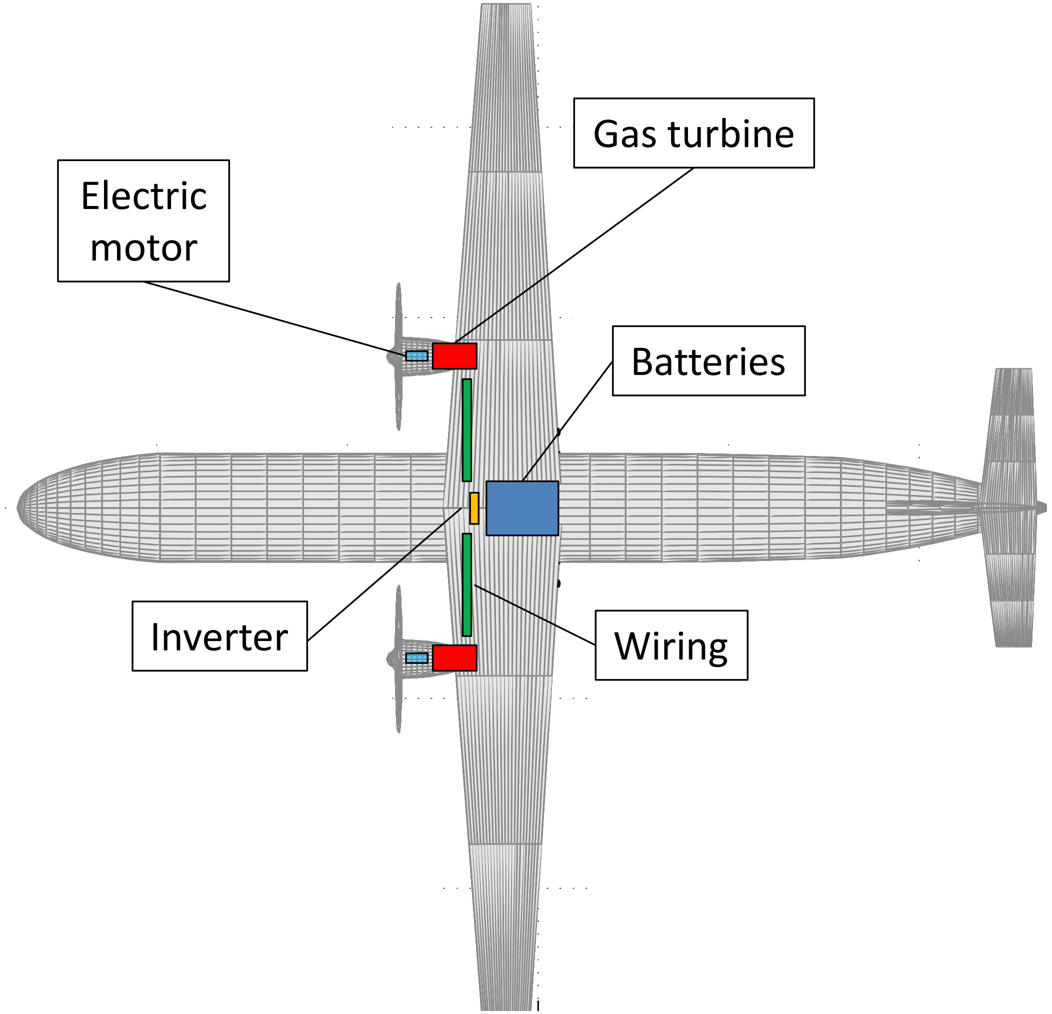
S1: Reference Aircraft

Reference aircraft design

Comparison between reference aircraft design and ATR-72-600:

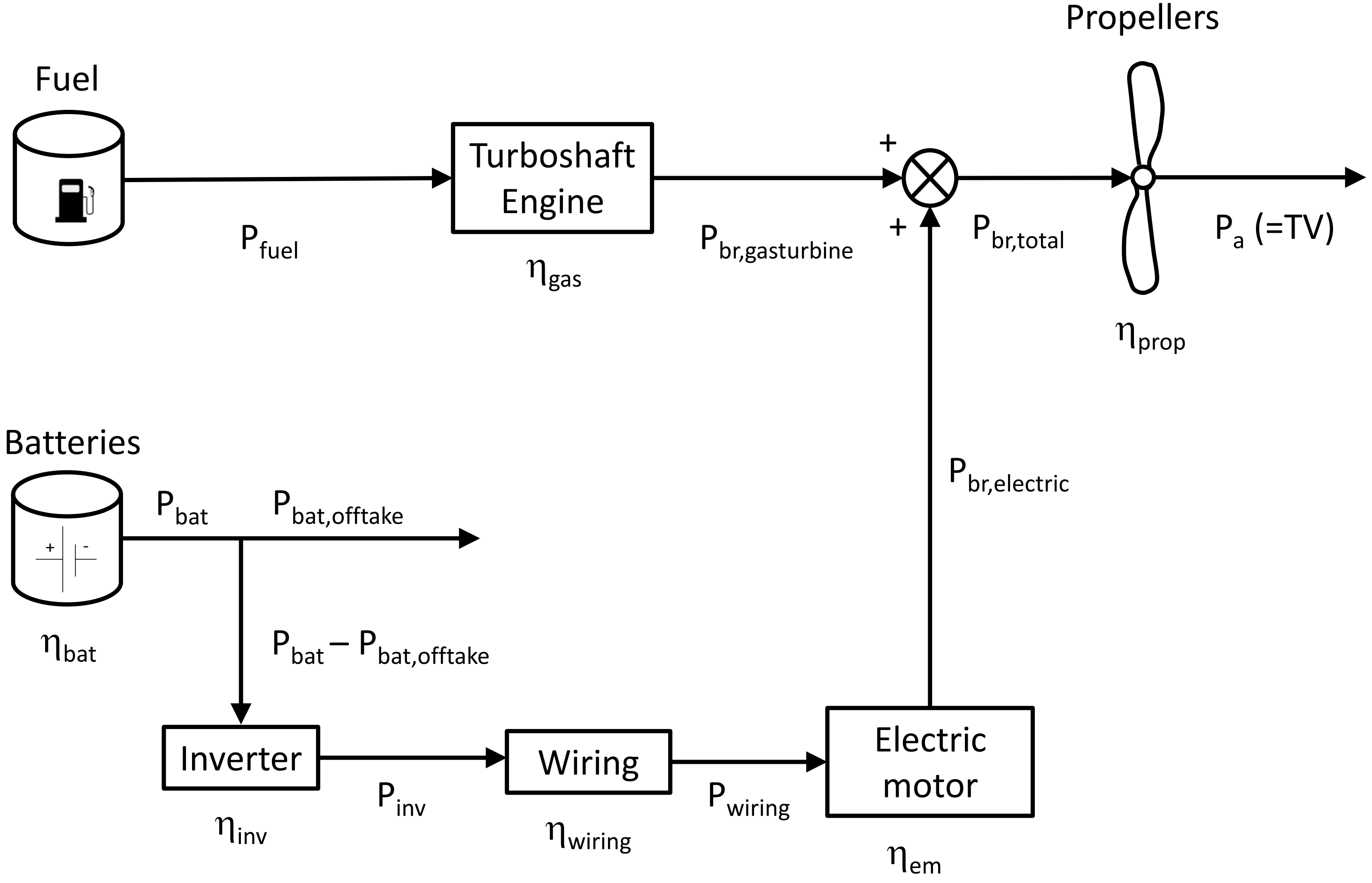
Parameter	ATR-72-600	Reference aircraft	Difference
MTOM [kg]	22800	22340	- 2.0 %
Mission fuel mass [kg]	2000	2050	+ 2.5 %
Empty mass [kg]	13010	12780	- 1.8 %
Wing span [m]	27.05	26.5	- 2.0 %
Wing area [m^2]	61	58.54	- 4.2 %
Fuselage length [m]	27.17	27	- 0.6 %

S1: Aircraft hybrid electric propulsion integration



- ❑ Traditional HEPS based AC layout
- ❑ Electrical motors coupled in parallel
- ❑ All additional systems and wiring taken into account

S1: Parallel hybrid electric propulsion system architecture



S1: New Brequet Range Equation

Instead of traditional Brequet range equation:

$$Range = \frac{\eta_{prop}}{SFC} * \frac{C_L}{C_D} * \ln\left(\frac{m_{start}}{m_{end}}\right)$$

Adapted version for hybrid electric propulsion:

$$Range = \frac{1}{\frac{S}{\eta_{el}} + (1 - S) * SFC * e_{fuel}} * \frac{C_L}{C_D} * \eta_{prop} * \frac{1}{e_{combined}} * ln\left(\frac{e_{combined} * E_{start} + m_{empty}}{m_{empty}}\right)$$

Where:

η_{el} = total electrical efficiency from battery to electric motor output

e_{combined} = combined specific energy of battery and fuel:

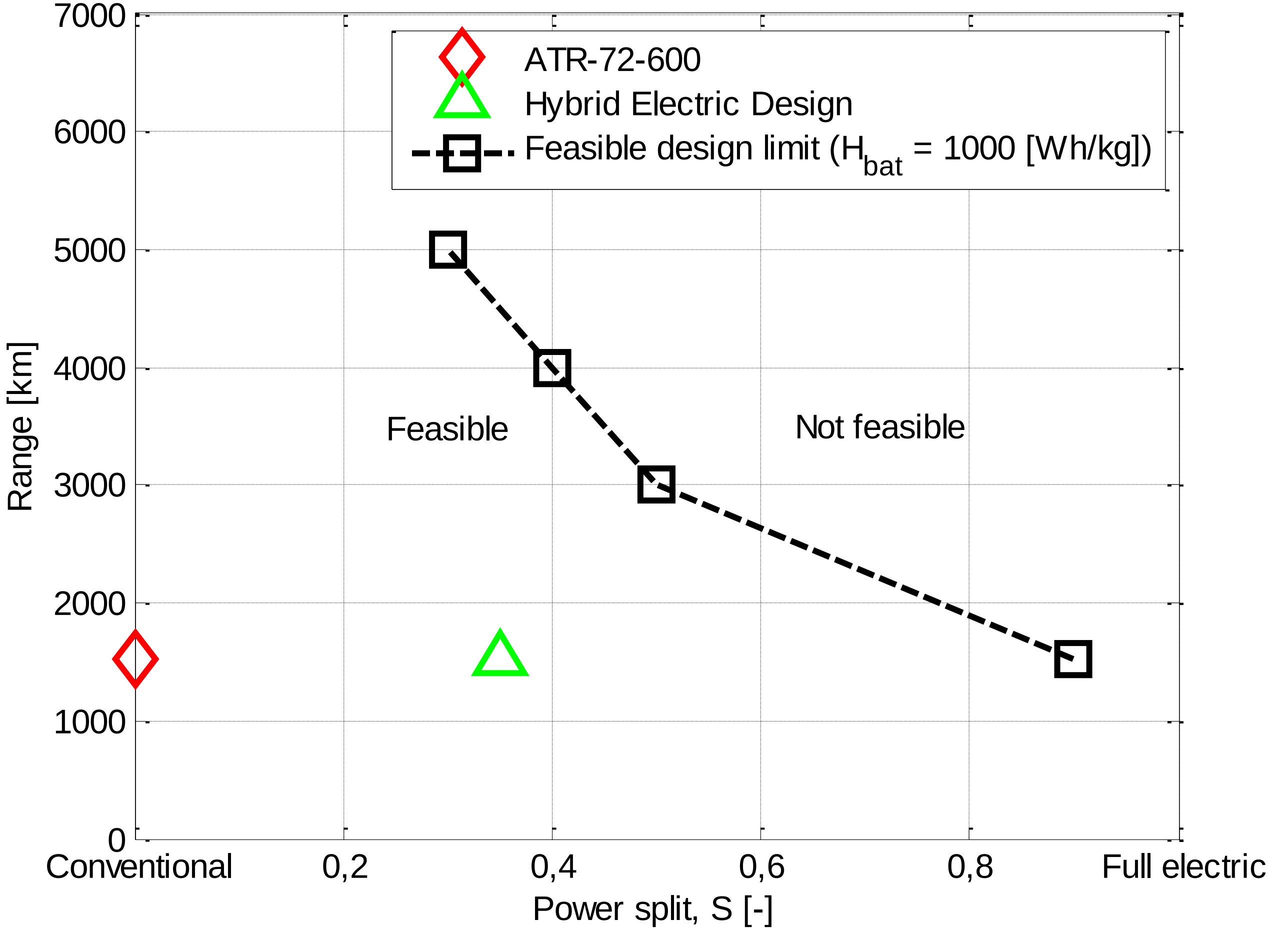
$$e_{combined} = \frac{H_E * e_{fuel} + (1 - H_E) * e_{bat}}{e_{fuel} * e_{bat}}$$

S = power split

H_E = degree of hybridization of energy:

$$H_E = \frac{E_{bat}}{E_{tot}} = \frac{S}{S + (1 - S) * SFC * e_{fuel} * \eta_{el}}$$

S1: Feasible design space hybrid electric regional aircraft



S1: AC comparison

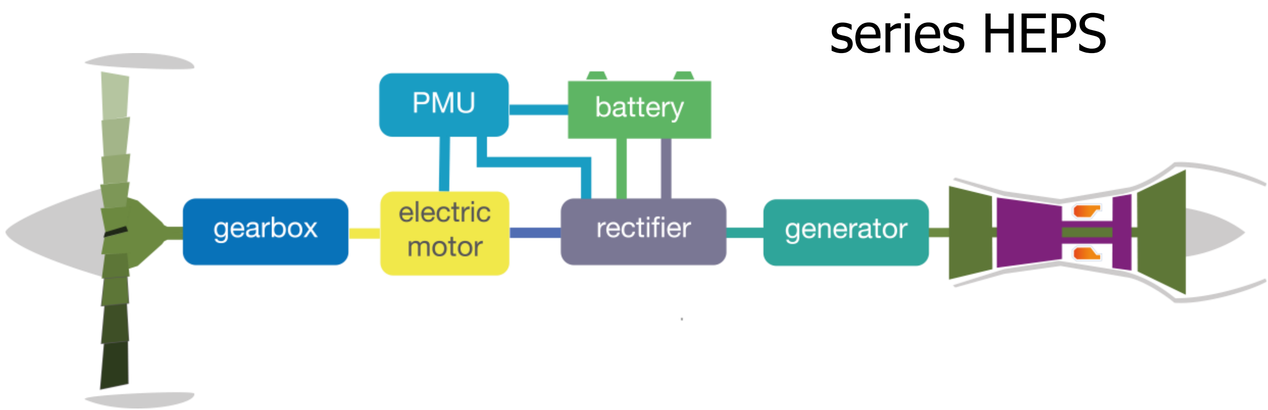
Comparison reference and hybrid-electric aircraft design

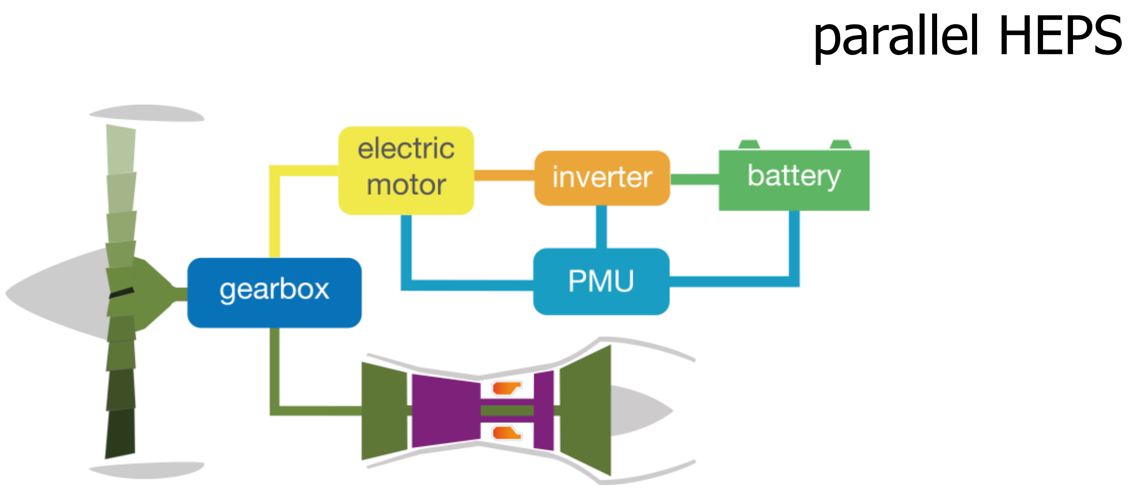
Parameter	Reference aircraft	Hybrid-electric aircraft	Difference
MTOM [kg]	22340	25470	+ 14 %
Mission fuel mass [kg]	2050	1470	**- 28 %**
Battery mass [kg]	0	2948	n/a
Battery energy density [Wh/kg]	n/a	1000	n/a
Empty mass [kg]	12780	13552	+ 6 %
Total energy stored in batteries and fuel [MWh]	26.19	21.73	- 17 %
Wing span [m]	26.5	28.8	+ 8.7 %
Wing area [m^2]	58.54	69.1	+ 18 %
Fuselage length	27	27	0 %

S1: Conclusion

- Significant fuel saving can be achieved (up to 30 %)
- Analysis only for regional aircraft
- Results depend heavily on technological progress
- Chosen operating mode has influence on final design
- Promising results, future research recommended

S2: Integrated performance analysis applied on short-range aircraft





Advantages:

- Operates at optimal RPM
- Higher effective BPR
- Design freedom in positioning of engine and fan

Disadvantages:

- Heavy
- Less efficient

Advantages:

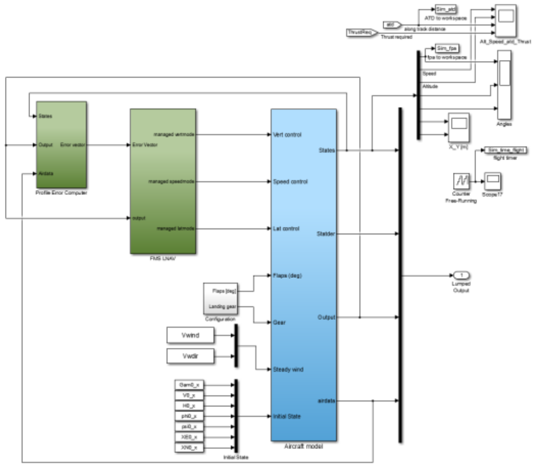
- Independent operation between engine and electrical system
- Independent design of power share between both subsystems

Disadvantages:

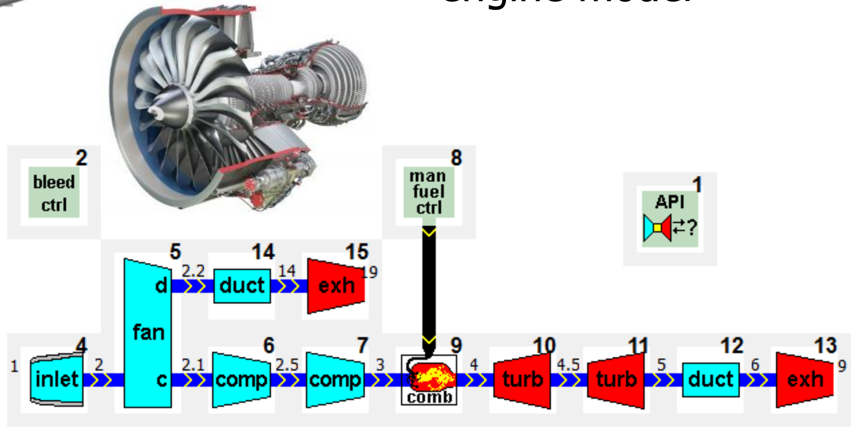
- See advantages series

S2: Simulation model: A320 with integrated HEPS

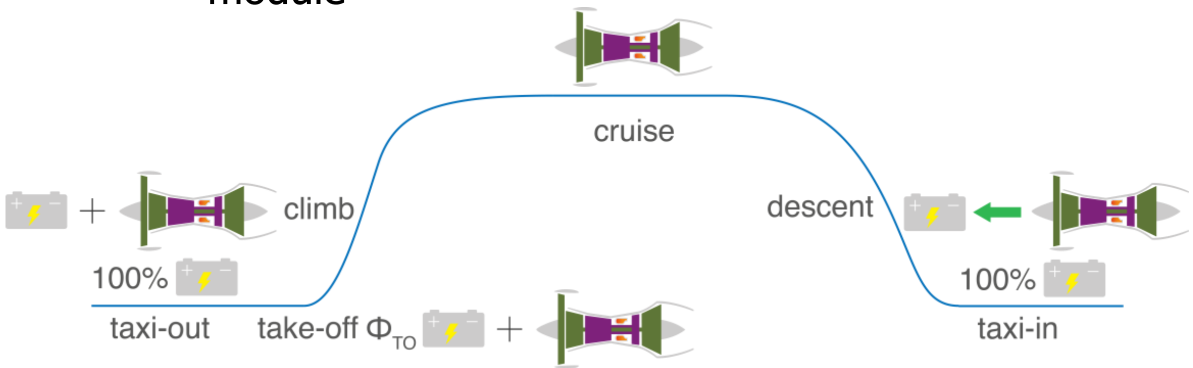
aircraft model



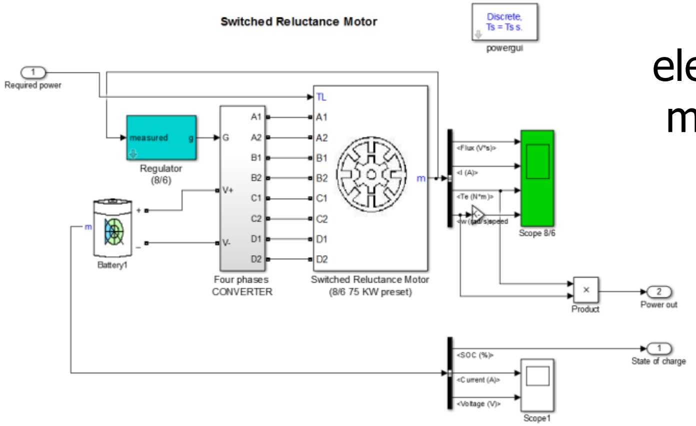
engine model



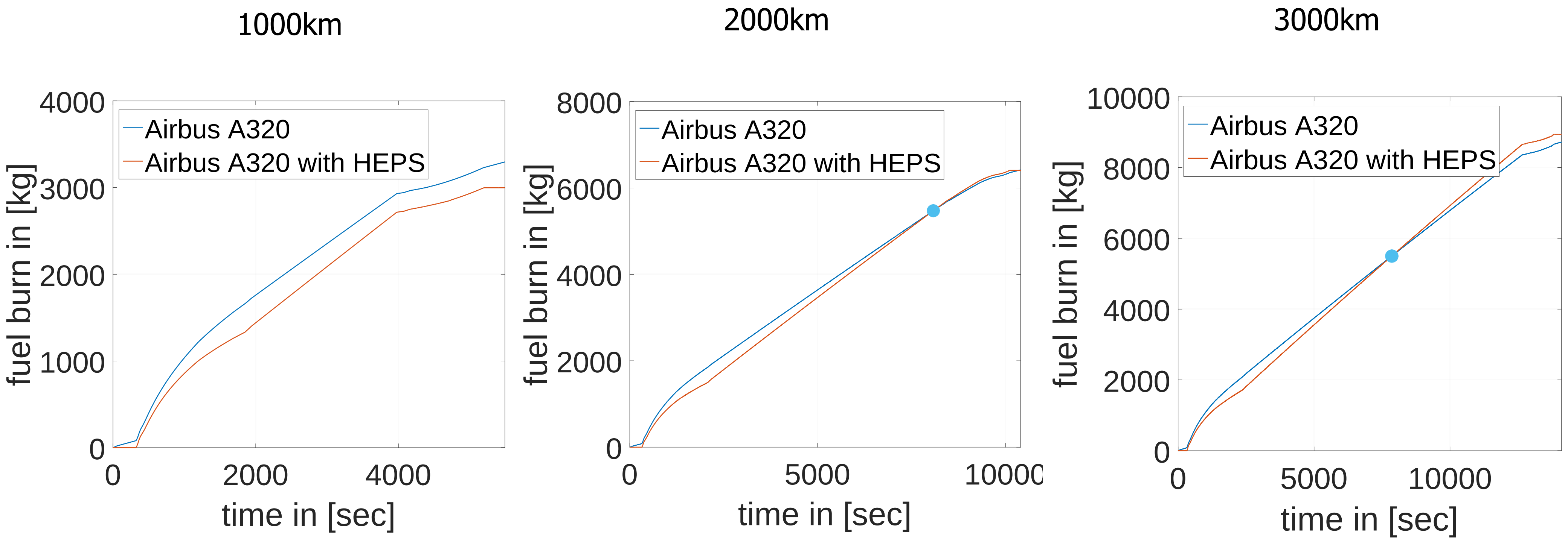
power management module



electrical module

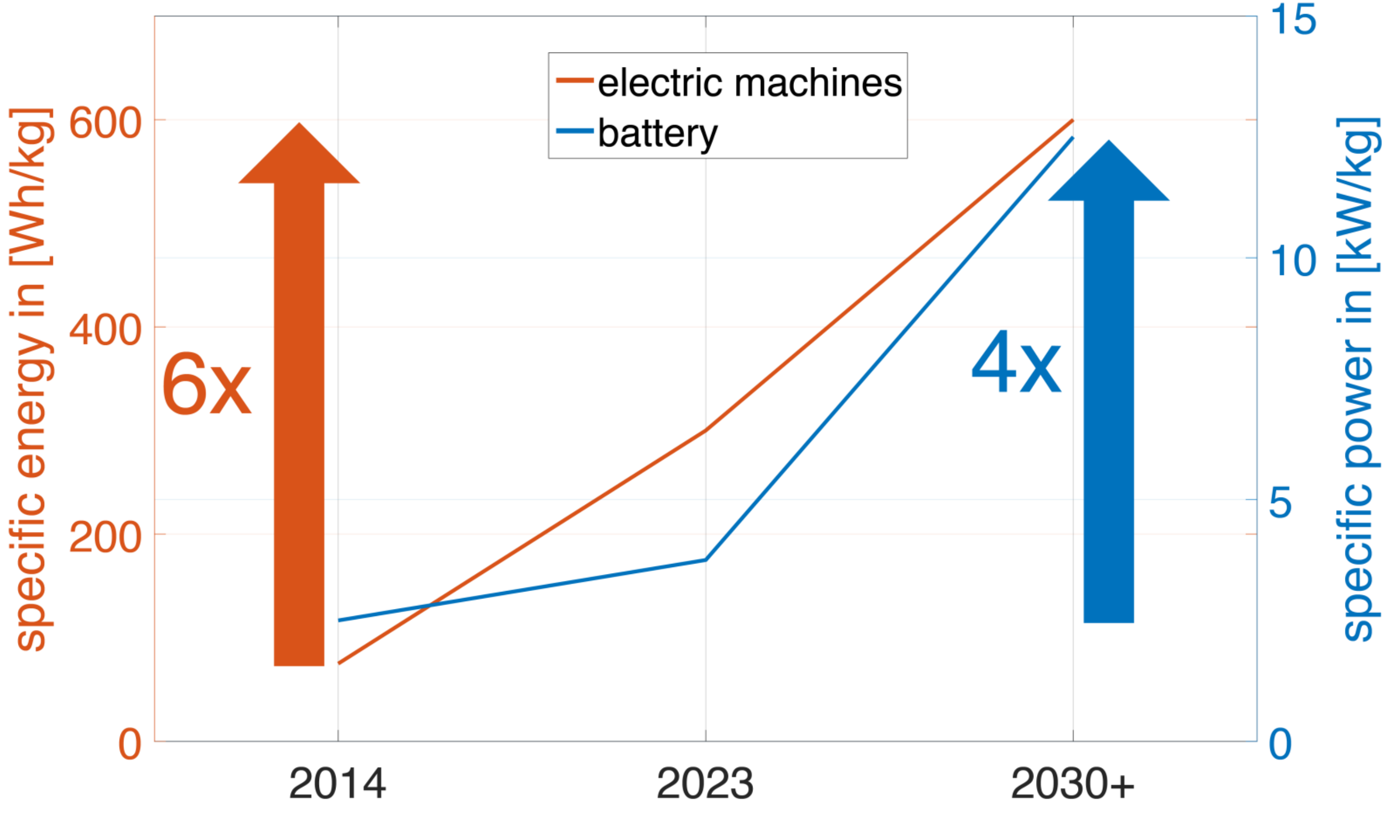


S2: Impact of range on fuel burn



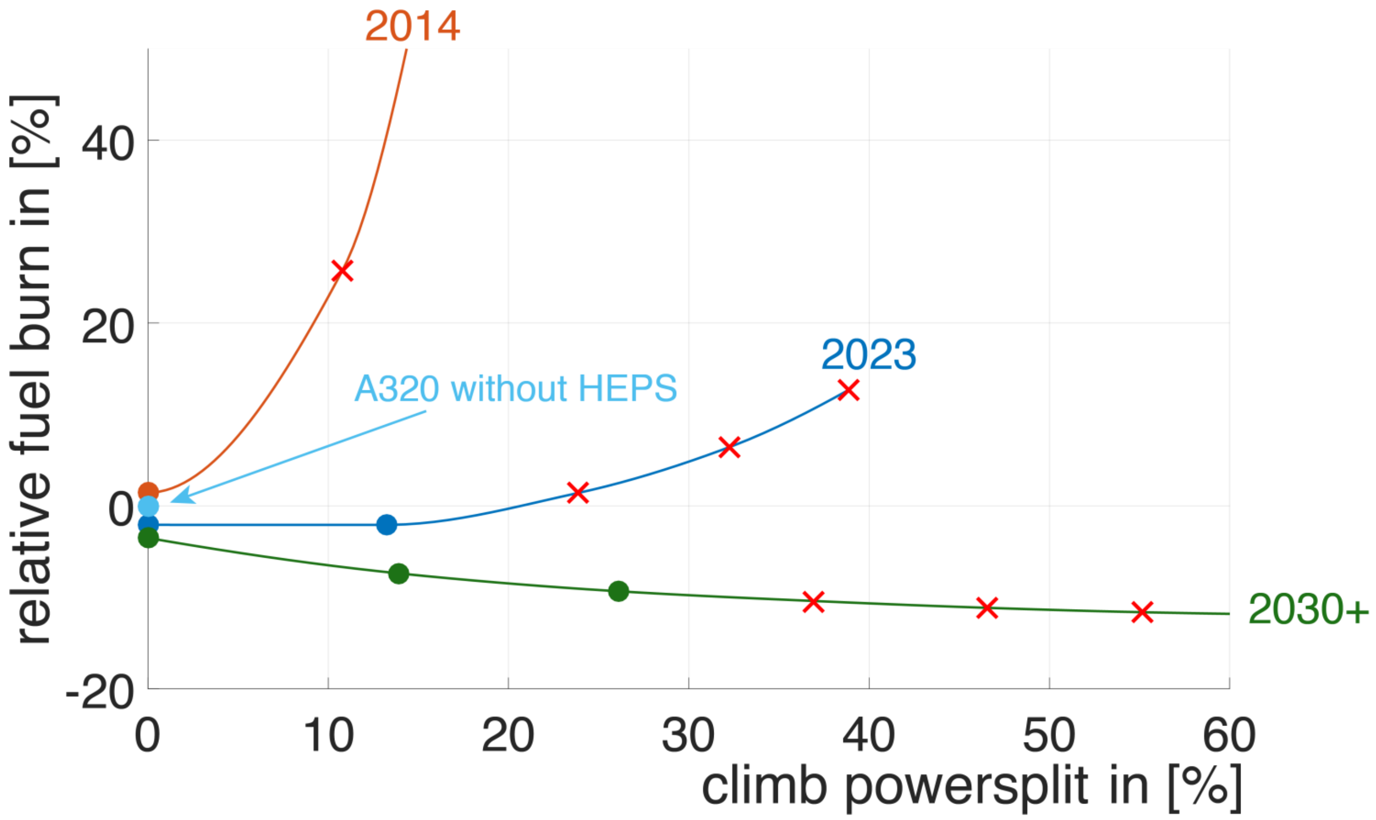
HEPS is beneficial for short ranges

S2: Technology development of electric components



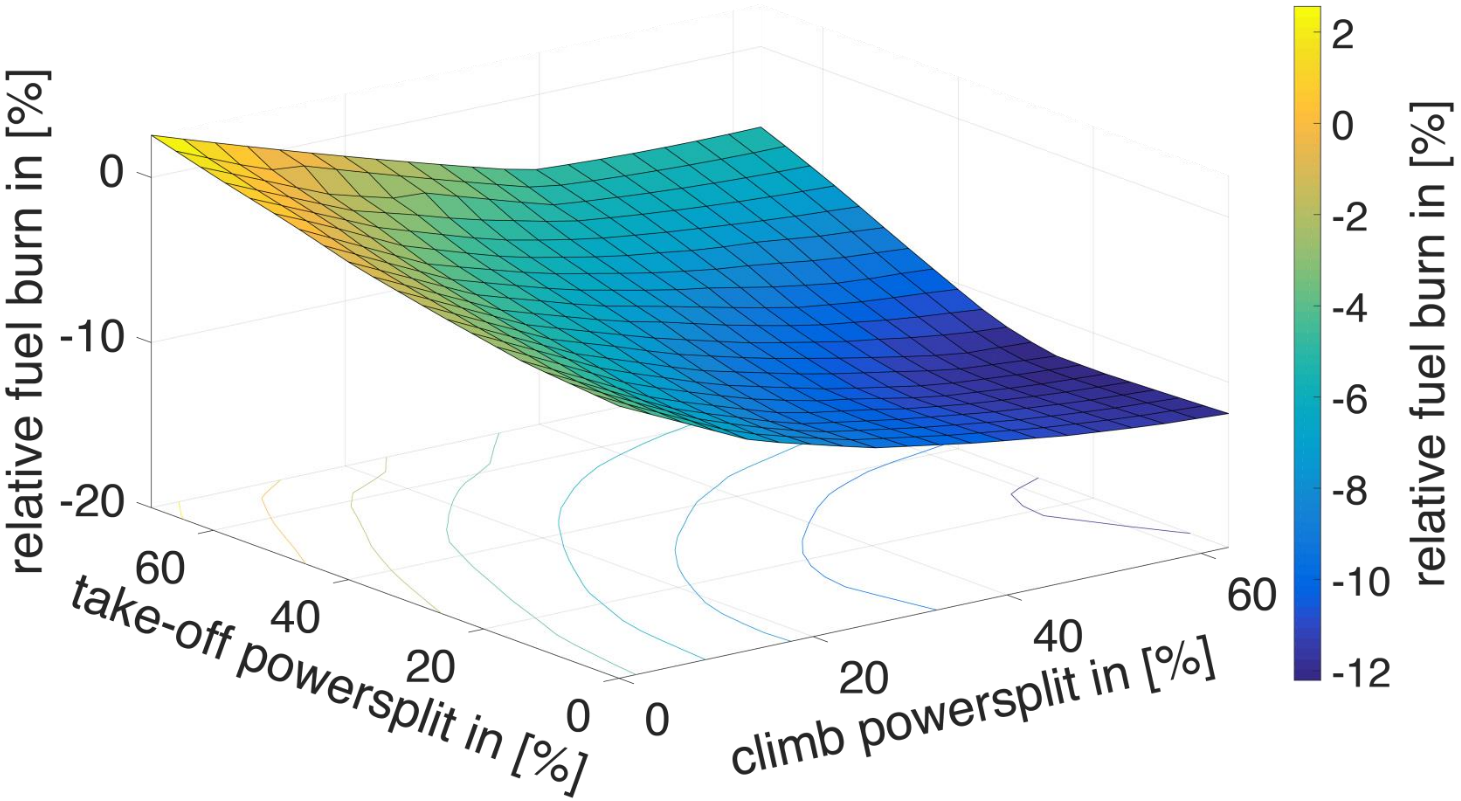
source: Airbus (2015)

S2: Effect of technology development on fuel burn



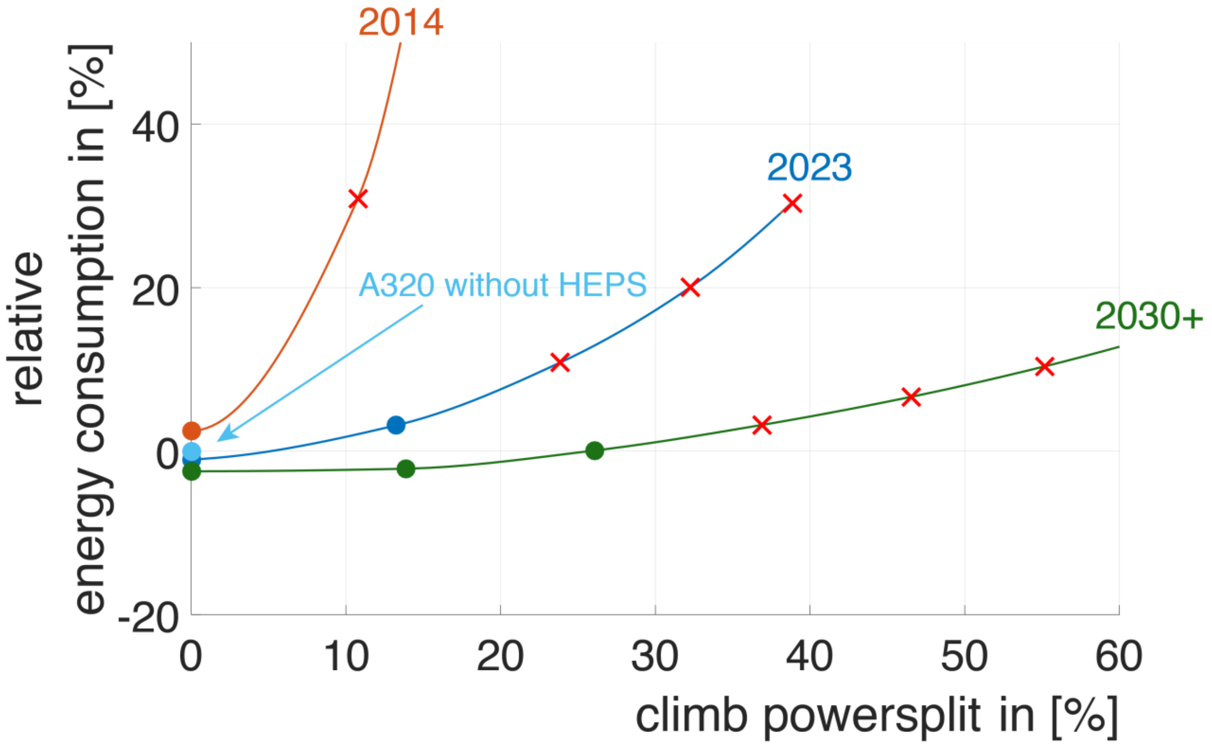
Based on 2030+ technology maturity level HEPS become beneficial

S2:Effect of hybridisation on fuel burn



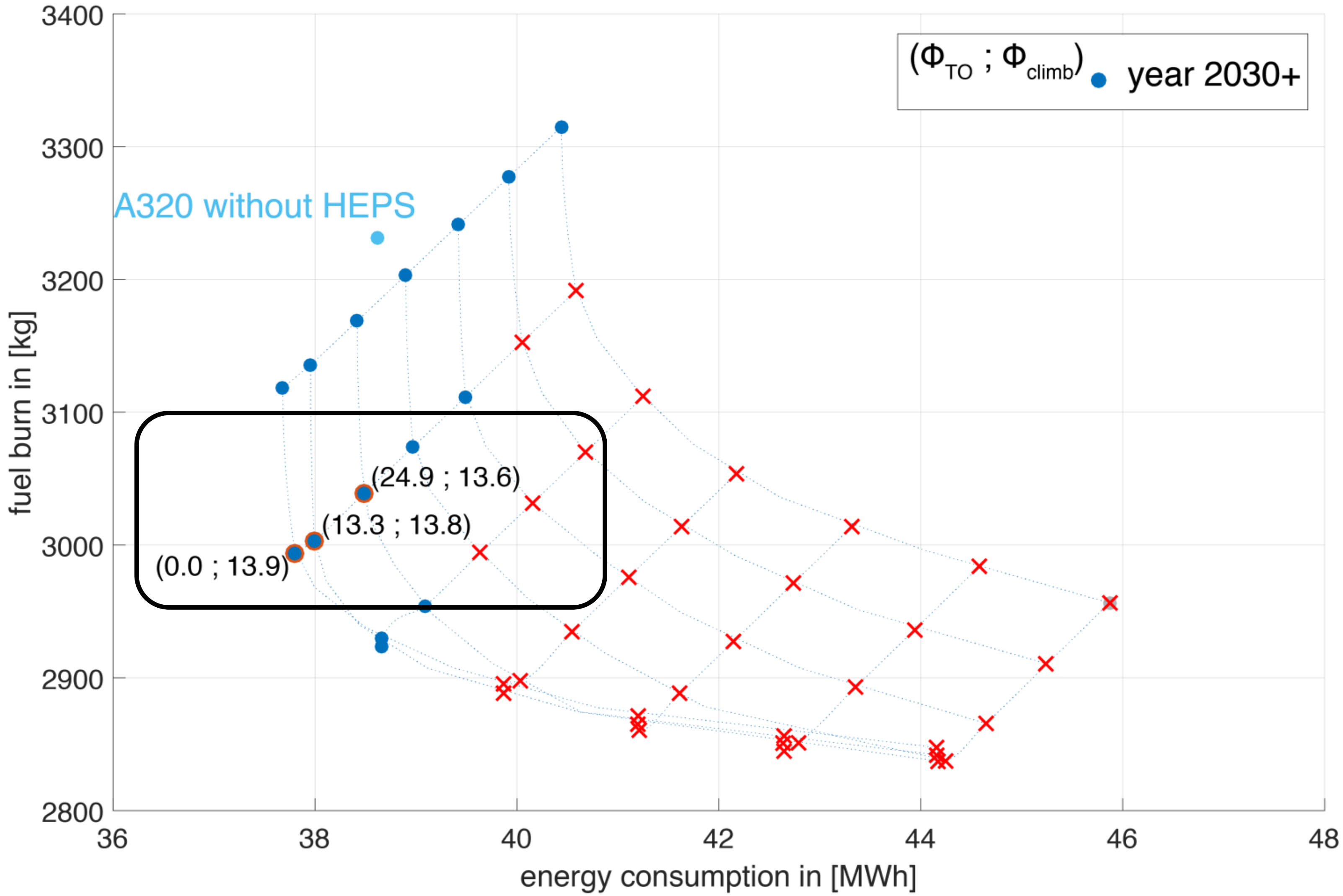
Take-off power split increases fuel burn (maturity 2030+)

S2: Energy consumption

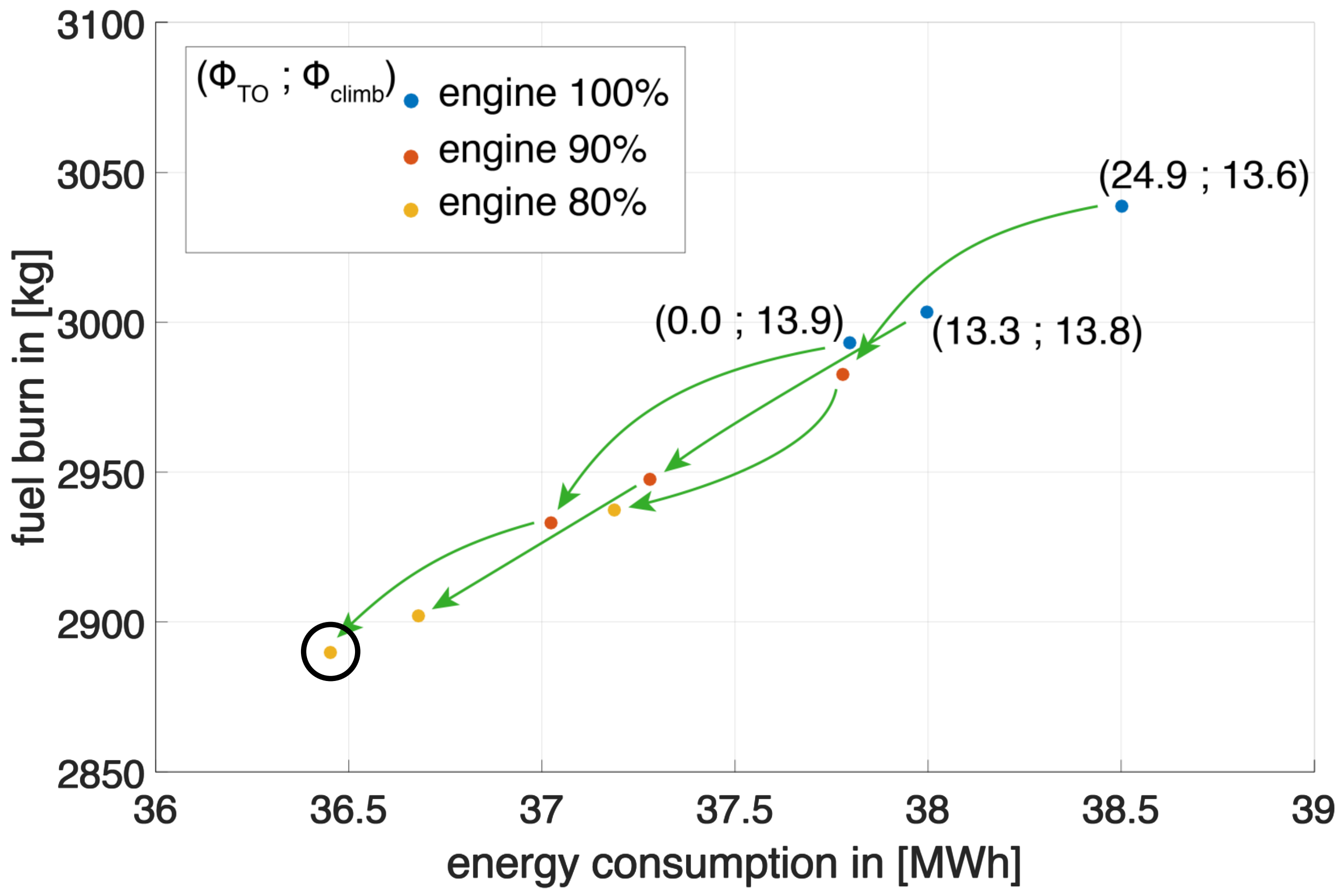


From an energy consumption perspective, HEPS are only slightly beneficial with technology development predicted by 2030+

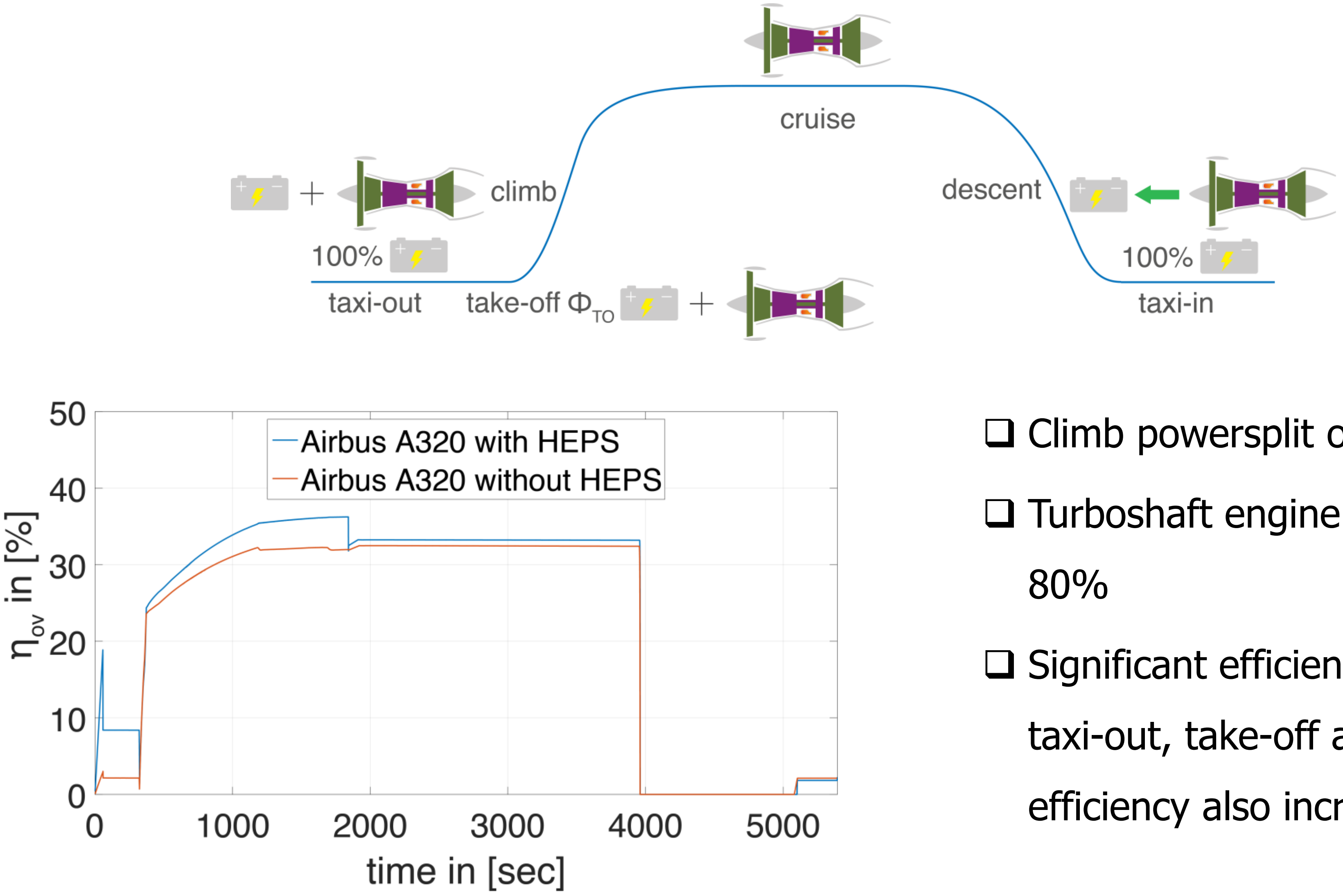
S2: Fuel burn vs. Energy consumption



S2: Effect of engine sizing on performance

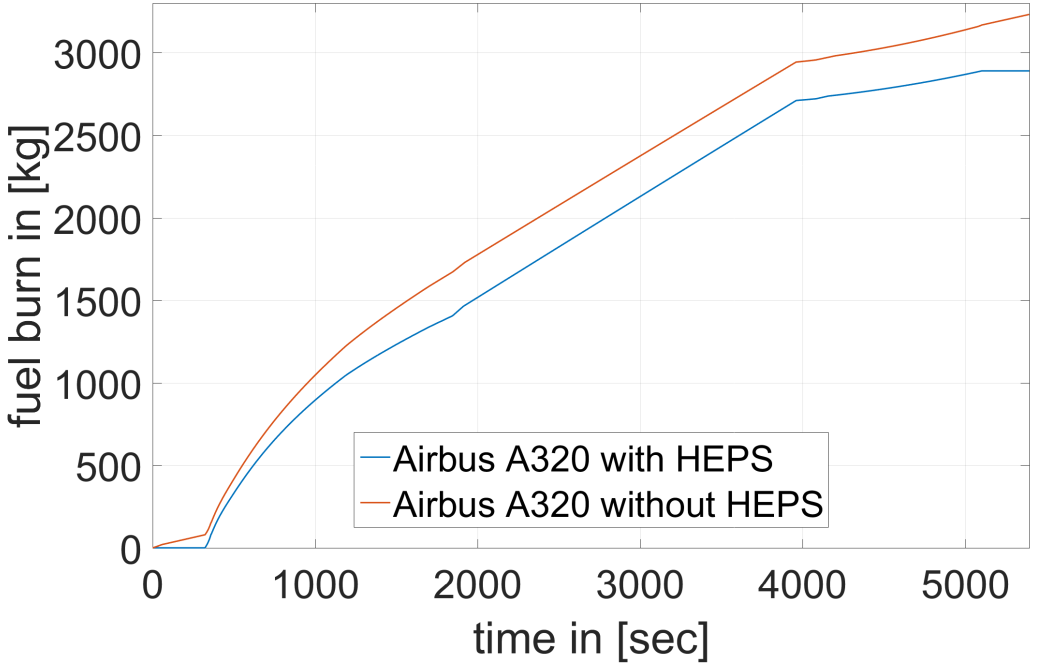


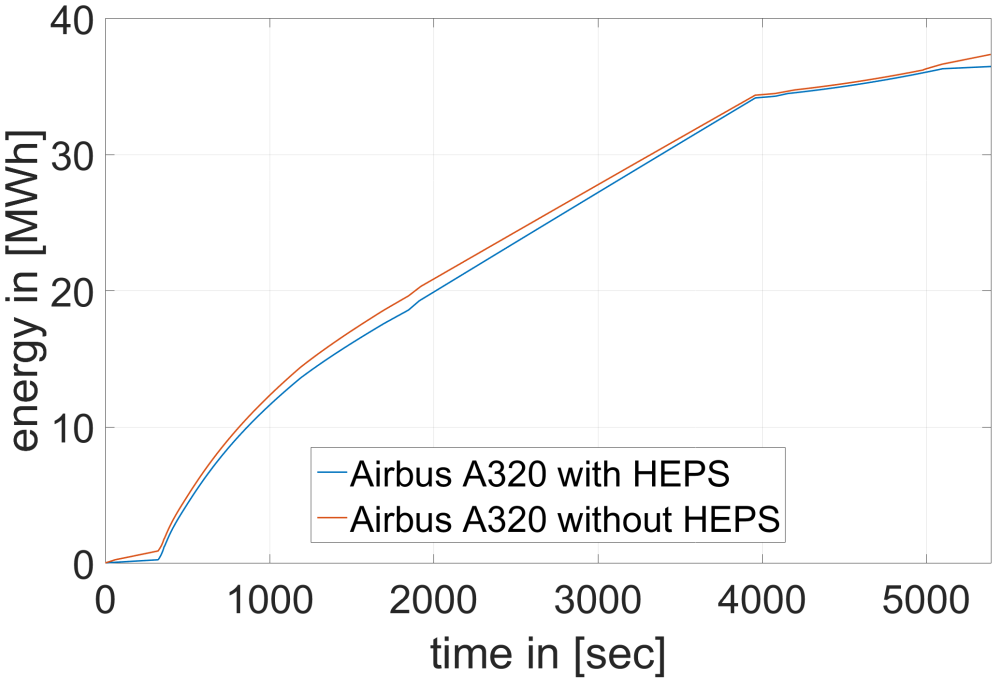
S2: Optimised HEPS overall efficiency



- ❑ Climb powersplit of 14%
- ❑ Turboshaft engine down scaled to 80%
- ❑ Significant efficiency increment during taxi-out, take-off and climb and efficiency also increases during cruise

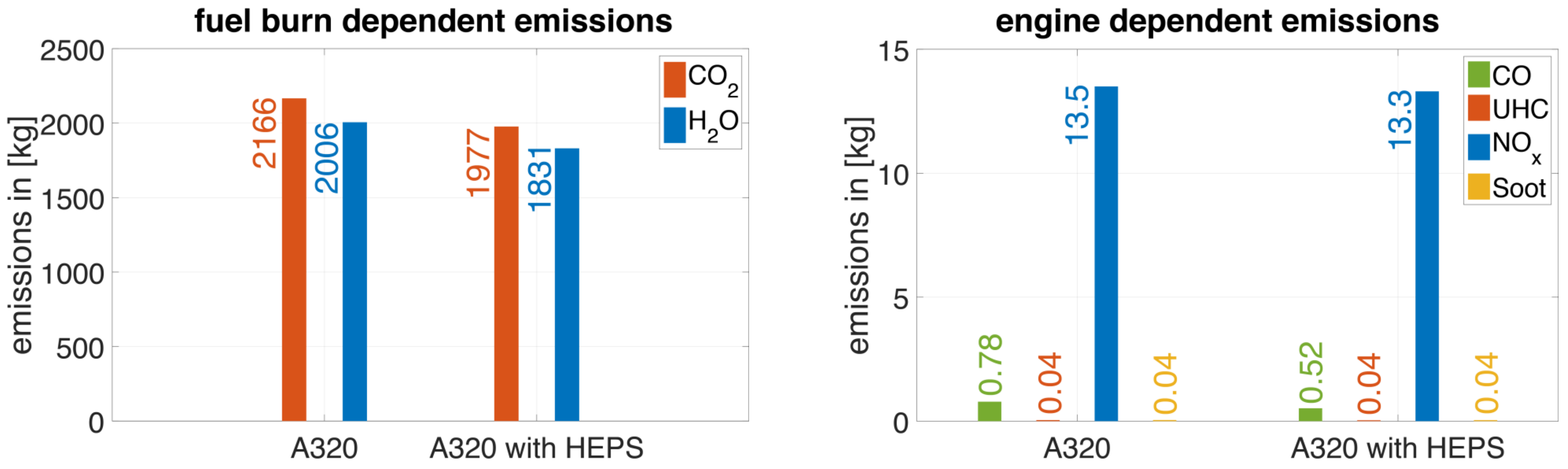
S2: Fuel burn and energy consumption of optimised HEPS





- ❑ Fuel burn saving: 11%
- ❑ Energy consumption saving: 6%

S2: Emissions

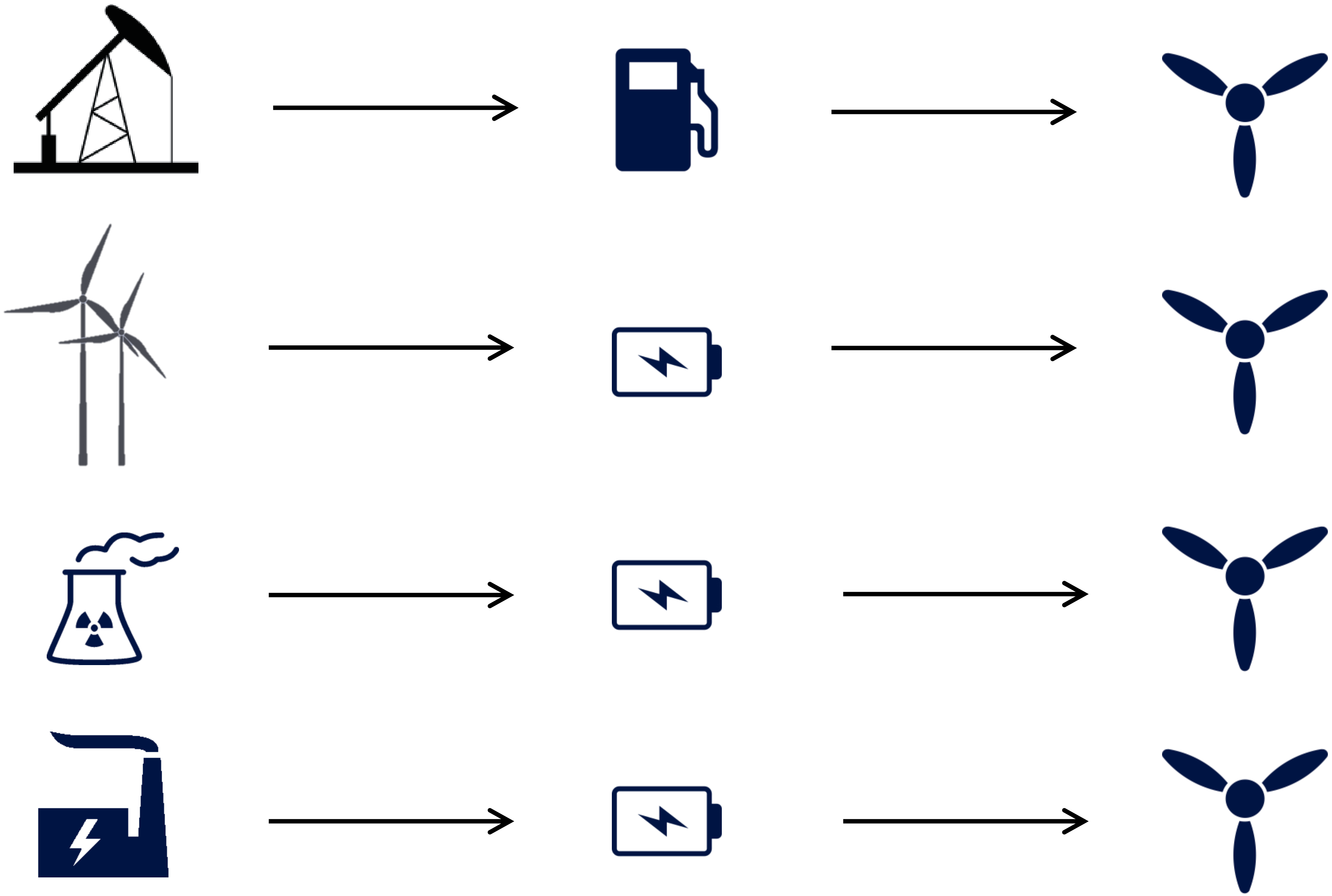


- ❑ Fuel burn dependent emissions can be reduced with 11%
- ❑ Engine dependent emissions can be reduced with 3% of which NO_x with 1%

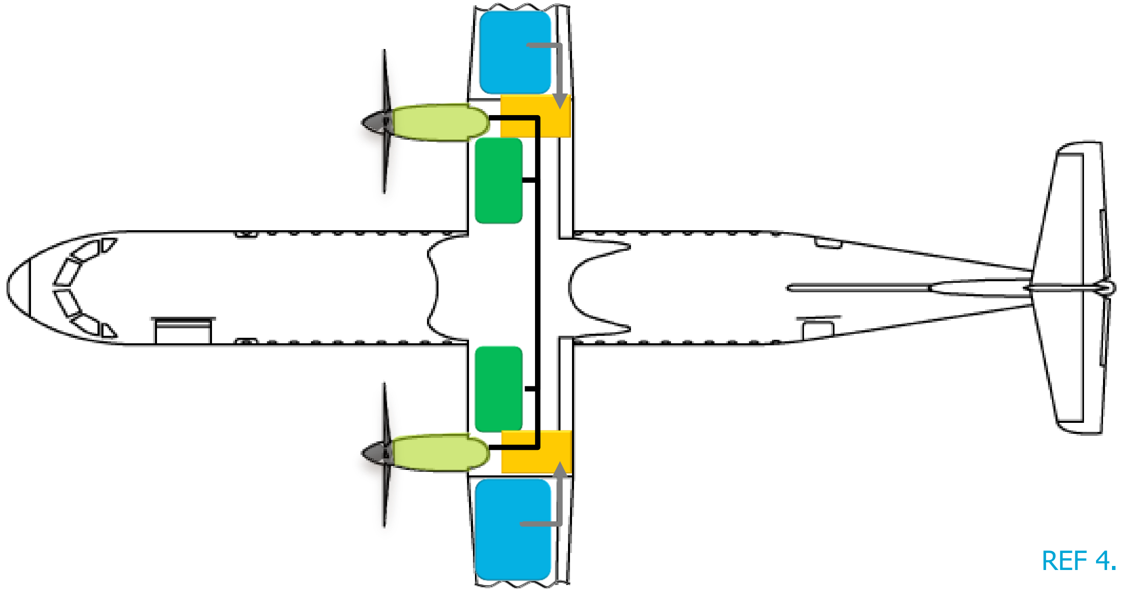
S2: Conclusions

- Investigation on HEPS as ‘retro-fit’ in A320
- Applied HEPS is beneficial for short ranges
- The application of HEPS in mid/long-term is heavily dependent on the technology maturity level of electric components (specific energy/power)
- Fuel burn can be reduced, but total energy consumption increases
- The parallel HEPS architecture allows a better sized engine, which is more efficient
- ‘Optimal’ power management control strategy (with power split of 14%) including 80% scaled engine yields in fuel burn reduction of 11% and total energy saving of 6% for a 1000km flight mission
- CO_2 and NO_x emissions can be reduced with 11% and 1% respectively (during taxi-phase zero CO_2 emission).

S3: Well (source) to propeller efficiency



S3: Series Hybrid Electric Aircraft



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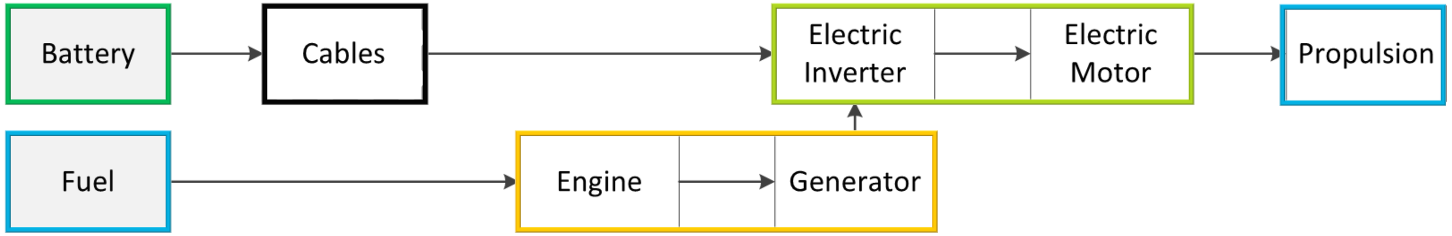


Results

η_{WTP}

Well-to-propeller Efficiency	R^2	Lower Value	Mean Value	Upper Value
$\eta_{WTP_{baseline}}$	0.75	12.5	14.3	16.1
$\eta_{WTP_{nobatteries}}$	0.70	9.2	10.8	12.4
$\eta_{WTP_{current,naturalgas}}$	0.70	11.2	13.2	15.2
$\eta_{WTP_{current,renewable}}$	0.70	11.3	13.3	15.3
$\eta_{WTP_{theoretical,naturalgas}}$	0.70	12.2	14.4	16.6
$\eta_{WTP_{theoretical,renewable}}$	0.70	13.1	15.5	17.9

S3: Conclusions

From an environmental perspective it is not a good idea to develop a Series Hybrid Electric Aircraft (SHEA)

- The well-to-propeller efficiency of a conventional aircraft is 14.3 with R^2 = 0.75
- The well-to-propeller efficiency of a SHEA is 14.4 with R^2 = 0.7 (natural gas)
- The well-to-propeller efficiency of a SHEA is 15.4 with R^2 = 0.7 (renewables)
- From literature study it is known:
  - Design cost will go up
  - Maintenance cost will go up
  - Sustainability battery technology uncertain
- Parameters that maximise the viability of Hybrid Electric Aircraft are:
  - Increasing the bus-voltage
  - Renewable energy as source
  - Not using distributed propulsion as the benefits are not proven
  - New technologies

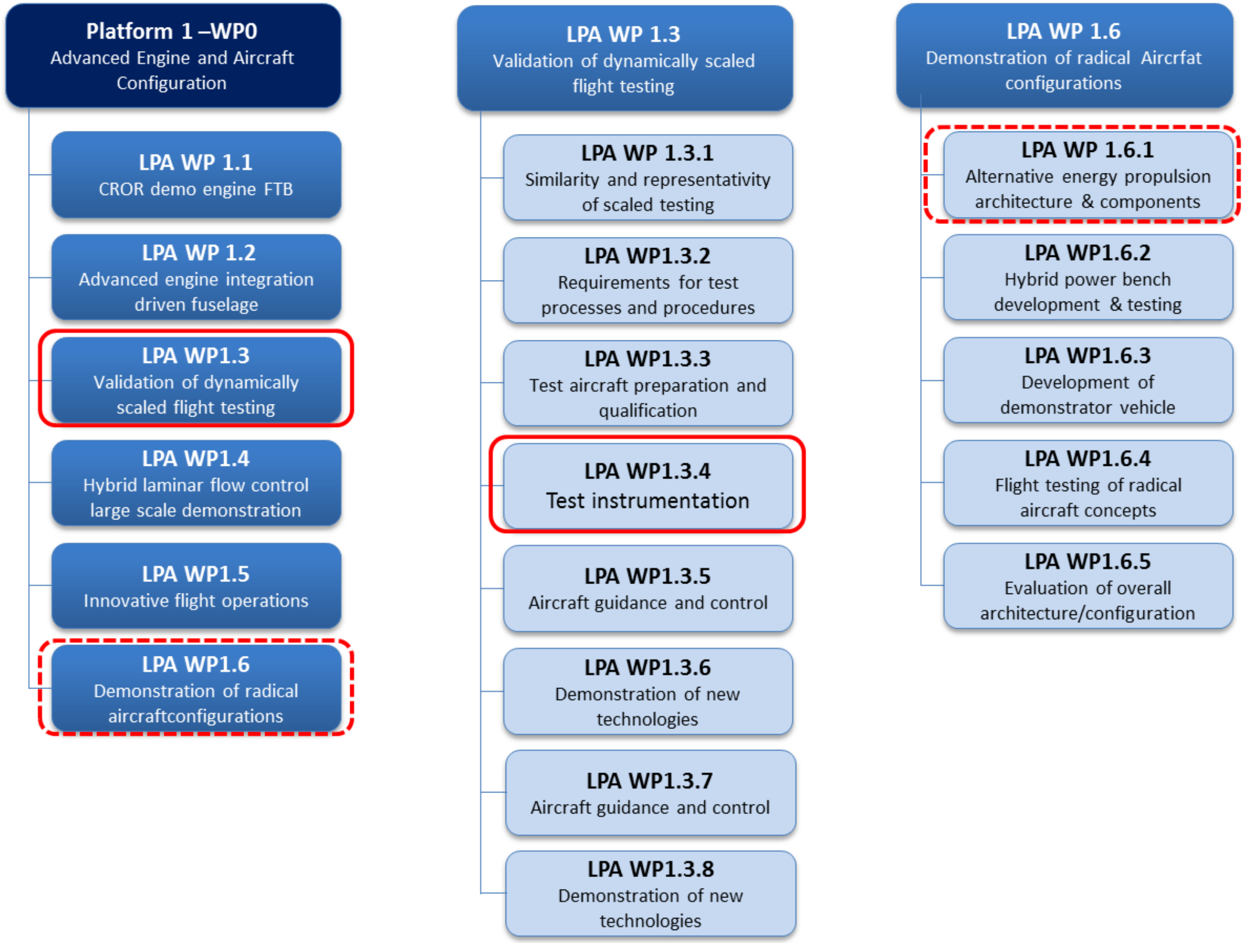
CS2 project: NOVAIR

Novel Aircraft Configurations and Scaled Flight Testing Instrumentationn

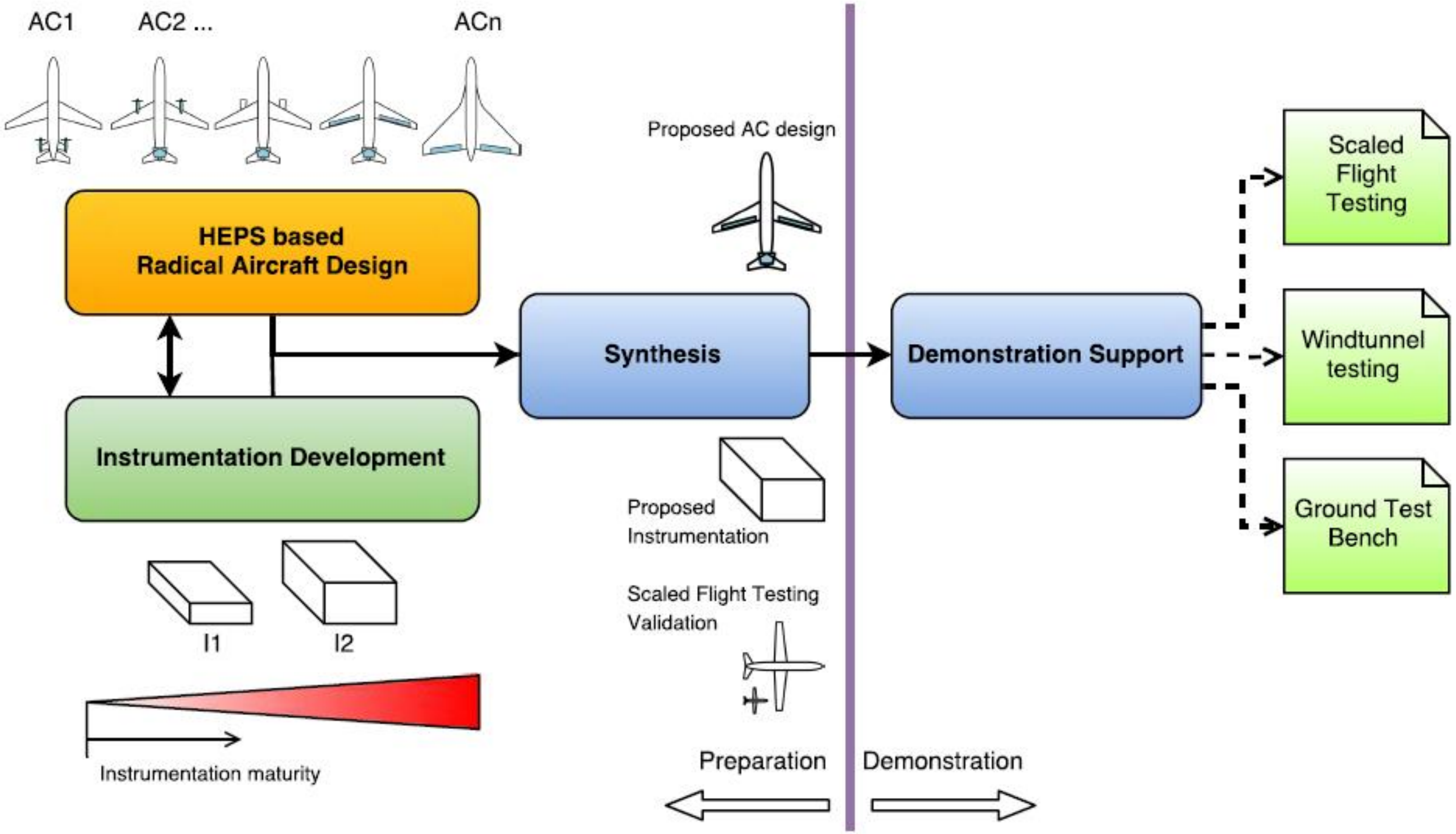
Call For Core Partners

Start: December 2016

Partners:
- NLR
- TU Delft

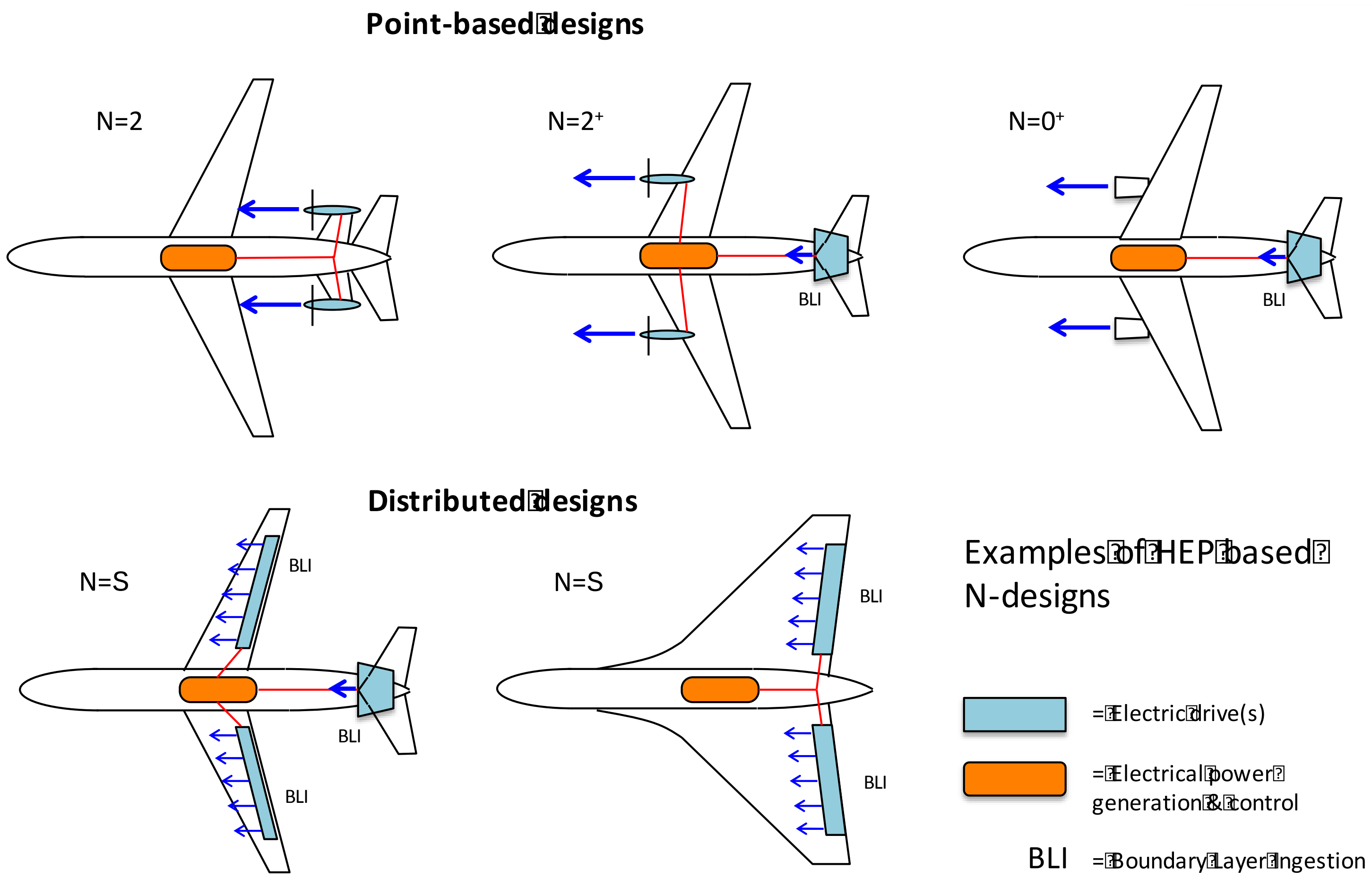


CleanSky 2 project: NOVAIR (start December 2016)



The development logic of NOVAIR

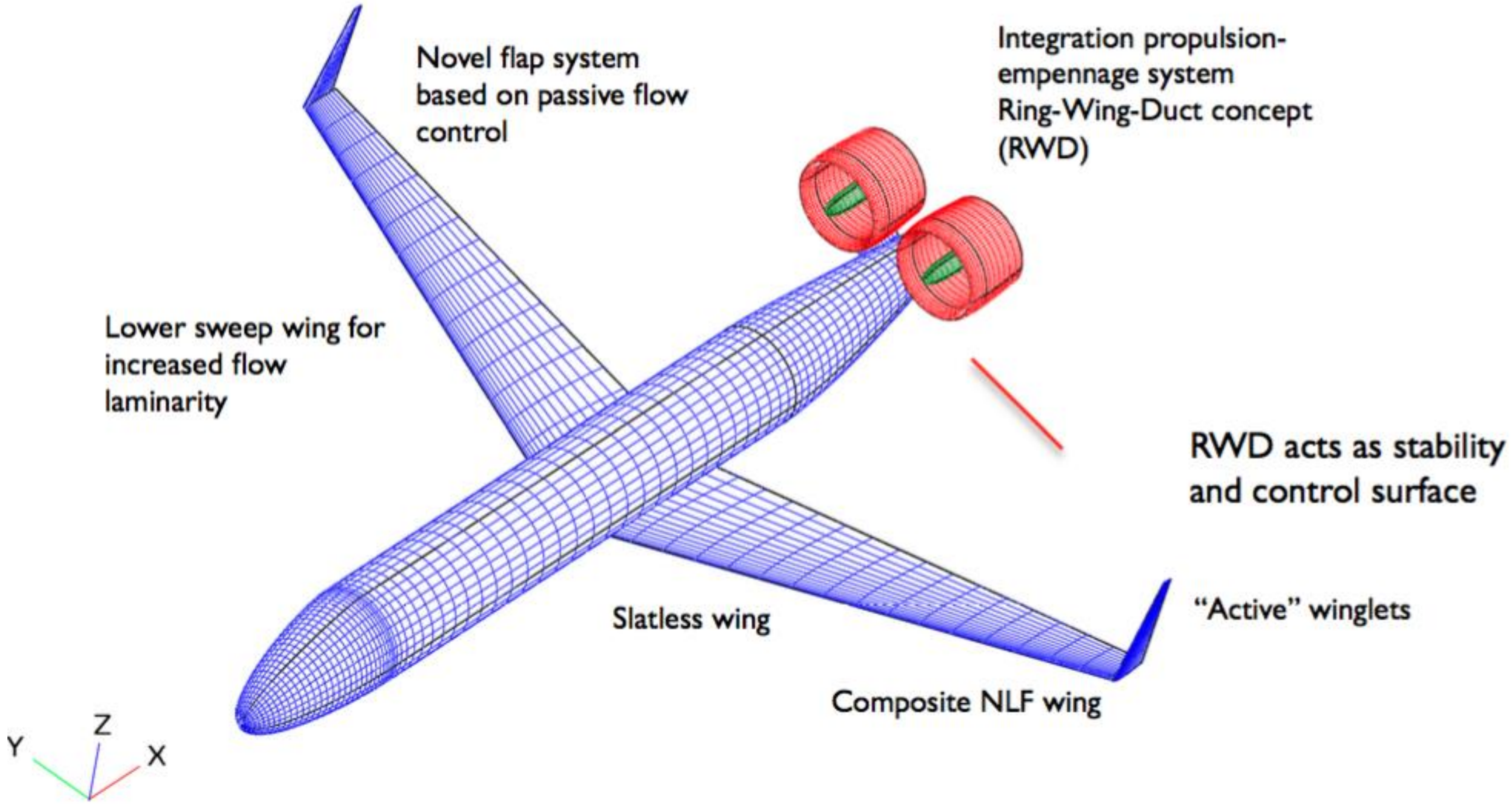
CS2 project: NOVAIR



Top-level approach to the assessment of radical hybrid-electric aircraft configurations

Delft University Unconventional Concept (DUUC)

TUD: Pioneering Innovations Project

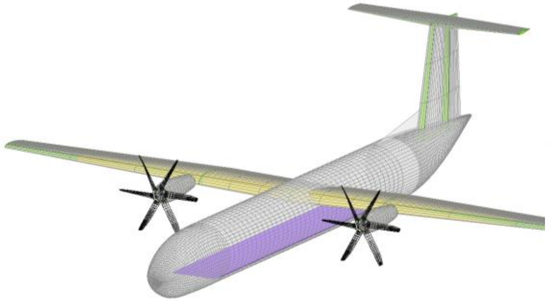


Delft University Unconventional Concept (DUUC)

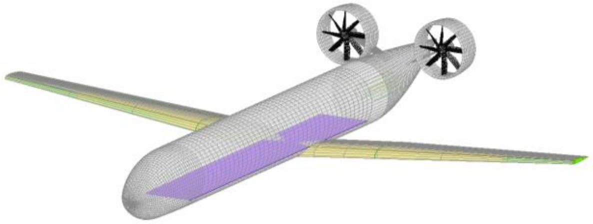
TUD: Pioneering Innovations Project

- ❑ Towards **Scaled Flight Testing** of Unconventional AC
- ❑ Propulsive empennage concept
  - ✓ Increased propulsive efficiency
  - ✓ Safe propeller operation
  - ✓ Enhanced upset recovery
  - ✓ Noise shielding
  - ✓ Increased cabin comfort
  - ✓ Hybrid Electric Vehicle?

DUUC-0.1 flight from Woensdrecht AFB



Model ATR72-600



Model DUUC

- ❑ Preliminary design and analysis ongoing
- ❑ First data set expected by end 2016

Concluding remarks

- Results on overall benefits of a hybrid electric propulsion system (HEPS) in regional aircraft seem inconclusive
- Next step in power density of subsystem and their efficiency is crucial before application can be considered
- Benefits of HEPS is mostly associated with opportunities for distributed propulsion
- NOVAIR and the Delft University DUUC project will contribute to this analysis in the coming years