IFAR | INTERNATIONAL FORUM FOR AVIATION RESEARCH

… since our last update.

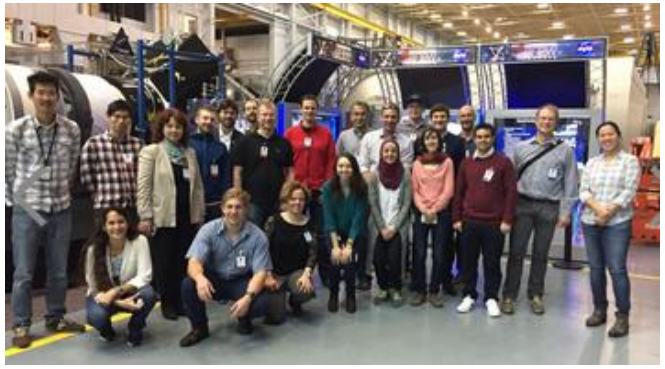
IFAR's Core Values

1
Information exchange and networking among the principals at IFAR Summits

2
Information exchange & discussion on technical issues to enable bilateral / multilateral international collaboration

3
Human resources development (empowering early career employees)

4
External partnership
Partners such as:
ICAS (2014)
ICAO (2020)



12TH IFAR SUMMIT - WARSAW

- Warsaw, Poland, hosted by the Łukasiewicz Research Network - Institute of Aviation (ILOT) on their 95th anniversary.
  - Theme: Sustainable Aviation
  - 17 IFAR Member Organizations in Attendance
- Key Takeaway: The future of aviation rests on our ability to meet sustainability objectives while leveraging international cooperation.

IFAR members give updates via first-ever IFAR hybrid Summit format

IFAR Members attending the Summit

Keynote Speaker Ligeia Paletti about the EREA Vision Study

IFAR Early Career Network

- Empowering young researchers for
  - early appreciation of international collaboration & developing life-long professional relationships
  - co-developing skills required for next generation of Aerospace researchers
- IFAR-X Challenge: currently in development, brings together young researchers from across IFAR to tackle big challenges in aviation research
- Thanks to its strong network, maintained valuable links between young researchers throughout the pandemic

IFAR Chair recognizes Prajwal Prakasha for Early Career Network Leadership

IFAR Working Groups

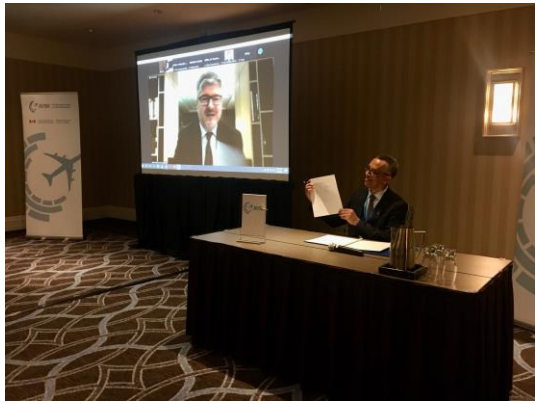
- 10 Technical Working Groups covering a range of topics including:
  - Composites
  - Deep Learning for CFD
  - Electric Hybrid Propulsion
  - Noise
  - Sustainable Aviation
  - Urban Air Mobility
  - Vertical Lift

IFAR-ICAO UAM Expert Meeting in Montreal, QC – April 5th, 2022

IFAR-ICAO Collaboration

IFAR-ICAO Collaboration

- **Why:** anticipate and evaluate trends in Aerospace innovation to provide independent scientific input to the standards-making process.
- **What:** ***Urban Air Mobility*** as a first topic
- **How:** Scientific Assessment covering 17 sub-topics ranging from technical to operational to societal acceptance.
- **Who:** IFAR-ICAO Expert Group informed by more than 80 IFAR researchers from over half the IFAR member organizations.
- **When:** Planned completion in Q1 2023



Transforming Aviation towards Zero Emission - to mitigate the climate impact

1. **DLR**: Application and measurement of sustainable aviation fuels in real environment (Markus Fischer)

2. **ONERA:** Technologies for the reduction of aviation emissions and their climate impacts (Bruno Sainjon)

3. **SARC:** Technology selection with respect to business cases and impact of regulations (Petter Krus)

4. **NRC:** Electric flights, Perspectives on electrification in aviation (Ibrahim Yimer)

5. **JAXA**: JAXA's Activities on the Electric Aircraft *(Yasushi Watanabe)*

Questions & Answers

IFAR-ICAS Award presentation

Application and measurement of sustainable aviation fuels in real environment

Dr.-Ing. Markus Fischer

Divisional Board Member Aeronautics
German Aerospace Center (DLR e.V.)

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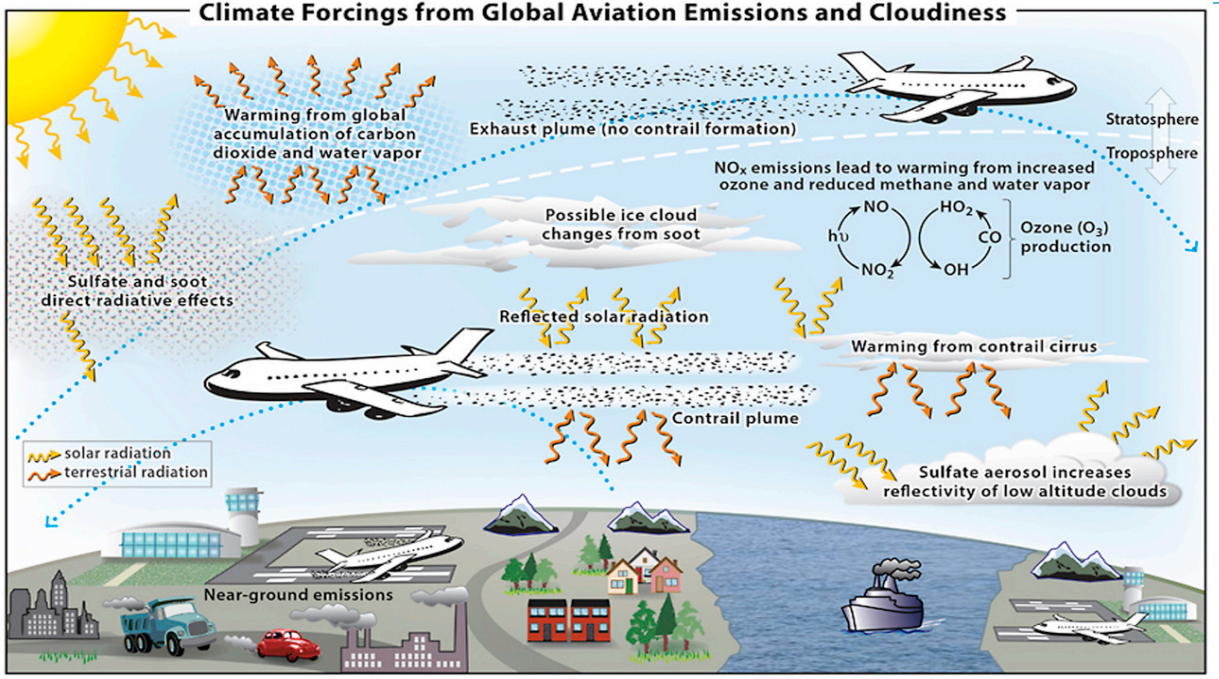
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

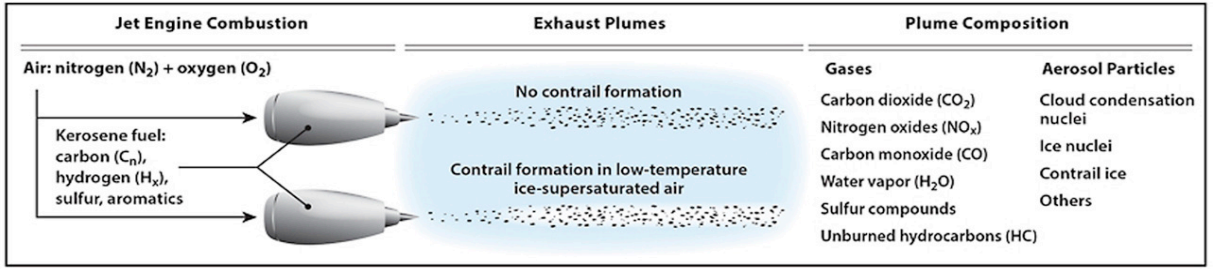
ICAS 2022 SWEDEN

Climate Impact of Aviation

- There is something other than CO2
- 2/3 of the climate impact from aviation (1940 to 2018) comes from non-CO2 effects
- Contrails have the largest contribution to Effective Radiative Forcing (in mW/m^2)

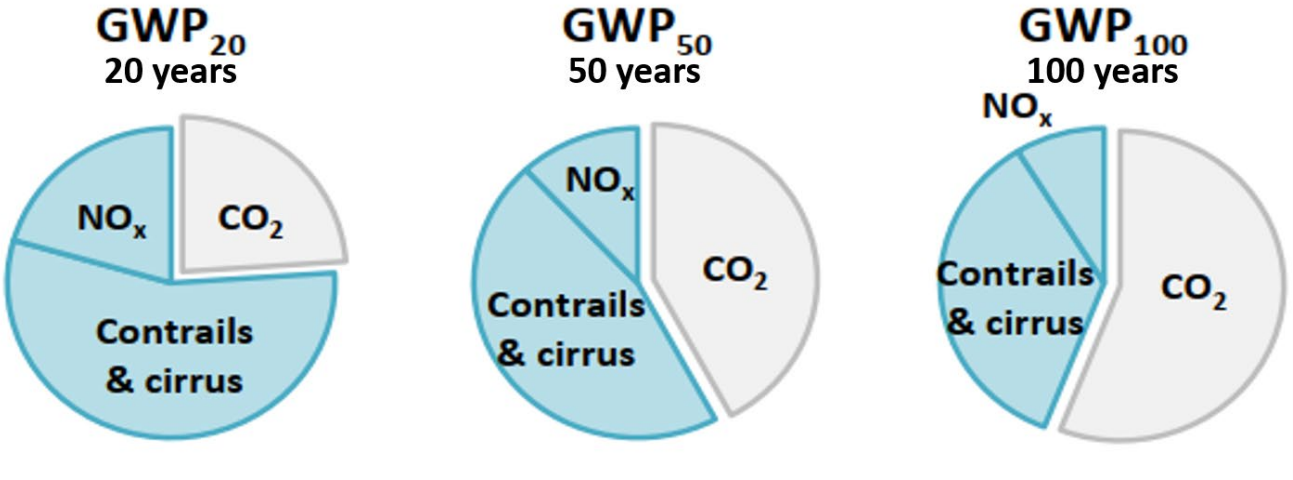
ref. Lee et al., Atm Env, 2021





Global Warming Potential of Aviation Emissions on Different Time Scales

- Non-CO2 effects are important,
  even on long time scales.



Effect	GWP_{20}	GWP_{50}	GWP_{100}
CO_2 (Gt CO_2)	1034	1034	1034
Contrails and cirrus (Gt CO_2-eq)	*2399*	*1129*	*652*
Net effect of NO_x (Gt CO_2-eq)	*887*	*293*	*163*
Others (Gt CO_2-eq)	*-188*	*-88*	*-51*
Total Gt CO_2-eq	**4128**	**2366**	**1797**
CO_2-eq to CO_2 ratio	4.0	2.3	1.7

ref. Lee et al., Atm Env, 2021

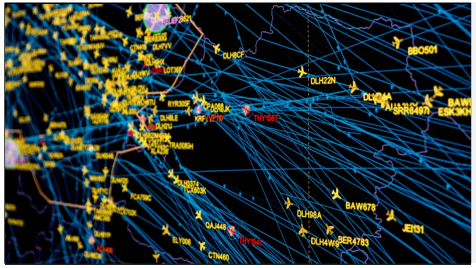
Our Missions for Shaping the Future of Aviation

Low-Emission Propulsion

- Direct Combustion of Hydrogen
- Fuel Cell
- Battery
- SAF

Energy Efficient Aircraft

- New Configurations
- Weight reduction by Lightweight System design
- Minimizing energy consumption



Emission-Reduced Air Transport System

- Climate Optimized Routing
- Atmospheric Research
- Impact Assessment

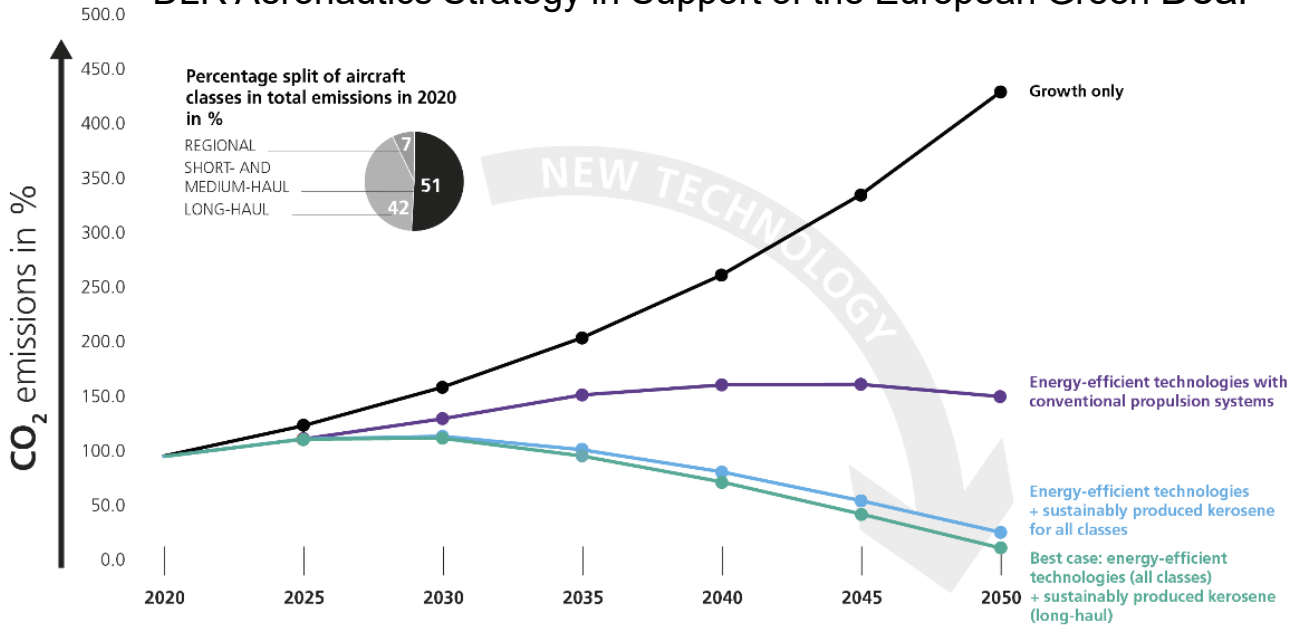
Digitalisation

- Simulation-based Certification
- Digital Twin
- Digital Thread

Maximum Technology Potential for CO_2 Emissions

TOWARD ZERO-EMISSION AVIATION

DLR Aeronautics Strategy in Support of the European Green Deal



POTENTIAL FOR REDUCING CO_2 VIA

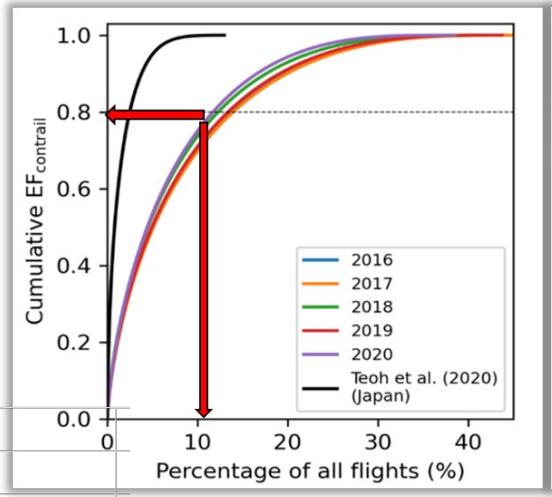
- Energy-efficient technologies 3.4% per year
- Hydrogen fuel cells 100%
- Hydrogen combustion 100%
- Sustainably produced kerosene 80%

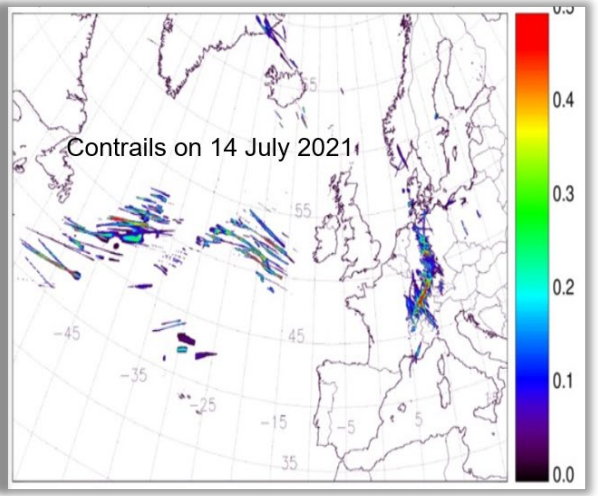
ASSUMPTIONS

- No delay for market introduction
- Sufficient quantities of fuels available
- Non-CO_2 effects not taken into consideration
- Not all technologies can be used on all aircraft classes

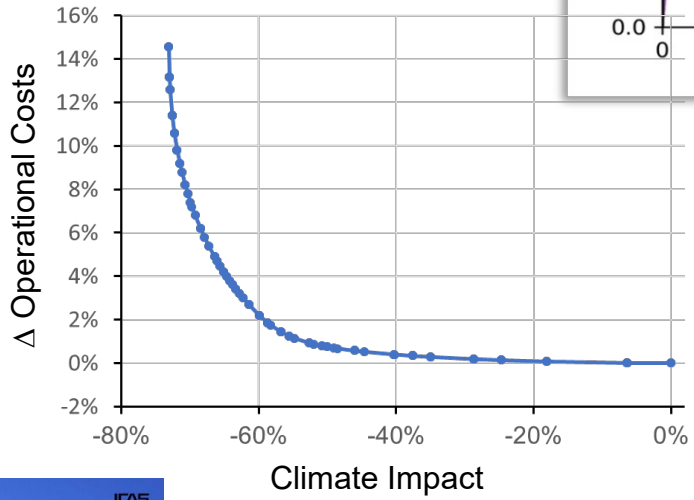
Emission-Reduced Air Transport System – Measures -

- Contrail avoidance and targetted use of SAF and PtL fuels
- Climate-friendly routing of aircraft





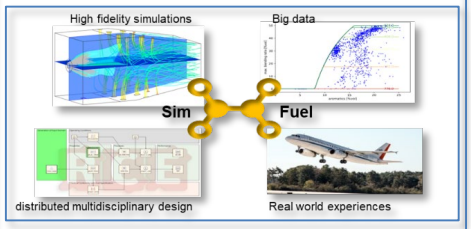
ref. Teoh, Schumann, Voigt et al., ACPD, 2022

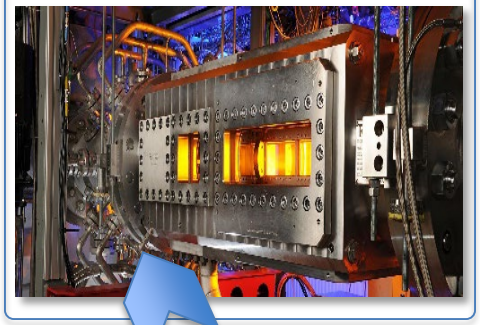


ref. Matthes et al., 2020

Process Chain: Fuel, Propulsion System, Emissions, Impact

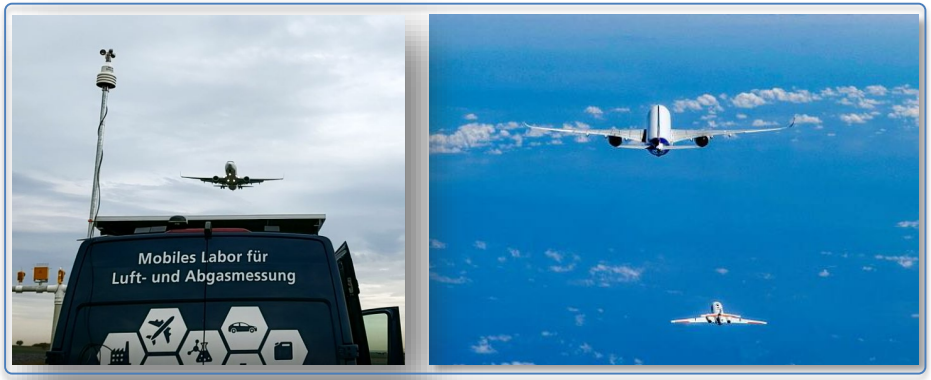
SimFuel-platform for fuel design



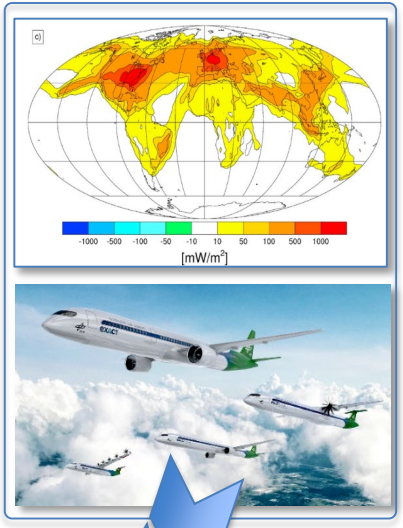


Ground based emission measurements

Measurements in jetwash



Validated climate models



Combustion of new energy sources

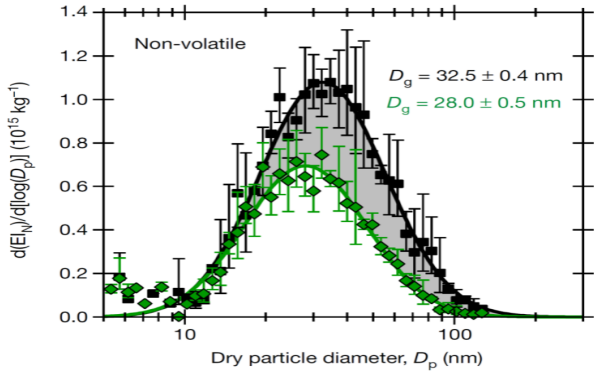
Aircraft concepts and enabling technologies

Application and Measurement of Sustainable Aviation Fuels in Real Environment

2014 ACCESS 2015 ECLIF1

NASA/DLR/NRC/FAA
Falcon/Falcon/DC8

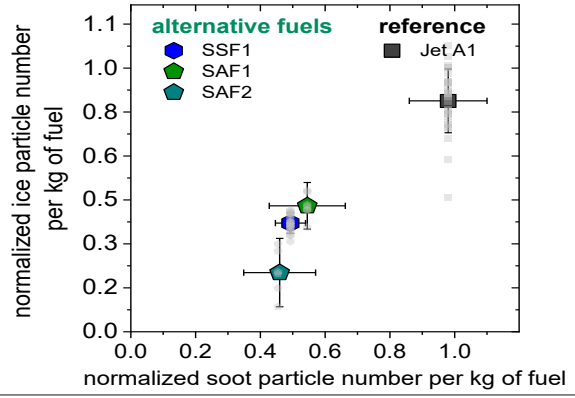
50% SAF (HEFA) → ~50% reduction in soot emissions



2018 ECLIF 2/ND-MAX

NASA/DLR/NRC/FAA
DC8/ATRA-A320

50% SAF (HEFA/FT) → ~50% reduction of soot and of ice particles in contrails



2021 ECLIF3

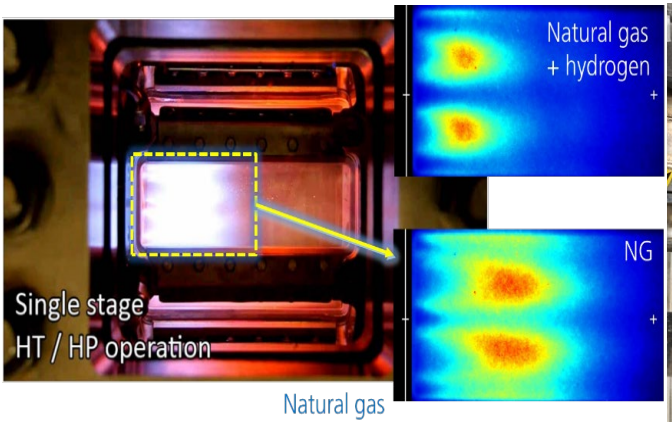
DLR/AIRBUS/
Rolls Royce/Neste
Falcon/A350

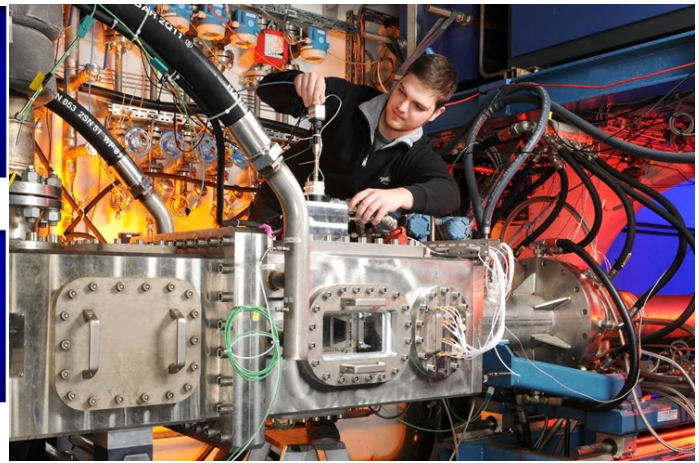
Measurements of 100% SAF (HEFA) behind large passenger aircraft

* Moore et al, Nature, 2017

Hydrogen Combustion Technology for Next Generation Propulsion Systems

Jet-stabilized combustion system in high pressure test rig	High pressure combustor test rig HBK1	H2 impact on upper atmosphere





- Development of technologies and methods for H_2 direct combustion in aero-engines
- Jet-stabilized lean combustion and aviation relevant rich-lean combustion
- Impact of H2-based engines on contrail properties linking CFD and experiments

TOWARDS ZERO-EMISSION AVIATION

DLR Aeronautics Strategy in Support of the European Green Deal

Thank you!

Markus.Fischer@dlr.de

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ICAS 2022 SWEDEN

www.dlr.de/luftfahrtstrategie

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Technologies for the reduction of aviation emissions and their climate impacts

Bruno SAINJON

Chairman and CEO, ONERA

IFAR Vice-Chair

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OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS 2022 SWEDEN

Context

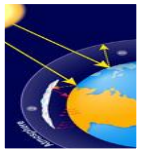
The mutation of air transport has started !

- For more than 3 years, aviation has been challenged because of its environmental impact and we have the duty to
  - → bring answer to such negative societal perceptions
  - → reduce the negative effects of aviation on environment
- The European Green Deal has provided a dynamic impulse to develop green disruptive technologies

Societal stakes

Mobility

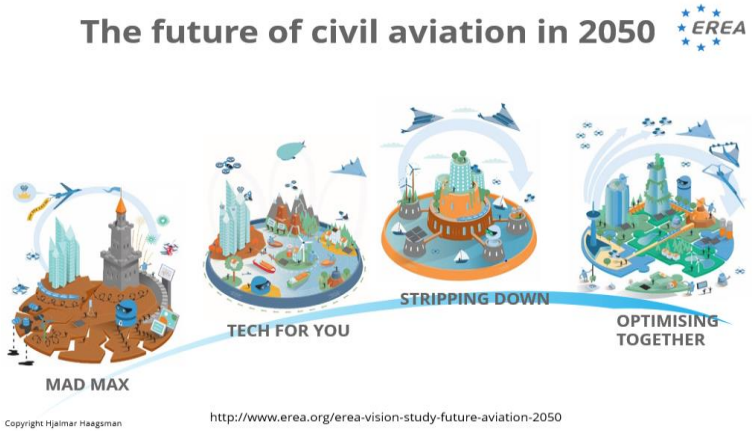
Safety



Climate urgency

For reminder, efforts made from the past decades

- → Aircraft consumption / pax / km reduced by 70% since 70s
- → Consumption gains of 15 to 20% between 2 aircraft generations have been achieved
- → Most recent Airbus aircraft can reach slightly 2 litters / pax / 100 km
- → Noise reduced by more than 20 dB since 80s



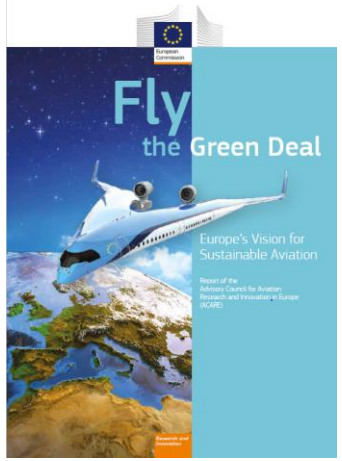
EREA Vision Study

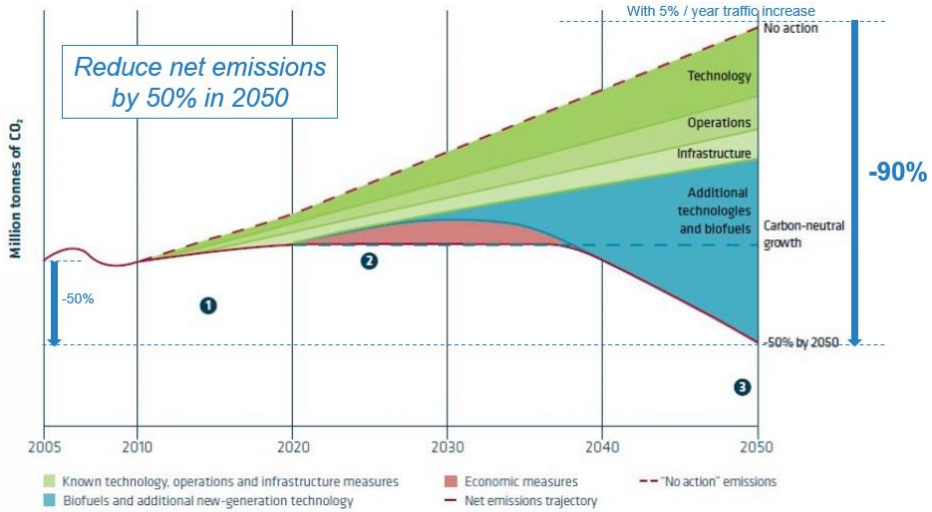
→RTOs have the duty to light up the future of aviation !

The 0 net emissions concept: a shared objective

Be it ATAG, Clean Aviation SRIA, ACARE « Fly the green deal », we share a common objective:

Climate-neutral air transport (0-net emissions) in 2050





And we have a common roadmap showing that :

conciliating **traffic growth** with **emissions reduction** is achievable with some requirements:

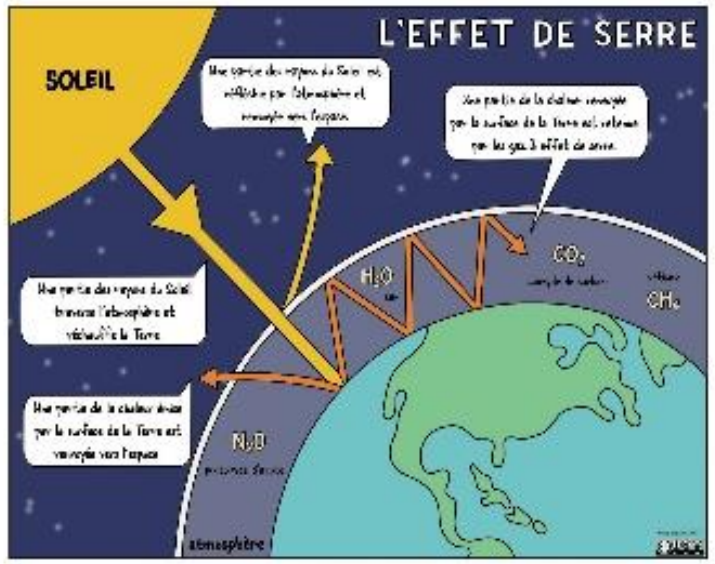
A combination of technologies & Technological breakthroughs

Access to green primary energy sources for aviation

Reducing emissions for reducing impact : which emissions?

Gaseous Emissions

CO_2, H_2O, CH_4…



Pollutants

NOx, SOx …

Air quality

Noise

- *Noise reduced by more than 20 dB since 80s*

Aviation contributes to ~ 2.5% of anthropogenic CO_2 emissions

NEW PARADIGM = reducing emission, but above all:

- **Reducing nuisance**
- **Reducing climate impact (global warming)**

Airport operator Fraport AG and start-up Volocopter explore the use of autonomous flying taxis at Germany's Frankfurt Airport. Photo: Volocopter

An artist's concept of an Urban Air Mobility environment, with both manned and unmanned air vehicles. Illustration: NASA/Lillian Gipson

How?

I. Low carbon fuels

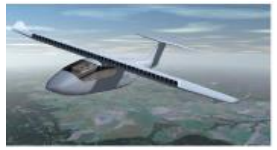
- SAF (bio-fuels, e-fuels)
- **Green** Hydrogen (**decarbonized**)

II. Energetic Efficiency

- BPR increase
- Integrated Engine Installation
- Drag Reduction
- Mass Reduction

III. Aircraft electrification

- Electric
- Hybrid electric – thermic



IV. Operations

- Perfect flight (green trajectories)
- Optimized Air Traffic
- New concepts (formation flight)
- Impact evaluation

I - Researches to prepare H_2 aircraft

- *Low density (fuel mass reduction by a factor of 2.8)*
- *(very) Low carbon footprint*

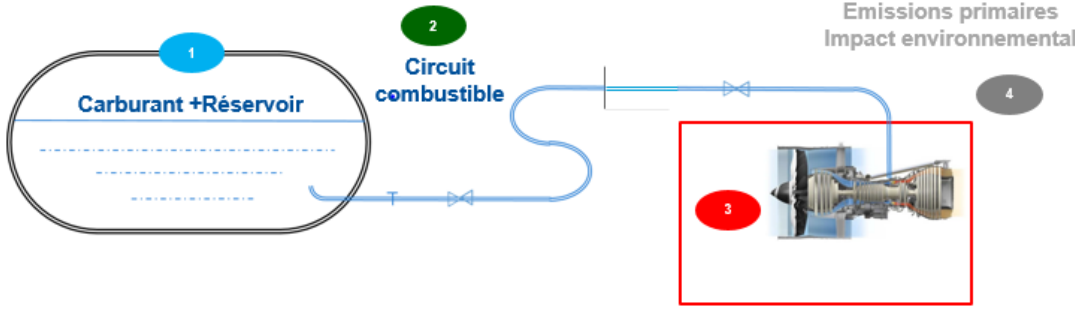
- *Very low volumic energetic density*
- *→ cryo (-253 ° C)*

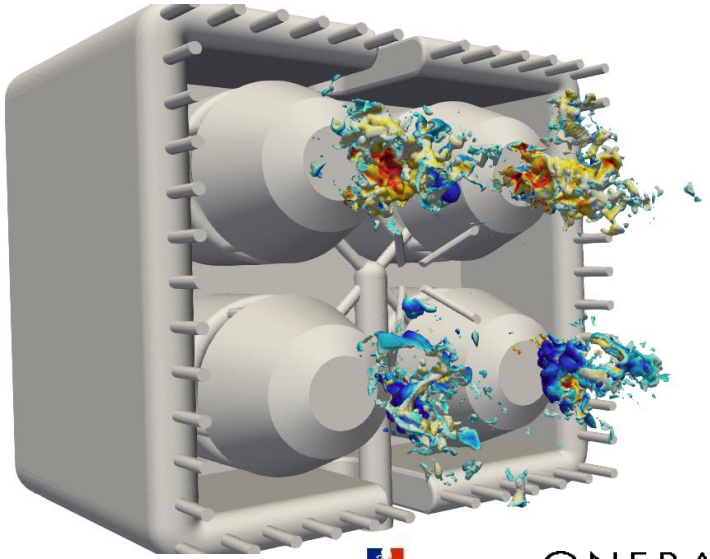
H2 challenges for aviation :

- Production :: **green** H2 (quantity, cost)
- Infrastructures : availability in (all) airports, refuelling safety
- Storage and distribution

Aviation R&T

- Aircraft Configuration: **volume** of fuel tank
- Storage & fuel system: **materials** (mass, thermo-mechanics, embrittlement, life duration), sloshing
- Cryogenic aspects
- **Injection** & combustion chamber: new conception methods, **NOx** control, flashback
- Turbine blades: **oxidation**
- Safety : fire protection, leaks…
- **Emissions** : NOx, Contrails

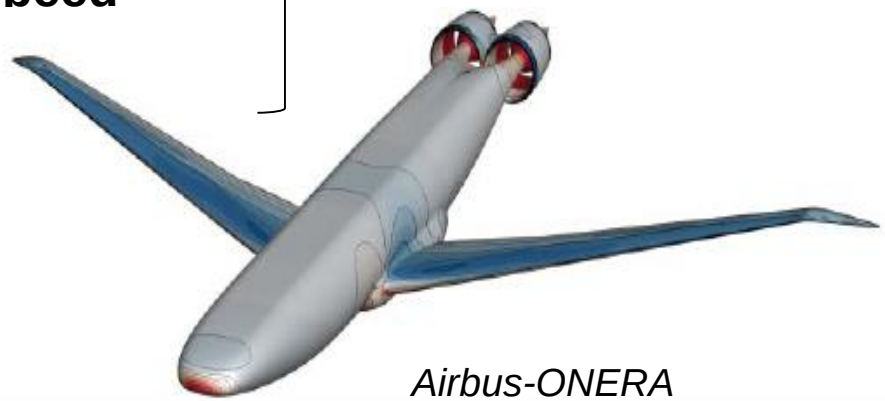




II - Buried engines: research on Boundary Layer Ingestion (BLI)

- Innovative engine integrations taking benefit of BLI are an attractive way to **improve propulsive efficiency**
- Gains at low speed quite will established, need of further experimental / numerical research to better **understanding physics at cruise speed**
- Impact of upstream **non uniform flow** needs to be quantified:
  - Performance and **engine** stability
  - **Aero-elastic** response of the fan
  - **Acoustics**
- … before proposing an optimized engine integration

On-going ONERA research, DGAC funded



Airbus-ONERA NAUTILIUS concept

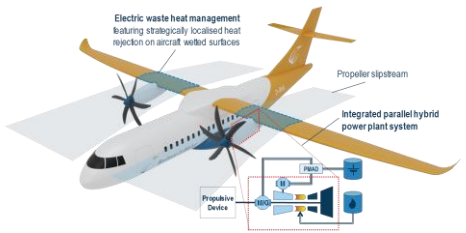
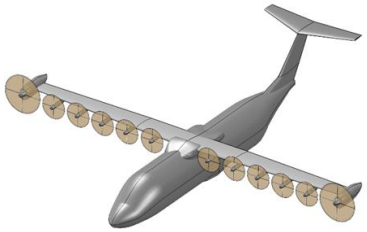
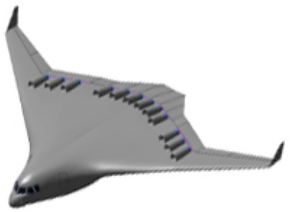
ONERA NOVA concept (Le Bourget 2015)

ONERA BWB concept (CICAV project)

III – IMOTHEP*: a hollistic evalution of hybrid electric propulsion (EU project coordinated by ONERA)

Ambition : a consolidated estimate of Hybrid Electric Propulsion potential

- A holistic investigation of electric systems integrated in a propulsion architecture (including superconductivity)
- The identification of the needs for tools, key demonstrations and certification adaptation for HEP development
- A synthesis of the project's findings through the elaboration of a sector-wide roadmap for HE

	Conservative	Radical
Regional	 Electrically assisted turboshaft	 Turboelectric + DEP + wing-tip propeller
SMR	Tube & wing, turboelec, DEP (from CS2)	 BWB, turboelectric, DEP, BLI

IMOTHEP* in figures

Four-year EU research project
33 partners (9 European countries , 2 international partners)
1311 PM effort (~27 FTEs)
10.4 M€ EC funding

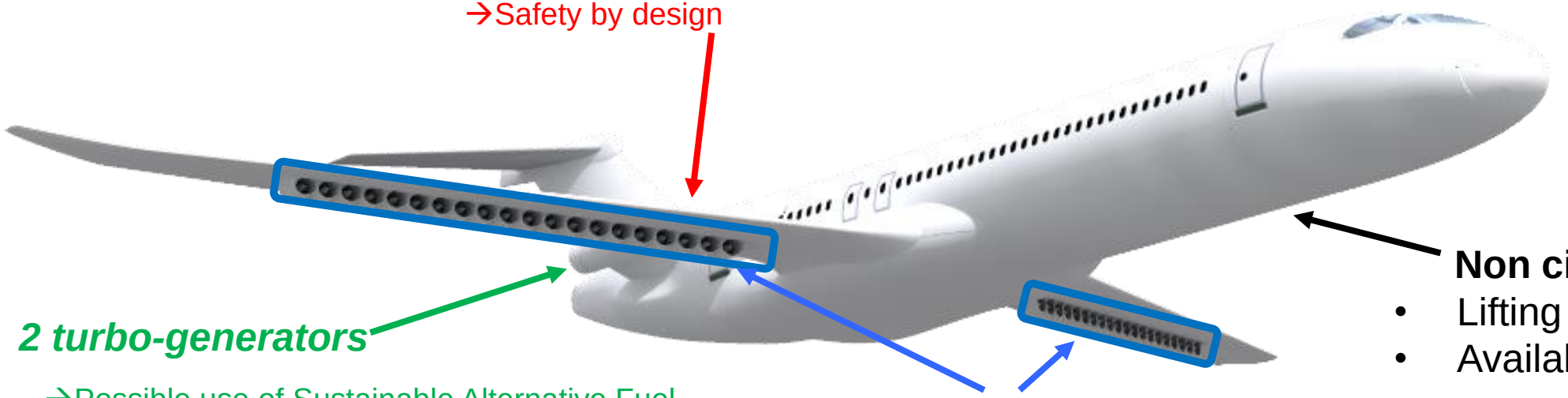
* Investigation and Maturation Of Technologies for Hybrid Electric Propulsion

Distributed fans Research Aircraft with electric Generators by ONERA

HYBRID-ELECTRIC CIVIL TRANSPORT (CONCEPT) AIRCRAFT. SMR (800 nm),150 pax, M=0.8

DRAGON

Distributed electric architecture
→Redundancy
→Safety by design



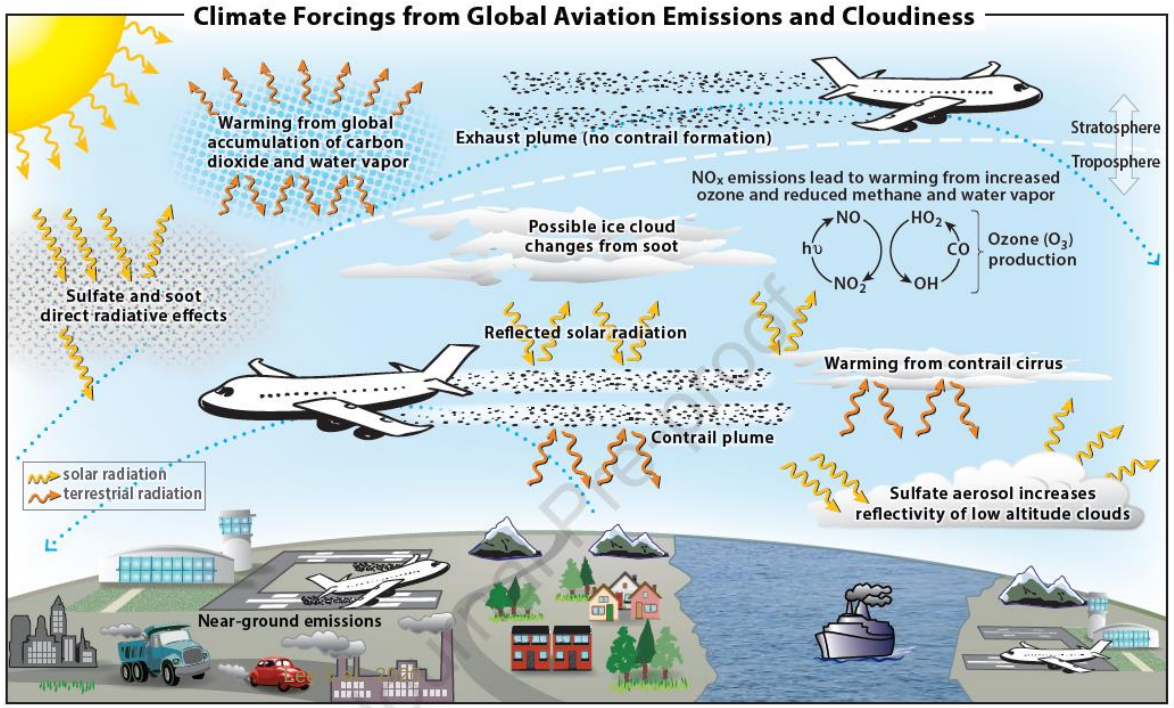
2 turbo-generators
→Possible use of Sustainable Alternative Fuel
→No thrust
→No batteries

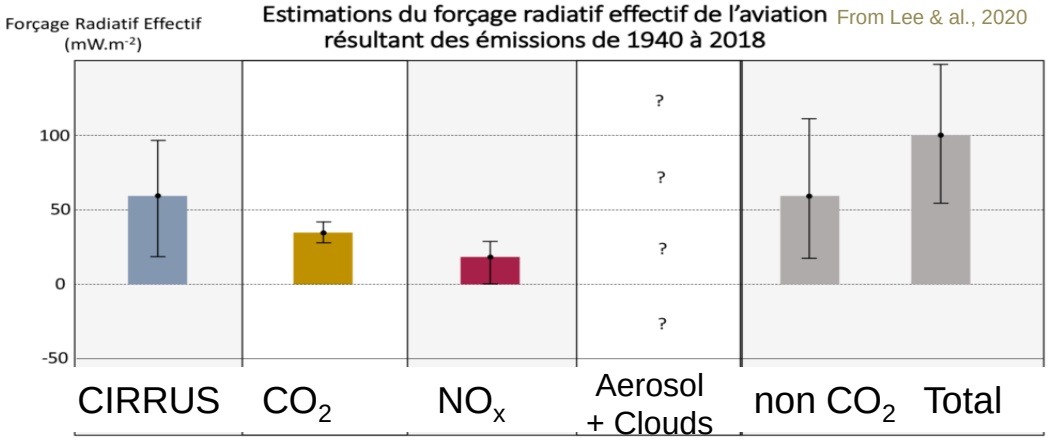
Hyper Distributed Propulsion
→Higher propulsive efficiency
→Blown single slotted flap
→Vertical tail size reduction

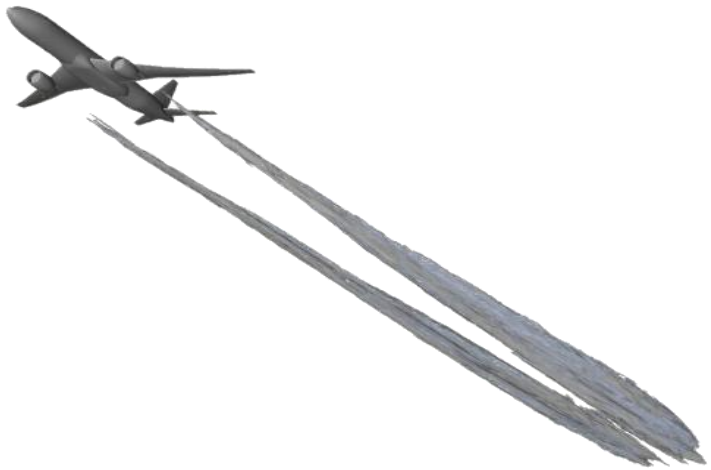
Non circular fuselage
- Lifting capabilities
- Available volume

19

CO_2 emissions are not the only impact of aviation







- Non CO_2 effects (contrails) **> 50%** of aviation present impact
- **High uncertainty** levels

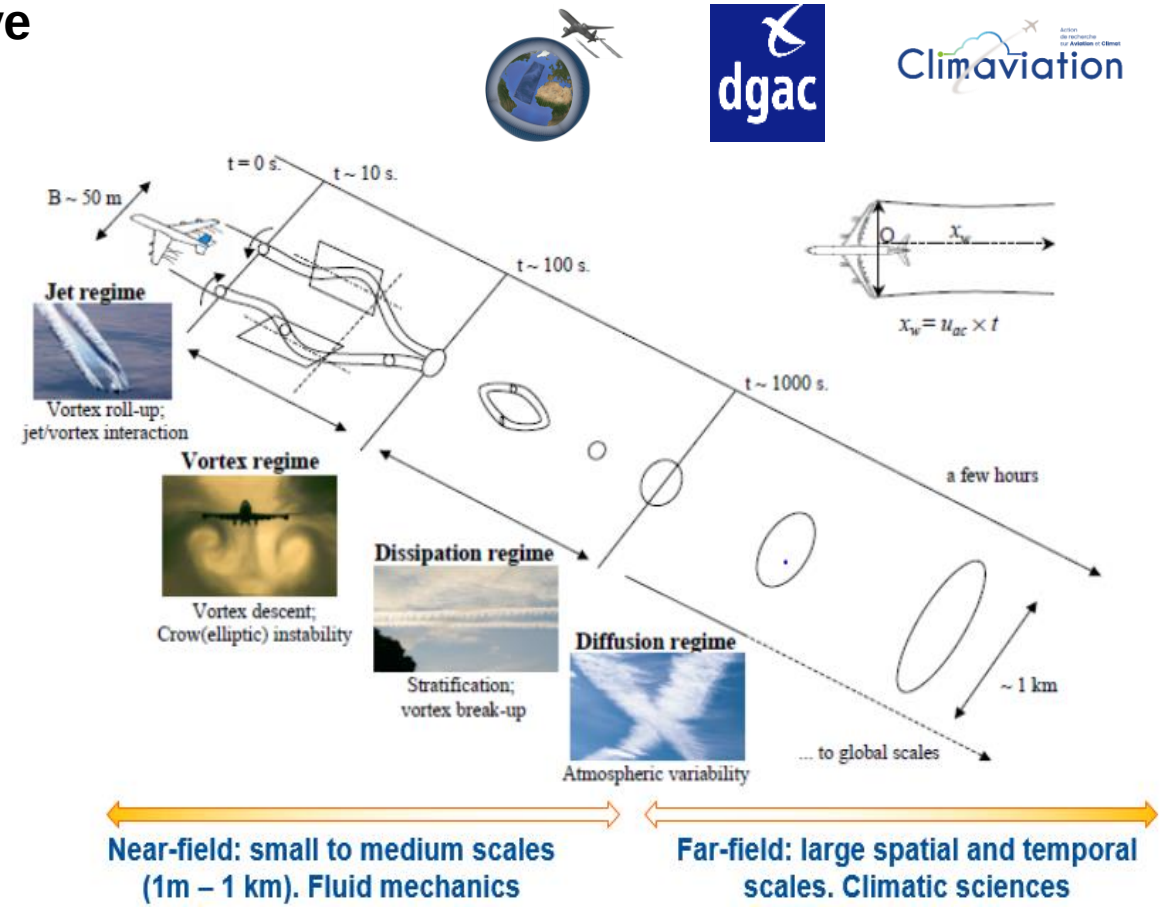
Scientific objectives wrt. non-CO_2 effects
CLIMAVIATION French project

1. **Improve understanding and modelling of radiative forcing most uncertain mechanisms (for Jet-A1)**
   - Contrails, Effects of aerosols on clouds
   - Impact of NOx, water vapour

2. **Understand and quantify the impact of new fuels**
   - Fuels with low aromatics
   - E-fuels without aromatics nor sulfur
   - Hydrogen

3. **Quantify aviation total climatic impact**

4. **Study of minimization strategies**
   - Metrics, green trajectories …



Unprecedented national effort, 5 years, DGAC funded, associating best experts in fluid dynamics (ONERA) and climate sciences (CNRS/IPSL)

No compromise on safety!

- Certification of a product indicates that it can be trusted in terms of safety
  - « There is nothing more important than safety »
- Role of RTOs (which generally do not certify products):
  - Understanding (complex) physics to be able to evaluate risks
  - Check that these risks are controlled

- How? ONERA roadmap:
  - Contribute of the definition of new regulations and Means of Compliance
  - Justify the trust to be put in new products
  - Propagate a ‘safety culture’
- Examples:
  - Atmospheric Risks : turbulences, icing, lightning
  - Risks linked to accidents : crash and impacts, fire

Digitalisation as a powerful accelerator: towards methodological breakthroughs

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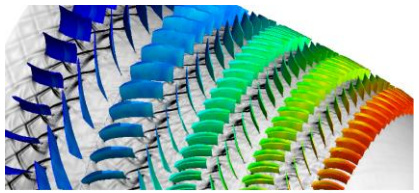
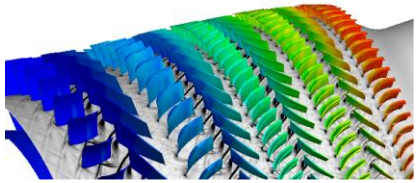
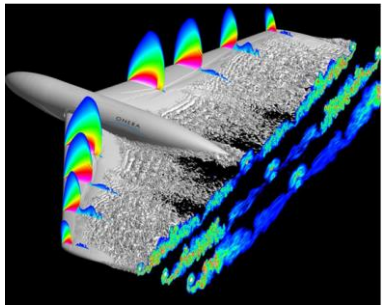
Continuous transfer of AI techniques

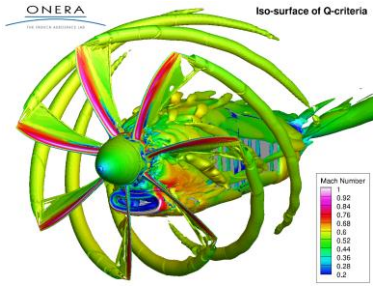
- Next Gen Simulation Tools
  - Revisiting our big numerical simulation tools (CFD, CSM…) : speed-up x 10, accuracy, adaptation to new hardware architectures (CPU+GPU, quantic accelerators)
  - From several disciplines towards multidisciplinary approaches
  - Conception and design tool: eco-conception, co-design
- Towards virtual certification
  - Uncertainty quantification and control
  - Mastering huge amounts of data
  - Digital twin
- Digital / Experimental Hybridization

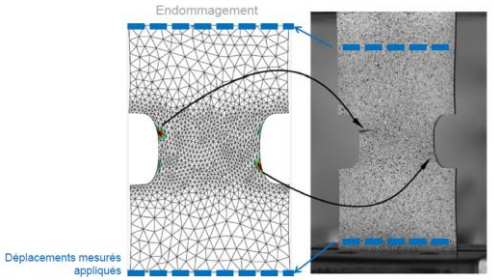
ONERA ELSA











RÉPUBLIQUE FRANÇAISE

ONERA
THE FRENCH AEROSPACE LAB

Conclusion

Mastering new competencies/disciplines

- Electrical engineering
- Climatic sciences
- Software engineering
- Data sciences, AI
- …

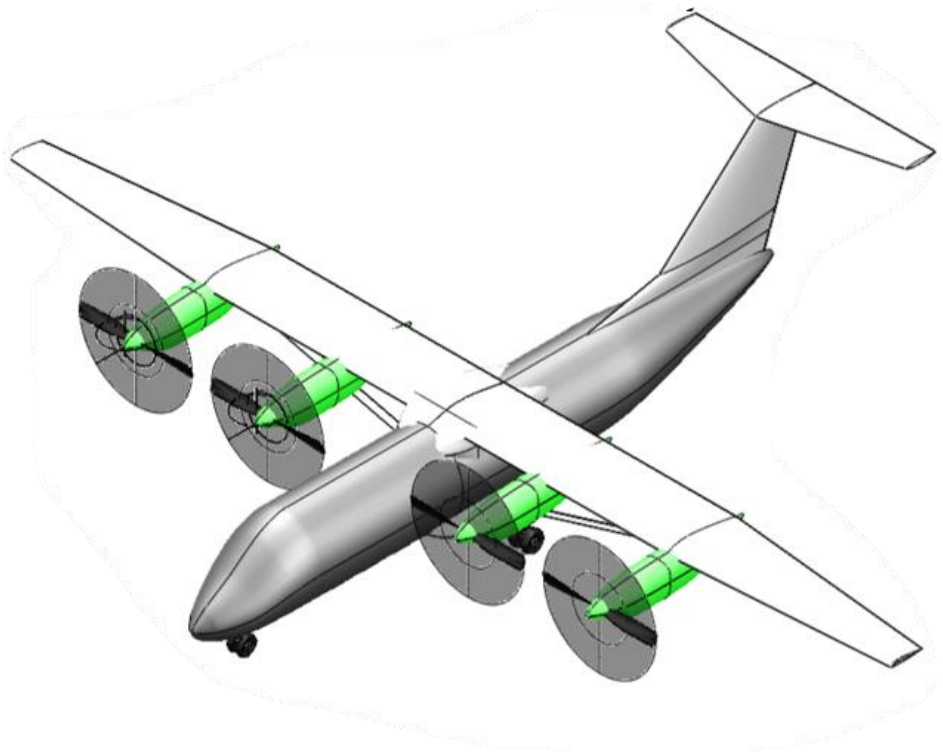
… while maintaining a **system approach** (multidisciplinary)

An international effort, for a huge ambition, **a role for RTOs**

Technology selection with respect to business cases and the impact of regulations

Petter Krus
Swedish Aerospace Research Center, SARC

Considerations for Electrification of aircraft

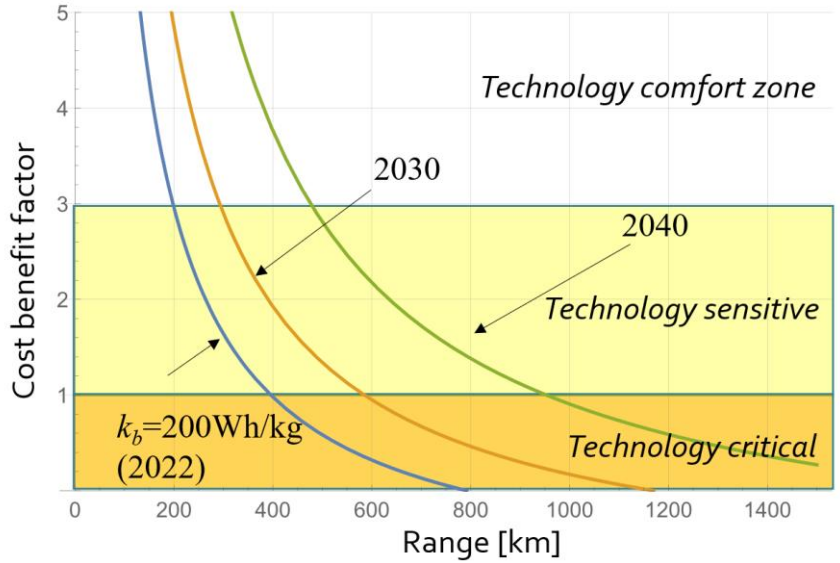


For electric aircraft there are several aspects to be considered.

- **Technical feasibility**
- **Commercial feasibility**
- **Regulatory compatibility**
- Climate impact reduction
- Societal impact

Cost Benefit factor

- If an increase in range with 1% requires an increase in cost, for the whole system, of 1%, the cost benefit factor is said to be one. At that value the 30% of the takeoff weight are batteries. Leaving only 30% of the takeoff weight for payload + crew. 40% is assumed for the rest, β, which is the structure fraction (aircraft excl. batteries).
- Lift over Drag (L/D) is set to 20 and over all propulsive efficiency is 90%.
- ϕ is the battery fraction. To be under CS/FAR-23 regulations implies 8618 kg and max 19 passengers. This means that payload 2586 kg which would allow for that number of passengers.



Range

$$R = \frac{\phi\eta(1-\beta)k_b(L/D)}{(\phi+1)g}$$

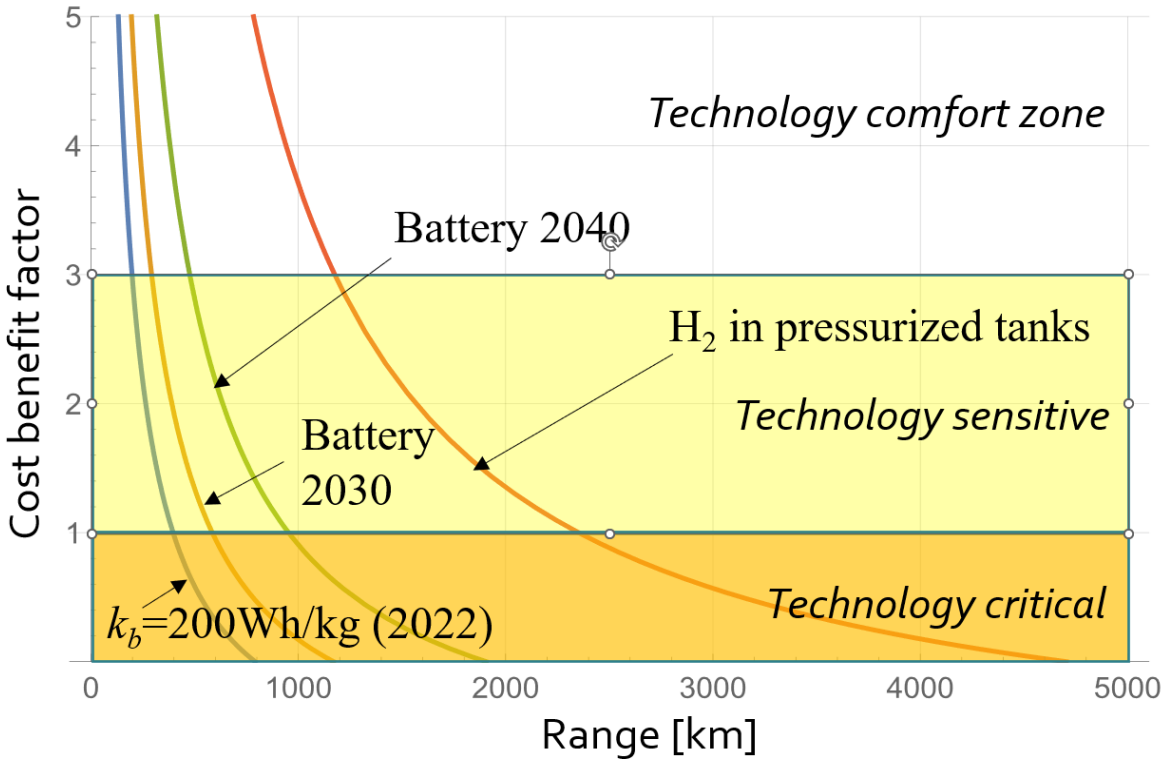
Normalized cost

$$c = W_0/W_{pay} = 1/(1-\phi-\beta)$$

Theoretical range without reserves.

Electric Hybrid with high pressure hydrogen storage

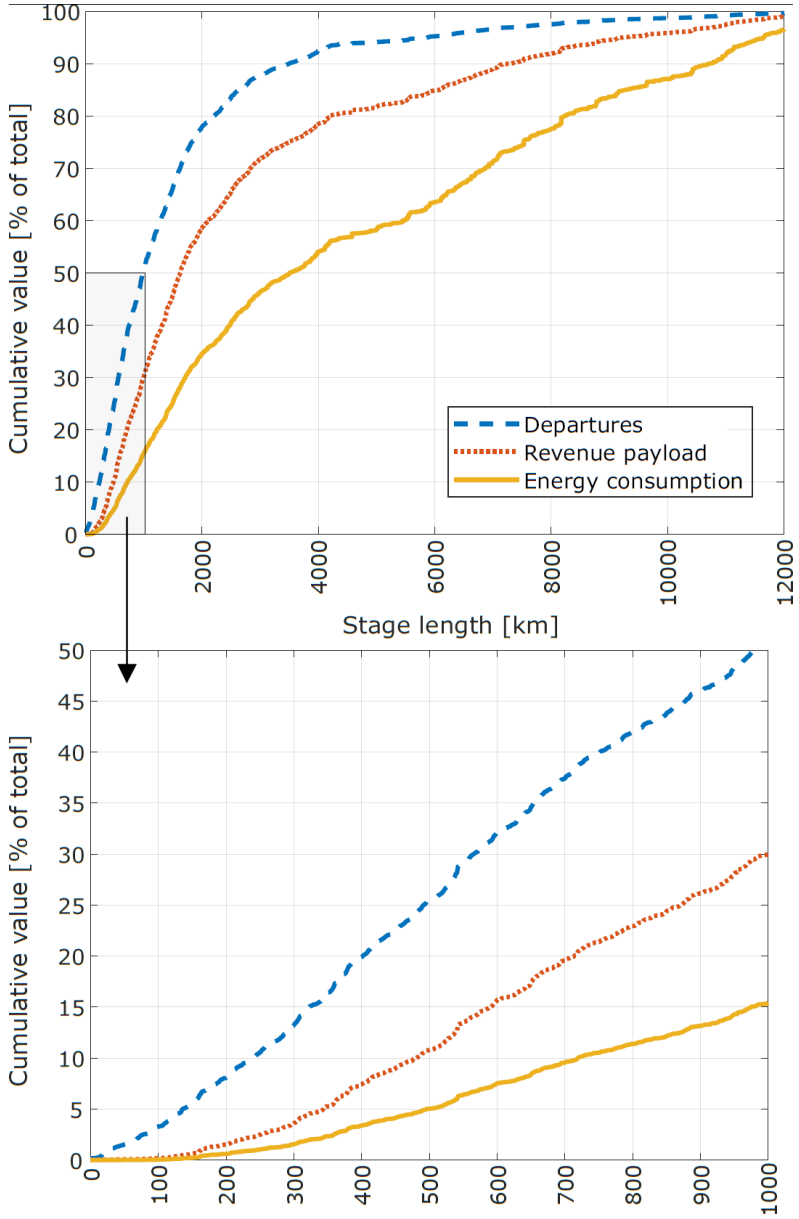
- With hydrogen storage+ fuel cells ranges in excess of 2000 km can be achieved (assuming a 6% hydrogen of fuel storage weight).
- Batteries specific energy is expected to increase 8%/year



Climate impact, energy consumption

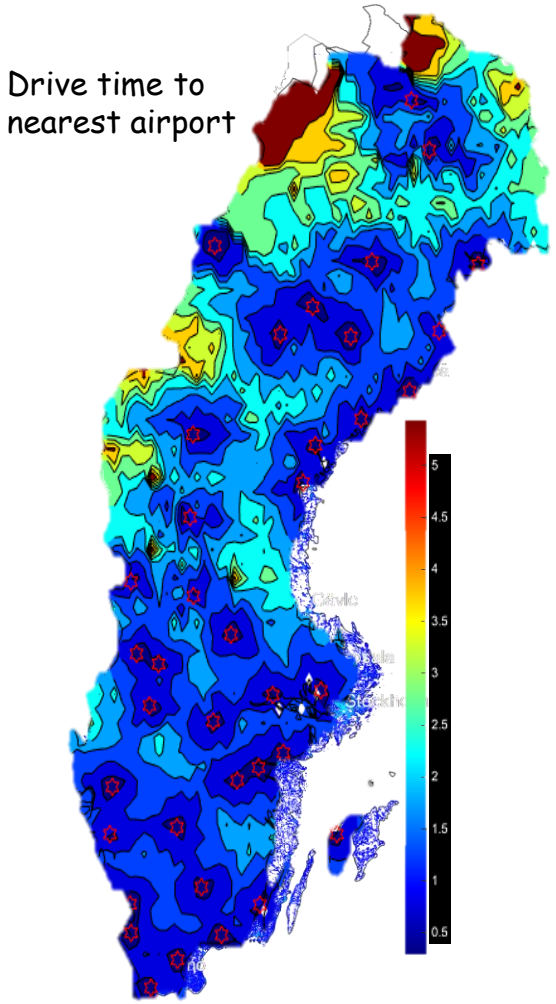
Consumed Fuel

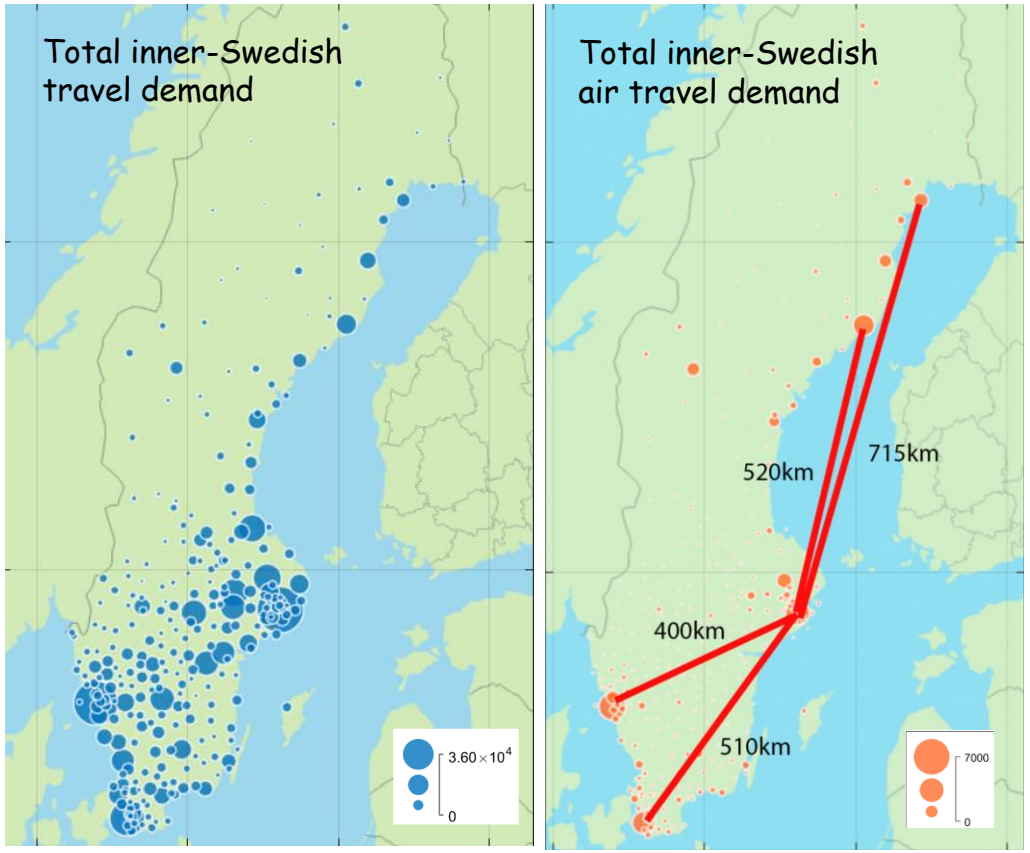
- Total consumed amount of fuel of all flights inside and to and from the US, as a function of stage length.
- Stages under 1000 km corresponds to about 15% of total consumed fuel.
- Stages under 500 km corresponds to less than 5% of total consumed fuel.
- ***Battery electric aviation will have very little climate impact in the foreseeable future.***

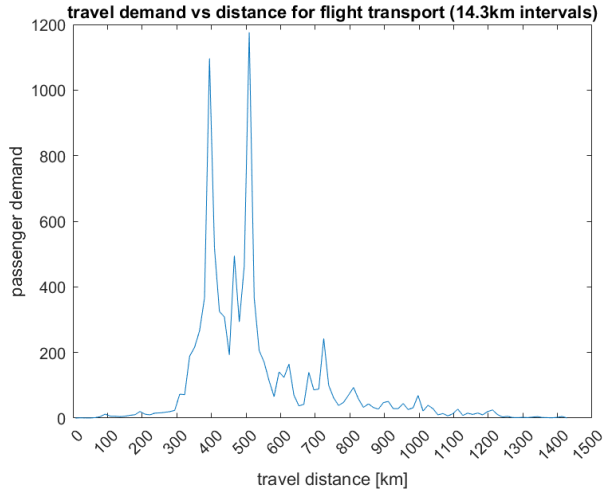


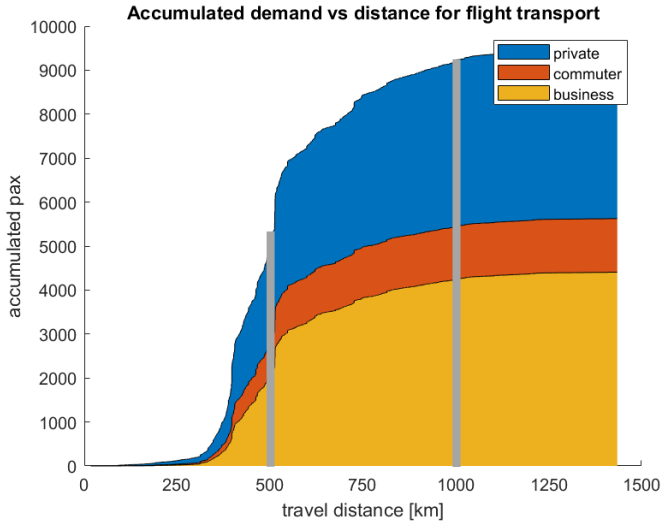
Sweden: Transportation Needs Based Analysis

MBSE Inspired ACD *Christopher Jouannet*









For domestic flights in Sweden 1000 km covers the vast majority of flights while 520km covers approx. 50%

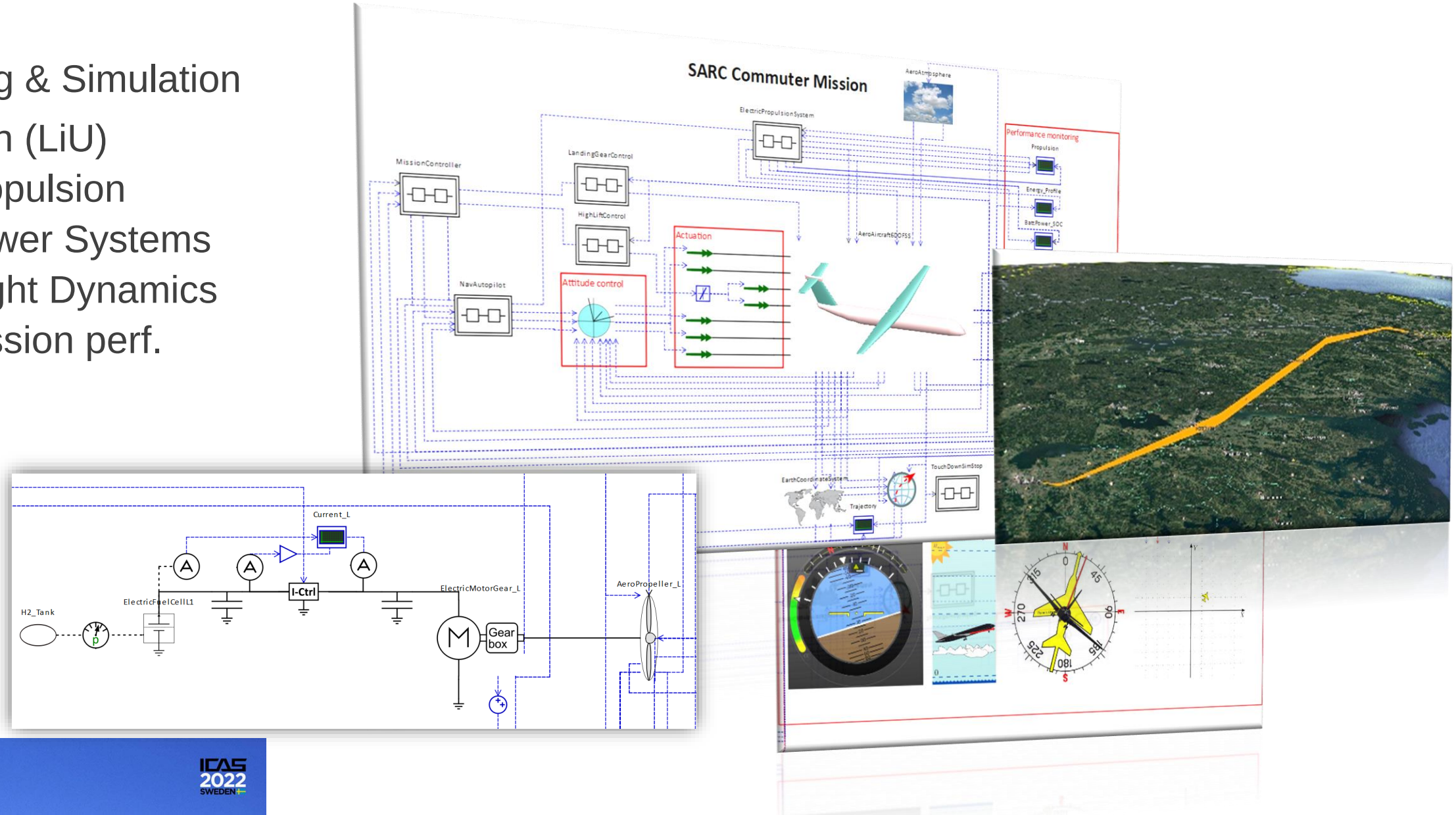
Societal Aspects

- Low-cost aviation could be a benefit for sparsely populated areas with poor infrastructure.
- Resources could be used to subsidize air transport instead of infrastructure.
- Otherwise, there is a risk of increased economic segregation of regions, since it otherwise will mostly benefit already economically strong regions.

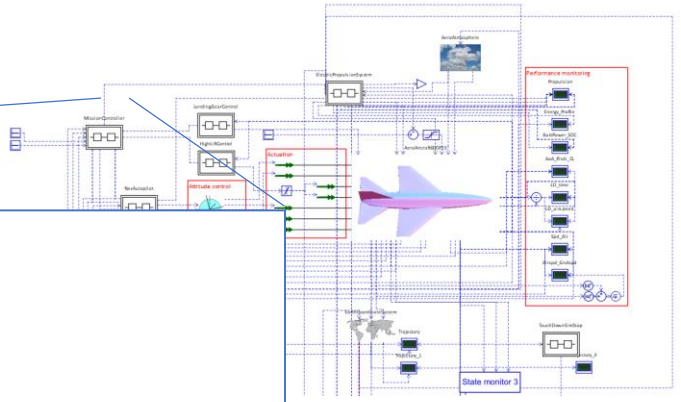
Hybrid aircraft Battery and Hydrogen storage

Modelling & Simulation

- Hopsan (LiU)
  - Propulsion
  - Power Systems
  - Flight Dynamics
  - Mission perf.



Electrical System



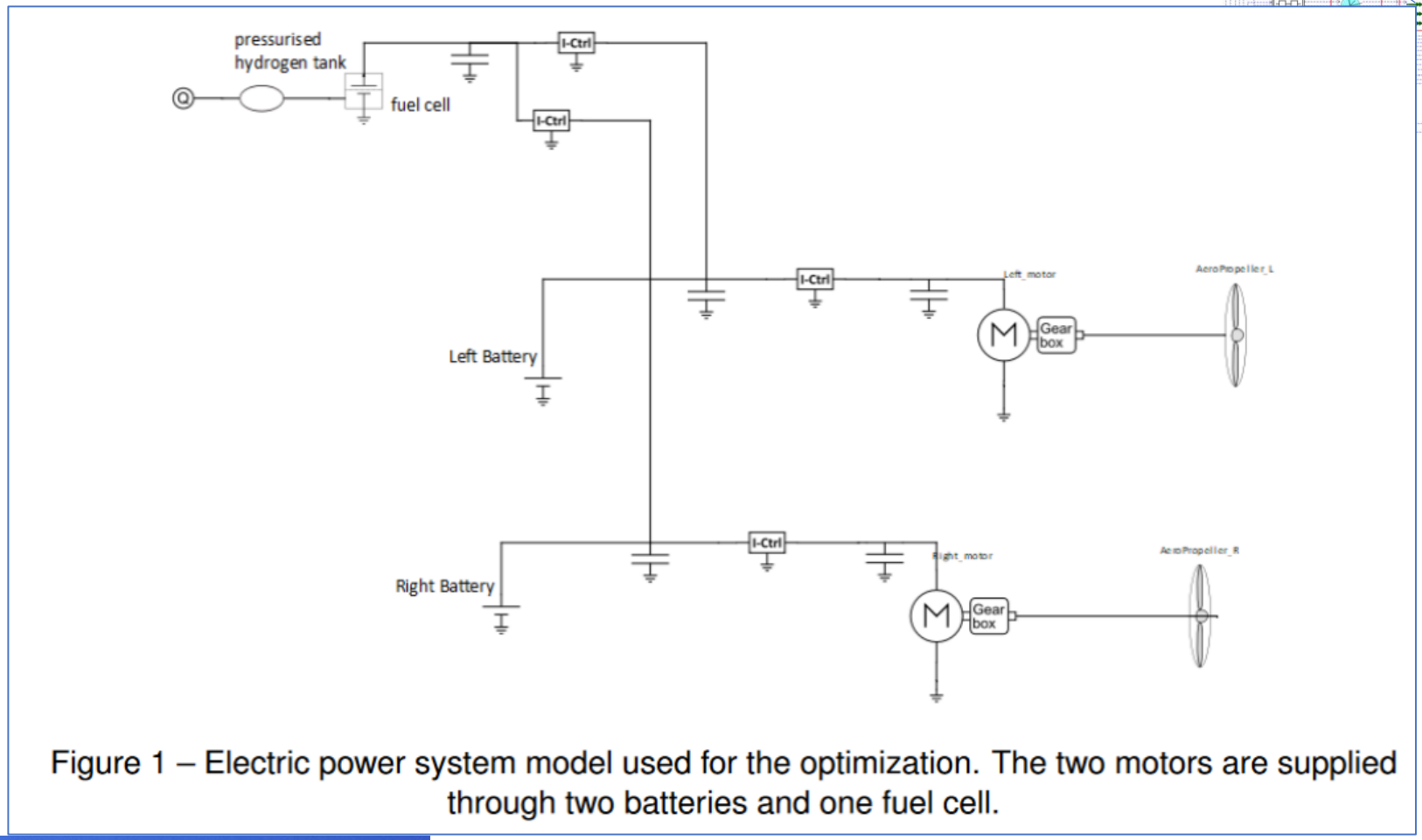


Figure 1 – Electric power system model used for the optimization. The two motors are supplied through two batteries and one fuel cell.

Hybrid aircraft Battery and Hydrogen storage

Case with 500 km range

- Present day technology 2022.
- Battery specific energy 200 Wh/kg
- Battery specific power
  - continuous 3C (600 W/kg), peak 10C (2 kW/kg)
- Fuel cell specific power 1 000 W/kg
- Pressurized hydrogen tank at 700bar
- Hydrogen fuel fraction is 6%
- Optimized for: Battery size, Hydrogen volume, Fuel cell area, Fuel cell max reference current.

Optimization Results

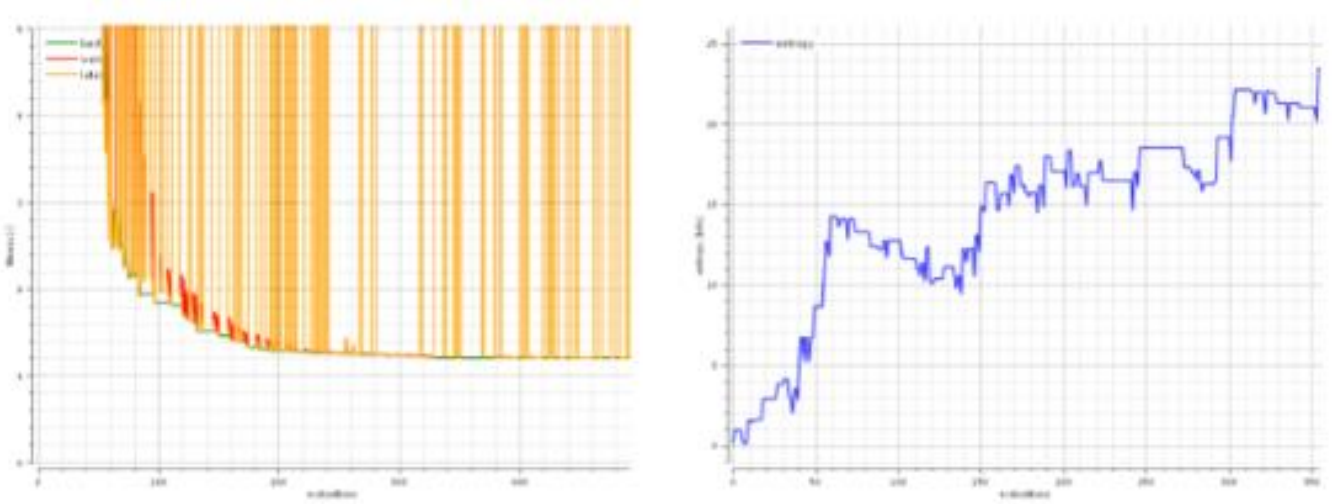


Figure 6 – The evolution of the objective function as a function of object function evaluations (simulations) left, and the estimated information entropy during optimization. It is a measure of the convergence of the optimization.

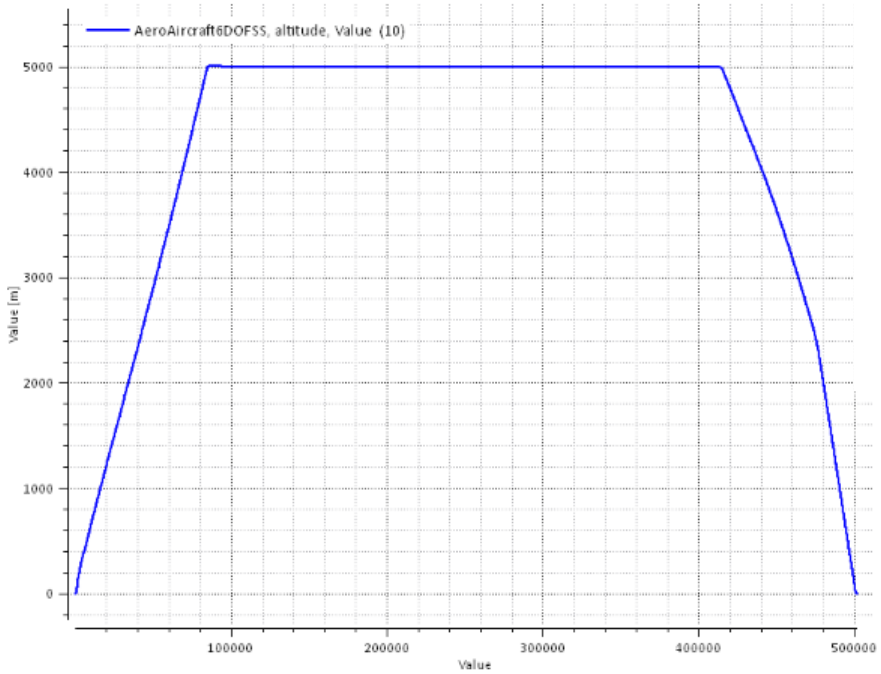


Figure 8 – Simulated mission. A 500km mission with a cruise altitude of 5000m.

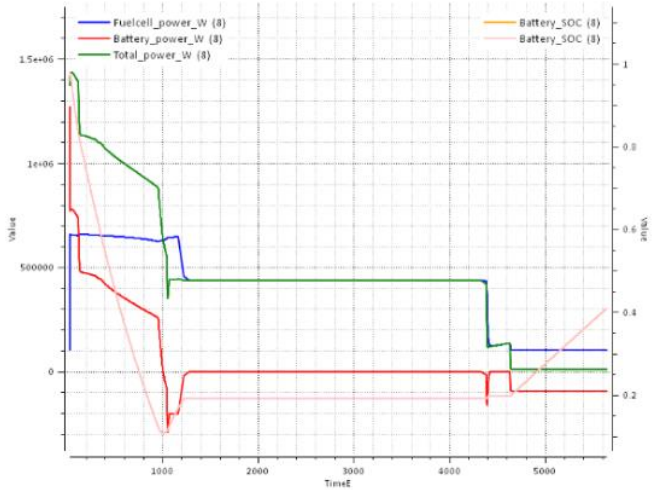


Figure 7 – Powerer from batteries, from the fuel cell and the total electric output.

Simulation Based Optimization

- Case with 500 and 1000 km range
  - Present day technology 2022 and future scenario.
  - Battery specific energy 200 and 400 Wh/kg (pack level)
  - Battery specific power
    - continuous 3C (600 W/kg, 1.2kW/kg), peak 10C (2 kW/kg, 4 kW/kg)
  - Fuel cell specific power 1 and 2 kW/kg
  - Pressurized hydrogen tank at 700bar
  - Hydrogen fuel fraction is 6%
- Maximizing weight available for payload.
- Optimized for: Battery size, Hydrogen volume, Fuel cell area, Fuel cell max reference current.
- Convergence in about 500 simulation runs

Optimized Result. 500 and 1000 km range

Table 2 – Optimization results. Different ranges and for different battery specific energies and fuel cell specific powers.

Case	I	II	III
Technology level	200 Wh/kg 1 kW/kg	200 Wh/kg 1 kW/kg	400 Wh/kg 2 kW/kg
Range	500 km	1000 km	1000 km
Total battery mass	640 kg	353 kg	351 kg
Hydrogen volume	0.587 m^3	1.071 m^3	0.906 m^3
Fuel cell area	0.189 m^2	0.246 m^2	0.232 m^2
Fuel cell max. ref current	*max*	*max*	668 A

Table 3 – Optimization weight results. Different ranges and for different battery specific energies and fuel cell specific powers.

Case	I	II	III
Technology level	200 Wh/kg 1 kW/kg	200 Wh/kg 1 kW/kg	400 Wh/kg 2 kW/kg
Range	500 km	1000 km	1000 km
Payload mass	2332 kg	1903 kg	2514 kg
Battery mass	640 kg	353 kg	351 kg
Fuel cell mass	726 kg	946 kg	446 kg
Hydrogen initial mass	34 kg	62 kg	52.5 kg
Hydrogen storage initial mass	602 kg	1098 kg	928 kg
Fraction of storage and fuel cell	22.8%	27.8%	20.0%

Conclusions

- Battery electric aircraft
  - **Technical feasibility.** Only for very short theoretical ranges (<<500km)
  - **Commercial feasibility.** For niche applications. I.e island hopping. Hard to compete where there are roads.
  - **Climate impact.** Potential <5%
- Electric hybrid aircraft (battery - hydrogen)
  - **Technical feasibility.** For theoretical ranges <2500km, with pressurized tanks. Limitations in speed due to the specific power of fuel cells, but this is very likely to improve.
  - **Commercial feasibility.** Commuter aircraft
  - **Climate impact.** Could potentially be 35% of all flights (inside and to and from the US)
- **Societal impact.** Low-cost regional aviation can be beneficial for sparsely populated areas with little infrastructure.
- **Operations and regulations.**
  - Allowing for single pilot operation would have a large impact on cost of operation.
  - Allowing for simpler passenger processing at airports (ok with <20 pax).
  - Reserves are hard to negotiate. I.e. one or two alternative airports, go around + 30 min loitering.
    - Charging/refueling infrastructure on all alternative airports

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Transforming Aviation Towards Zero Emission Aviation - A perspective on electrification

Dr. Ibrahim Yimer
National Research Council Canada

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OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4–9 SEPTEMBER, 2022

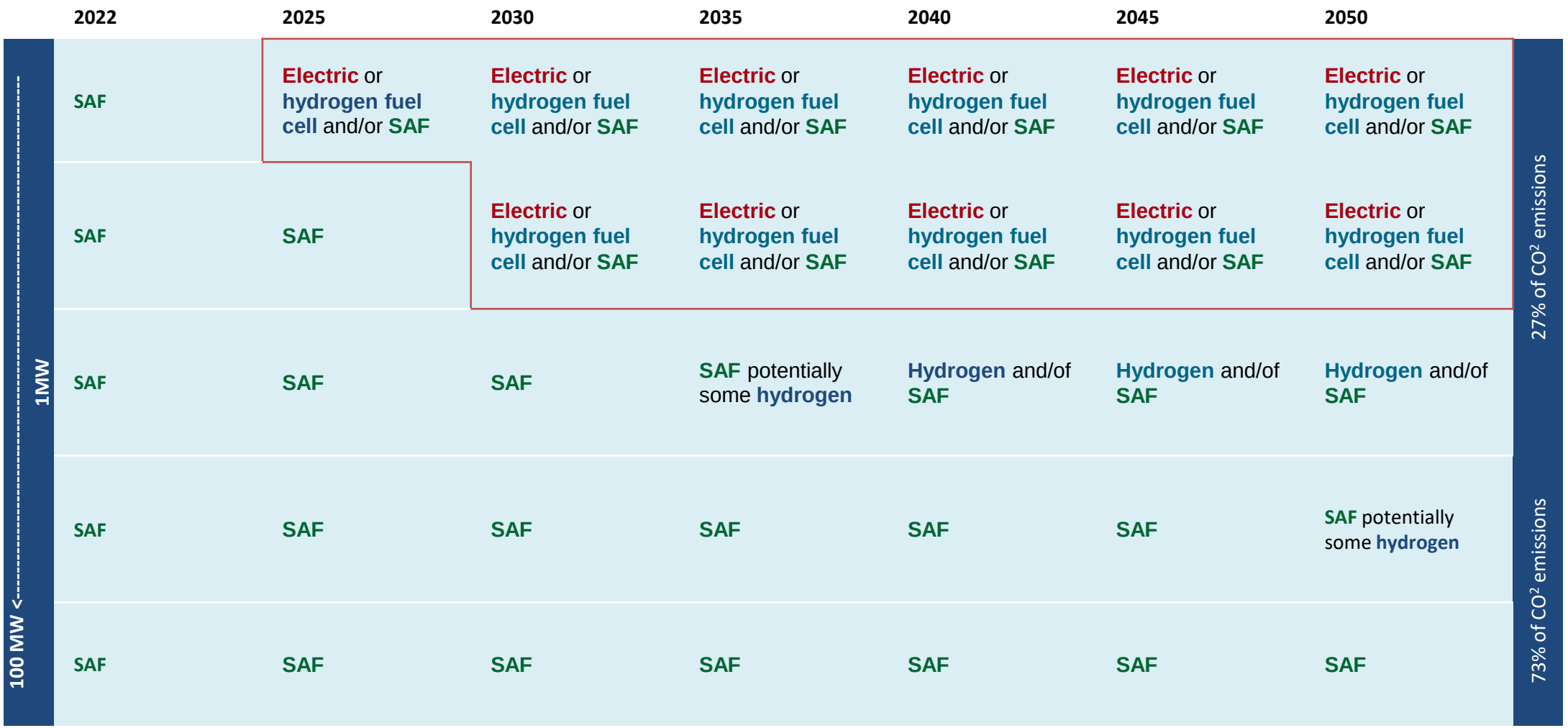
ICAS 2022 SWEDEN

Outline

- Role of Electrification for Net-Zero Aviation
- Technological Progress (Battery & HV Cables)
- Facilities and demonstrators

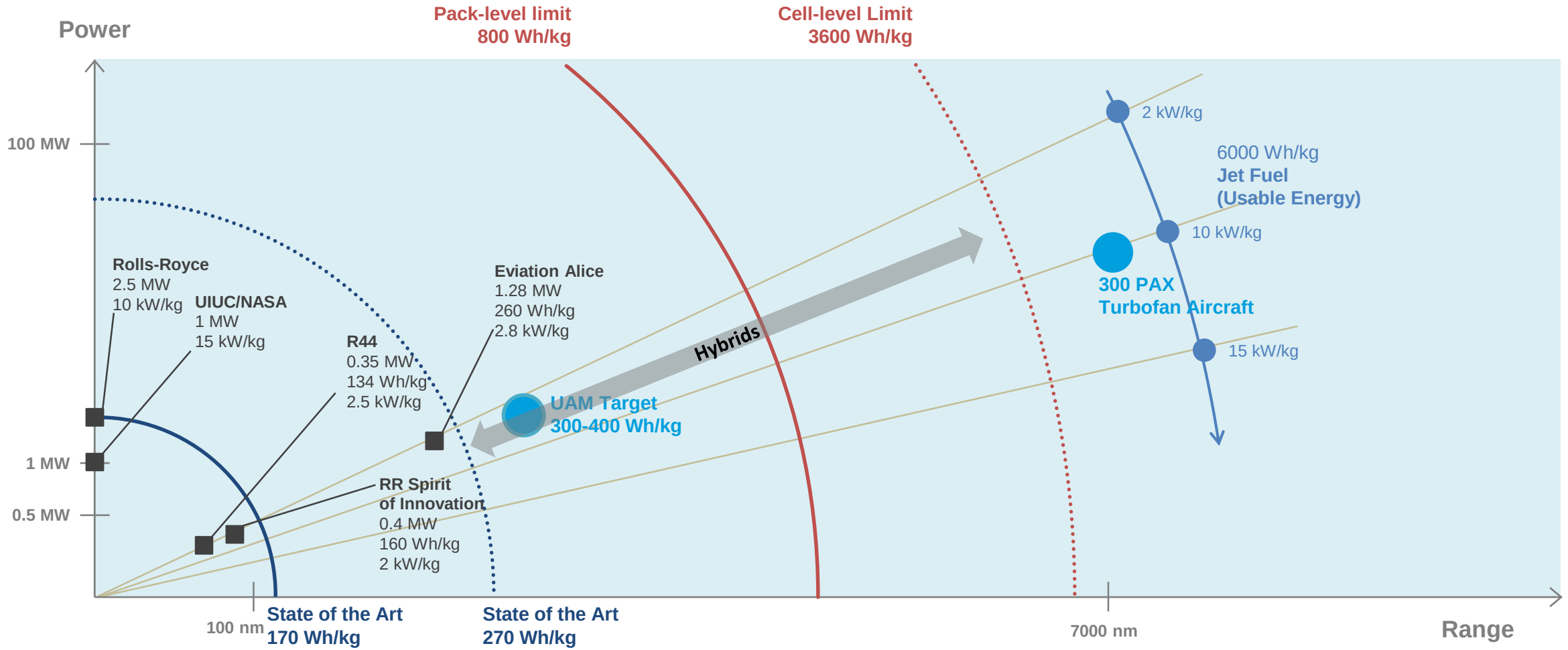
Electrification is just one potential solution for mitigating aviation’s climate impact.

Impact of Electrification



*Assumes that electrical grid and/or hydrogen production are “green”.
Source: Air Transport Action Group’s (ATAG) Waypoint 2050 – A vision of net-zero aviation by mid-century

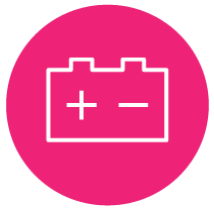
Impact of Electrification



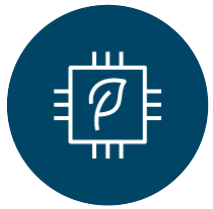
Note: Chart is for illustrative purposes only – not to scale

OPQ
HEAT
AEEH

Lessons Learned from past demonstrations



- Specific regulations related to the design of battery systems for propulsive application are lacking.
- Battery thermal management is crucial for system design and operation.



- Supplier selection can be challenging especially with unknown reliability and failure modes.
- High voltages at altitude introduce new risks and challenges.

- Implement system verification and validation processes early (e.g. SAE ARP 4754)
- Control and cockpit indication of electric propulsion systems is a new area.
- Global regulatory agencies not fully harmonized on approach for certification.

Future Demonstrators

DLR / MTU

Dornier 228

Hydrogen Fuel Cell Hybrid Electric
Re-engine one side (600 kW)

NASA / GE / Boeing

Saab 340B

Battery Hybrid Electric

Re-engine one side (1 MW)

P&WC / DHC

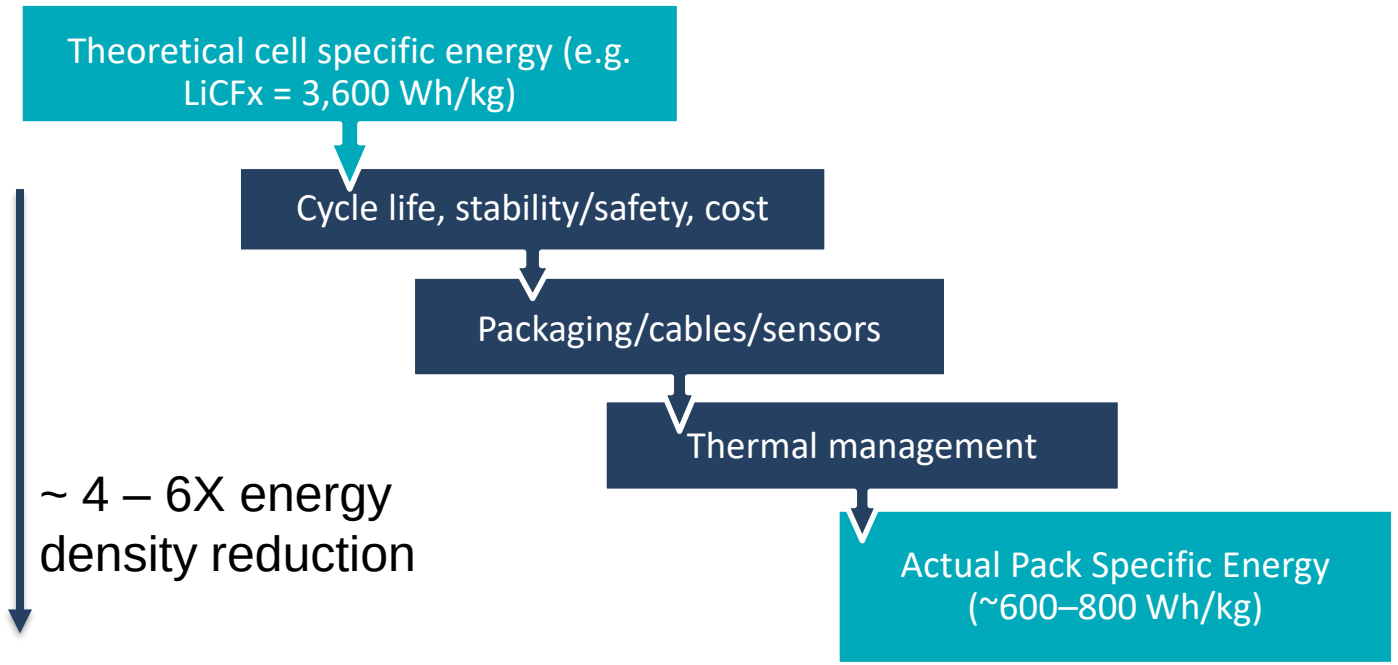
DeHavilland Canada
Dash 8-100

Battery Hybrid Electric

Re-engine one side (2 MW)

Battery Design

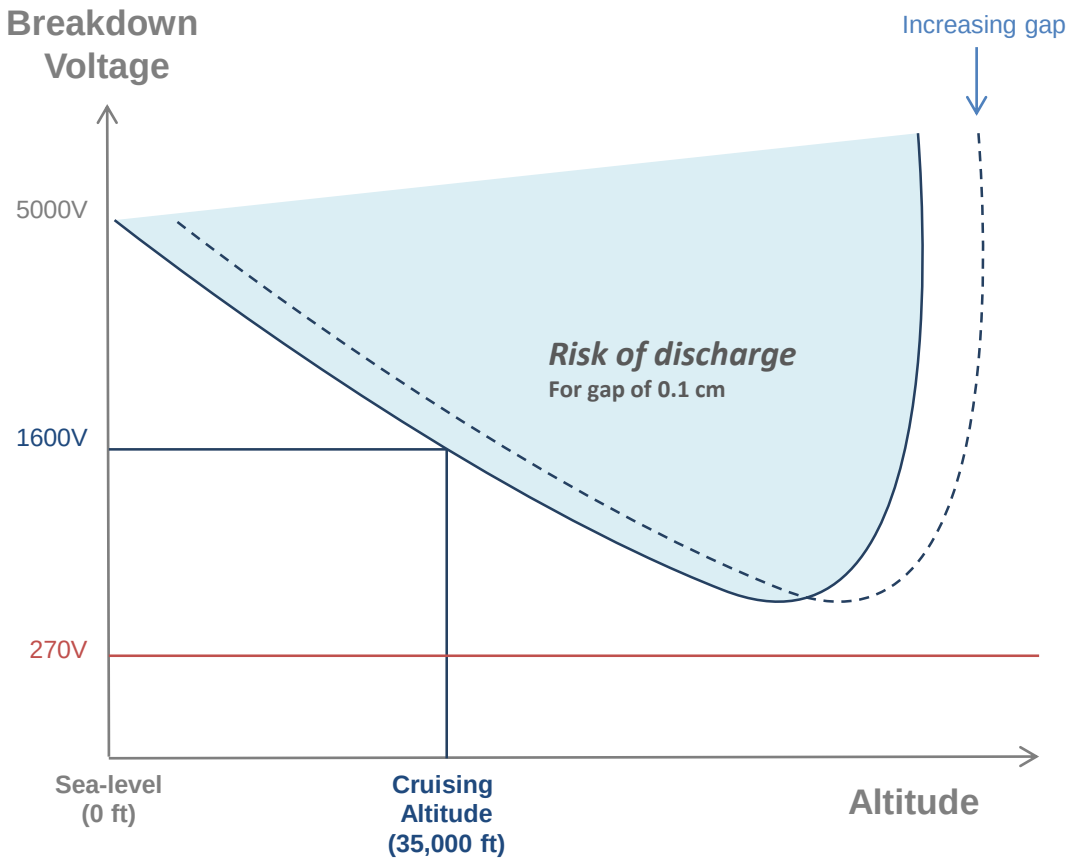
- Optimization for energy density vs. cost
- Can still learn from other sectors (e.g. automotive)
- Further R&D required for aviation specific needs



1 Viswanathan, V., et al. “The challenges and opportunities of battery-powered flight”, Nature, 2022.

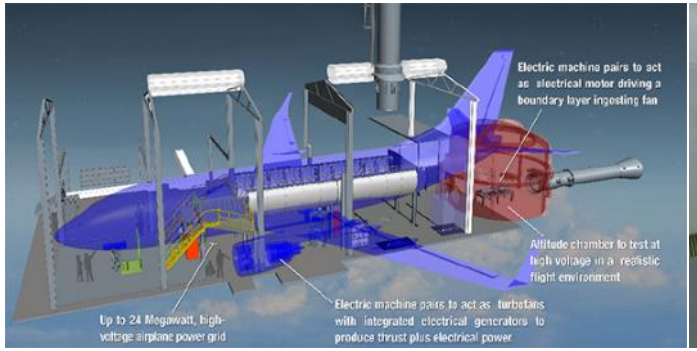
High voltage cables

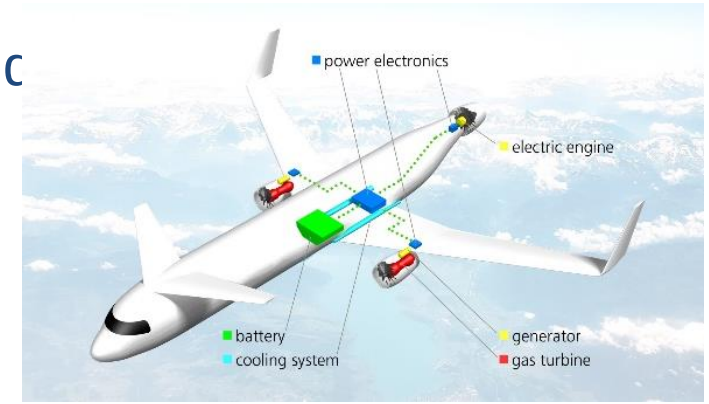
- Maintaining safety while reducing size/weight
- Altitude effects (voltage breakdown & cosmic irradiation)
  - Low voltage & large gaps > increasing cable weight
  - High voltage and small gaps > decreasing cable weight
- Other energy storage devices (e.g., fuel cells) and reducing overall energy requirements



Test Facilities

- Limited number of test facilities to conduct certification tests on larger scale hybrid-electric propulsion systems.
- More specialized facilities required for means of compliance (e.g., altitud & environmental)
- Complex, capital intensive with low utilization rates





Summary

- Electrification is just one potential solution for mitigating aviation's climate impact
- There is room for optimizing battery design and HV cables for aviation applications
- Demos and specialized facilities are complex & capital intensive with low utilization rates
- Cooperation is needed to accelerate development, assess technology impact and harmonize rule-making.
- IFAR continues to provide a collaboration forum in accelerating innovation safely, e.g., IFAR-ICAO partnership.

JAXA's Activities on the Electric Aircraft

Yasushi Watanabe
Japan Aerospace Exploration Agency

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JAXA Explore to Realize

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STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

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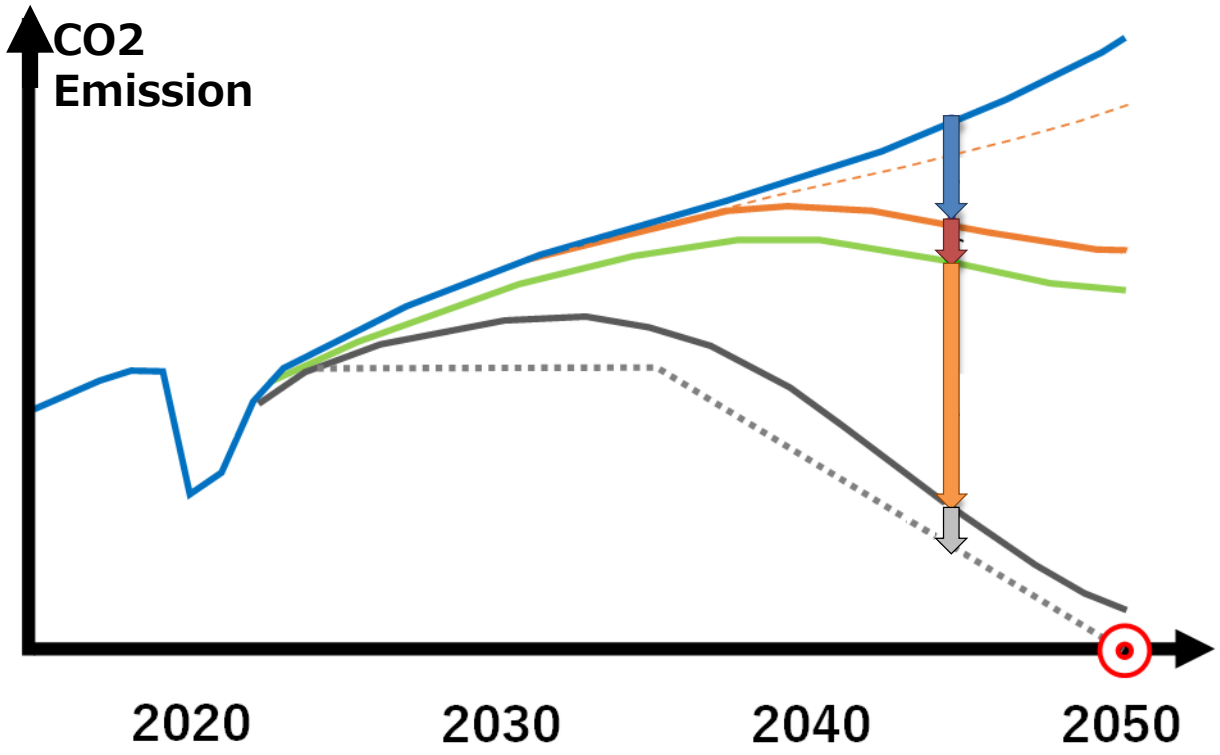
Background : Social Requirement

- **Next-generation technologies are expected.**
  - ✓ SAF, electrification
  - ✓ JAXA's considerations for achieving the goals outlined in WAYPOINT 2050.



https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/

1) Improvements of aircraft performance

- ✓ Improvement of conventional technology
- ✓ Application of new technology

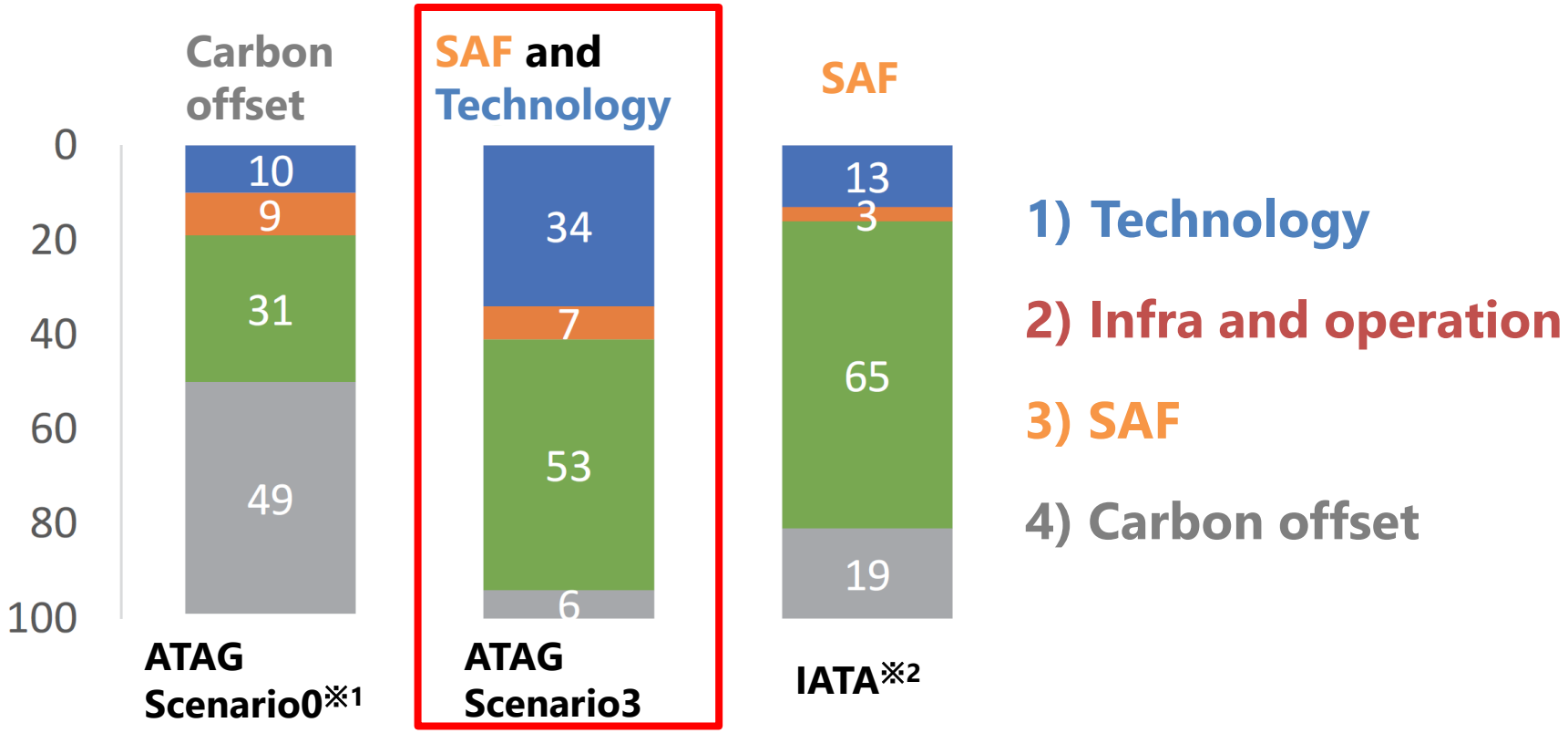
2) Ground infrastructure and operation

3) Replacement to SAF including hydrogen

4) Carbon offset

Contribution of each measure to CO2 emissions

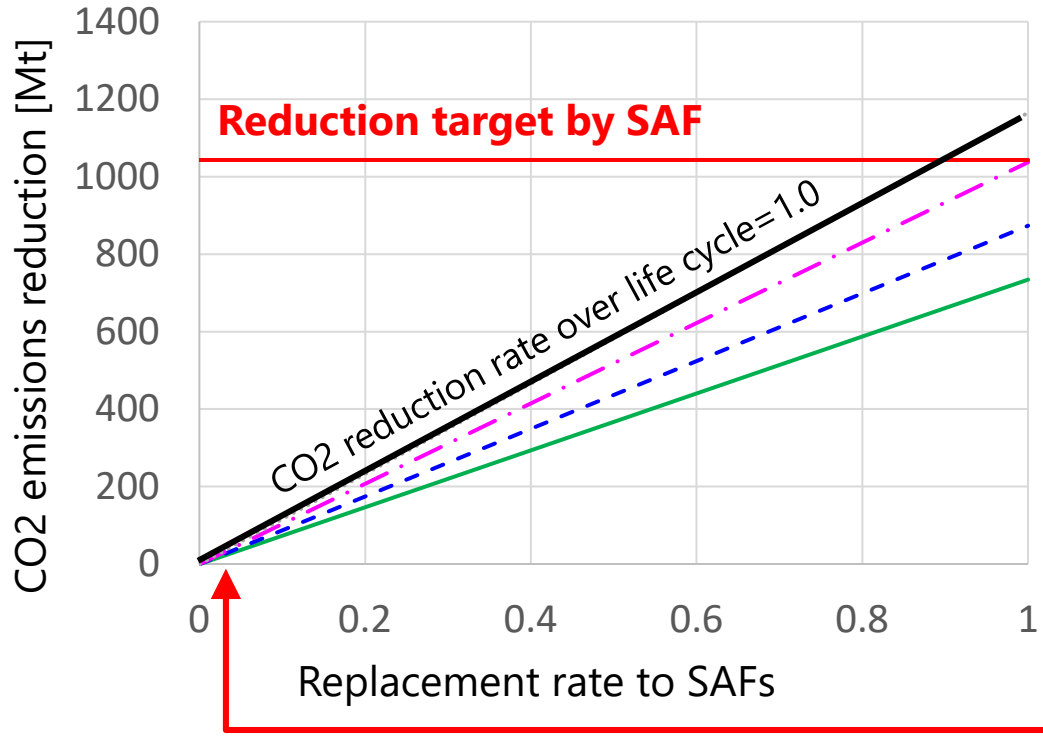
- **Various scenarios have been presented by various agencies.**
- **JAXA's consideration was focused on “Scenario 3“ presented by ATAG.**



※1：https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/
※2：https://www.iata.org/en/pressroom/2021-releases/2021-10-04-03/

Will replacement to SAF meet the goal?

- **It is important to consider CO2 emissions during the life cycle of the SAF.**
  - ✓ Quality needs to be better than current SAF.
  - ✓ The supply of SAF needs to be dramatically increased.

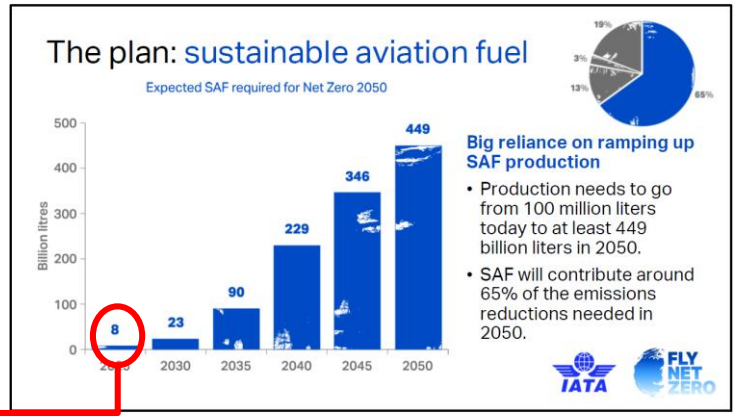


1.00 ➡ ideal SAF

0.89 ➡ Reduction rate to meet target

0.75 ➡ Equivalent to CO2-free hydrogen fuel

0.63 ➡ Equivalent to biofuels



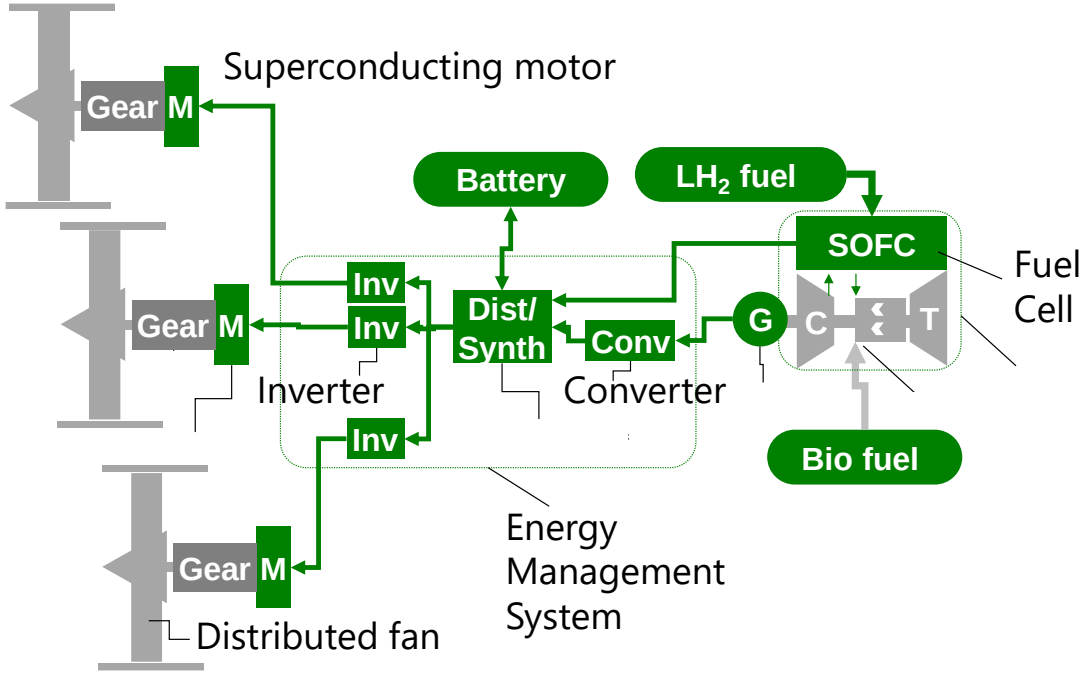
Projected changes in production required by SAF

https://www.iata.org/en/pressroom/2021-releases/2021-10-04-03/

Can we wait for the ultimate in innovation?

- **Ideal electric aircraft for the 2050s and beyond**
  - ✓ Distributed fans by series hybrid
  - ✓ Application of innovative aerodynamic shapes such as Blended Wing Body
  - ✓ Application of CO2-free hydrogen fuel

Conceptual drawing of Emission-Free Aircraft

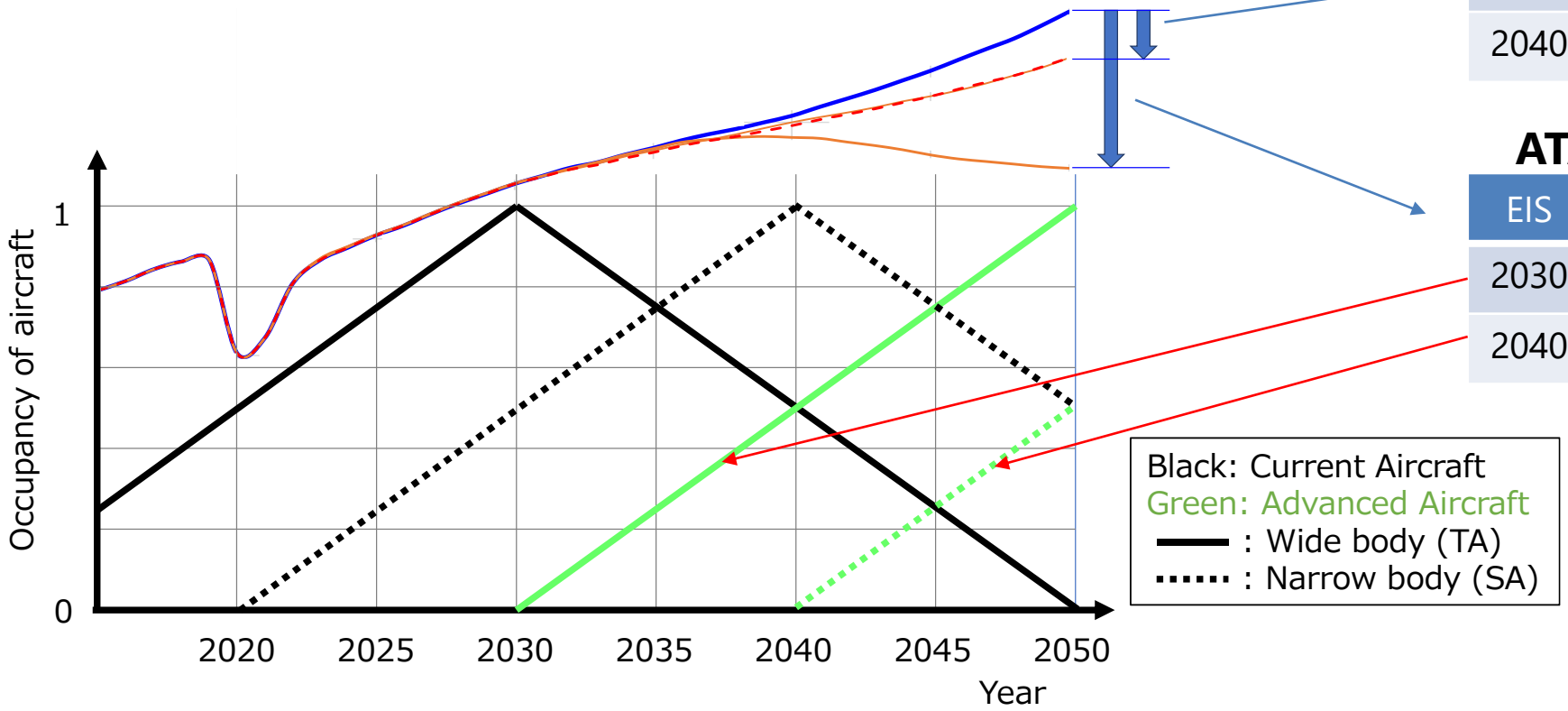


Overview of series hybrid

It is not feasible in current status

Issues of current business model

- **Long aircraft life cycles prevent the effects of technological innovations from fully penetrating the market.**
  - ✓ emission targets will be extremely difficult to achieve



Reduction rate of Fuel consumption;
ATAG Scenario 0

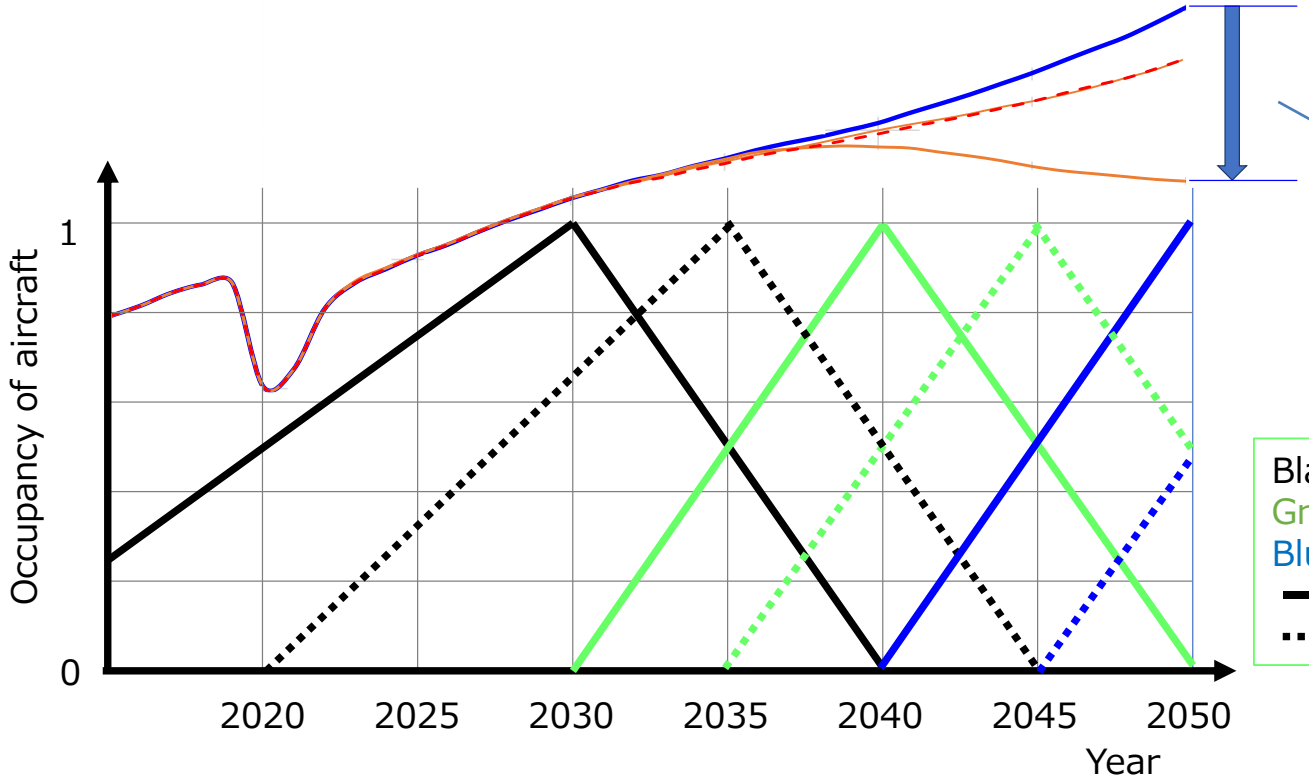
EIS	Type	Target
2030	TA	11%
2040	SA	18%

ATAG Scenario 3

EIS	Type	Target
2030	TA	20%
2040	SA	95%

One idea to solve the issue of business model

- **Shorter aircraft replacement times will make it easier for the benefits of technological innovation to penetrate the market.**
  - ✓ Business model needs to be reformed
  - ✓ Performance goals are more easily realized.



Black: Current Aircraft
Green: 1st Generation
Blue :2nd Generation
: Wide body (TA)
: Narrow body (SA)

Reduction rate of Fuel consumption;
ATAG Scenario 3

EIS	Type	Target
2035	SA	20%
2040	TA	35%
2045	SA	45%

Key Points of Technological Strategy

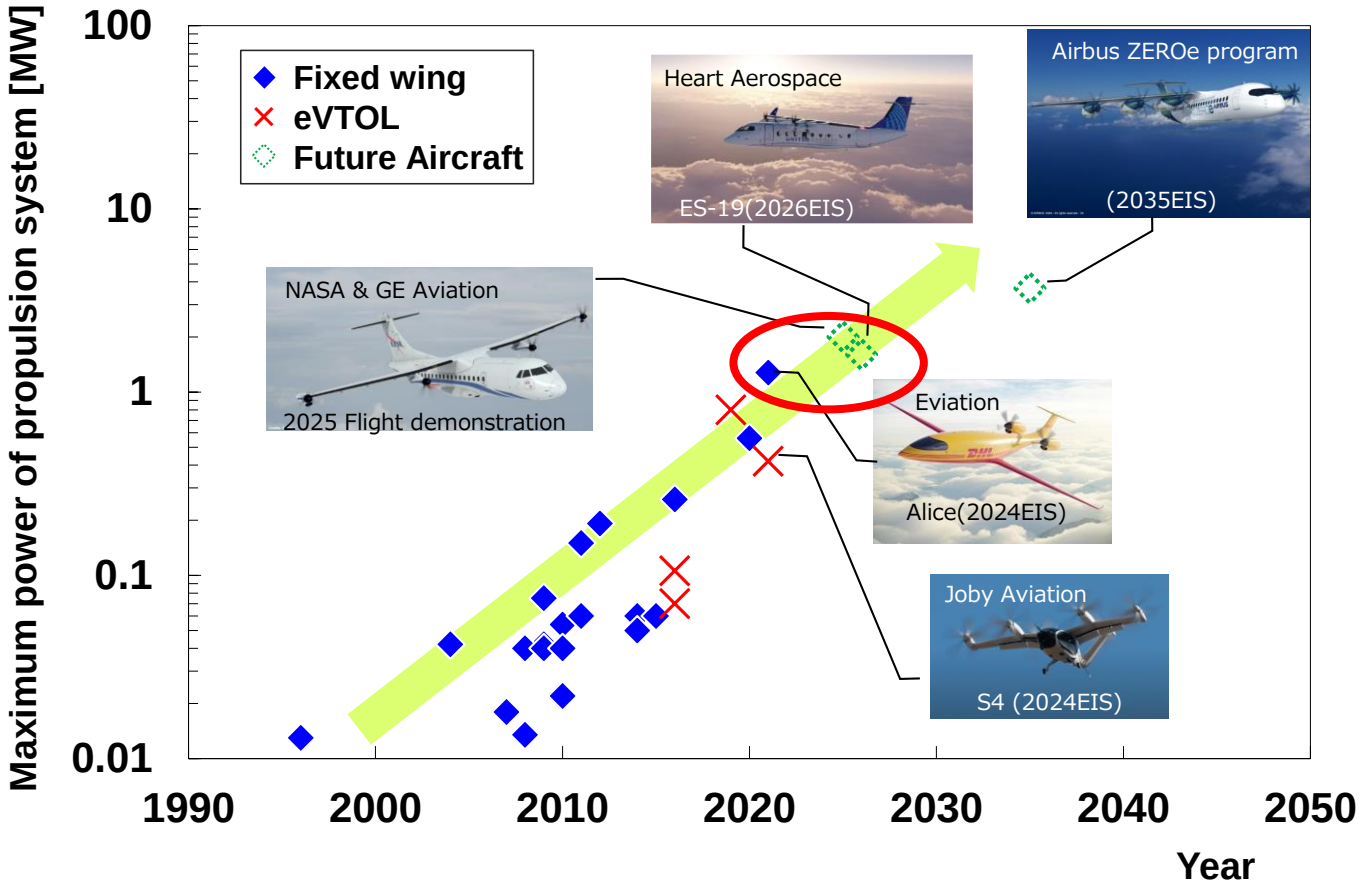
- **It is essential to develop technologies that improve fuel efficiency.**
  - ✓ Replacement of SAFs alone may not achieve emission targets.
  - ✓ Fuel consumption should be reduced regardless of fuel type.

- **Early implementation of technology is critical.**
  - ✓ The first innovation should be realized by 2030.
  - ✓ On that basis, we need to promote continuous innovation.

JAXA will promote the development of electrification technologies for aircraft that are effective in reducing fuel consumption.

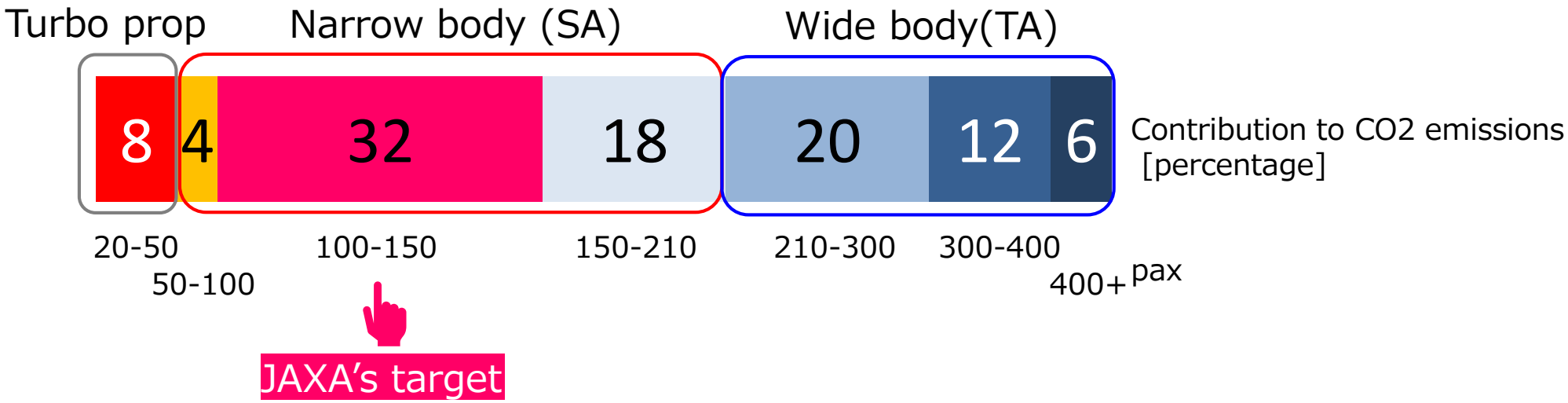
Trends in Technology Development

- **MW-class propulsion system electrification is becoming possible.**
  - ✓ The elemental technologies for partially electrifying the propulsion systems of passenger aircraft are coming together.



Targets for social implementation in the 2030s

- **Evaluation of the contribution of new aircraft to overall aircraft CO2 emissions.**
  - ✓ **Turbo prop;** Contribution to CO2 emissions is **low**. Current technology is **available**.
  - ✓ **Narrow body;** Contribution to CO2 emissions is **high**. **Low risk** of development.
  - ✓ **Wide body;** Contribution to CO2 emissions is **maximum**. **High risk** of development.



Projected contribution of each size to CO2 emissions in 2050

Source: James, D.H. 2015@NASA

Comparison with ATAG's goals

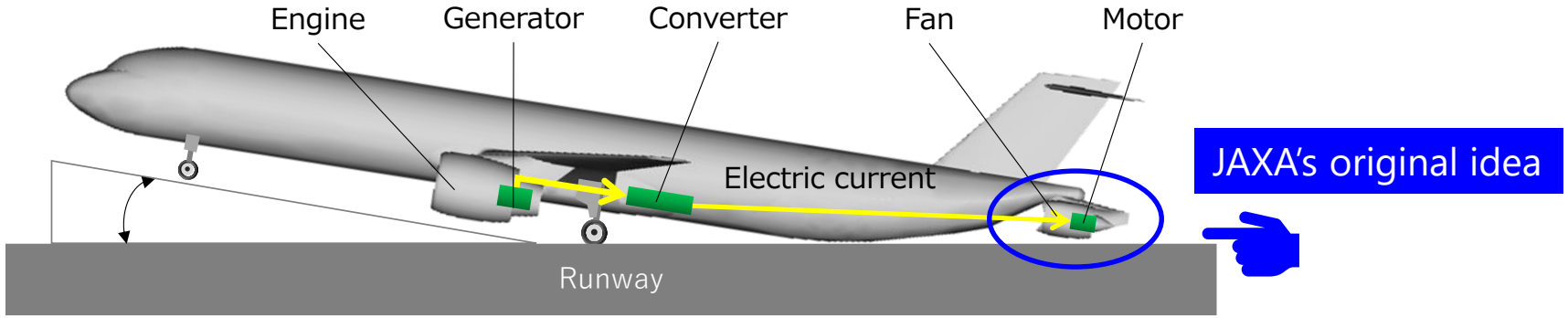
➢ **Established a goal of applying electrification technology to larger aircraft.**

	2020	2025	2030	2035	2040	2045	2050
Commuter » 9-19 seats » < 60 minute flights » <1% of industry CO_2	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Regional » 50-100 seats » 30-90 minute flights » ~3% of industry CO_2	SAF	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Short haul » 100-150 seats » 45-120 minute flights » ~24% of industry CO_2	SAF	SAF	SAF	SAF potentially some Hydrogen	Hydrogen and/or SAF	Hydrogen and/or SAF	Hydrogen and/or SAF
Medium haul » 100-250 seats » 60-150 minute flights » ~43% of industry CO_2	SAF	SAF	SAF	SAF	SAF potentially some Hydrogen	SAF potentially some Hydrogen	SAF potentially some Hydrogen
Long haul » 250+ seats » 150 minute + flights » ~30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

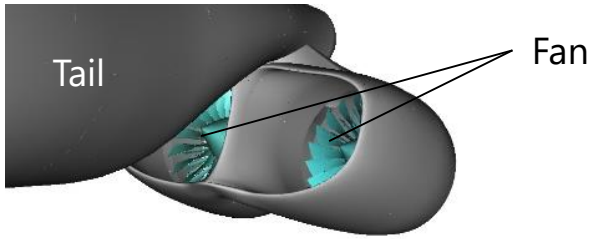
https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/

JAXA's concept

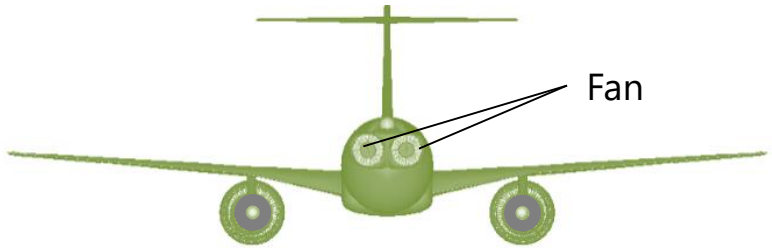
- **Concept to reduce fuel consumption regardless of fuel type.**
  - ✓ Simplest system; generators and distributed electric fans.
  - ✓ Fuel consumption reduction of about 10% is possible
  - ✓ JAXA's goal is to demonstrate technical feasibility through demonstration.



JAXA's original idea



BLI（Boundary Layer Ingestion）Nacelle



Back view

Thank you for your attention!

Questions and Answers

IFAR-ICAS Awardee Manish Nagaraj

IFAR and ICAS signed a cooperation agreement in 2014 to support exchanges among their members

As part of the collaboration, the IFAR-ICAS award is a jointly established award to honor a PhD candidate who has made significant contribution to aeronautical science

This year, the IFAR-ICAS award recipient is Manish Nagaraj, in recognition of his exceptional PhD thesis at CIRA (Italy)

Please congratulate Manish on his accomplishment

Title of Ph.D dissertation	Name of the author
Higher-order layer-wise models for the progressive damage and impact analysis of composite structure 1	**Manish Nagaraj (CIRA)**
Analyzing and Modeling Capacity for Decentralized Air Traffic Control	**Emmanuel Sunil (NLR)** 2
Experimental investigation of the circulation flow and the heat transport in turbulent mixed convection	**Michael Mommert (DLR)** 3