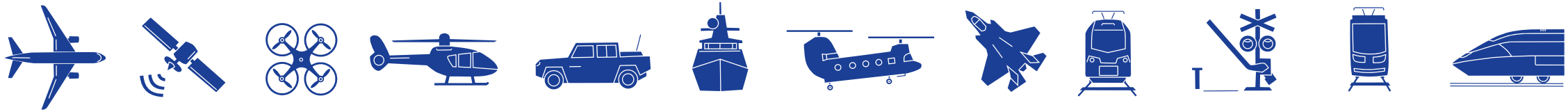
ADSE
CONSULTING AND ENGINEERING

Impact of Hybrid-Electric Propulsion Technologies on Aircraft Operators

02/09/2020

Yorick Teeuwen



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Company introduction – ADSE

Fokker Aircraft Heritage

Established **1996**

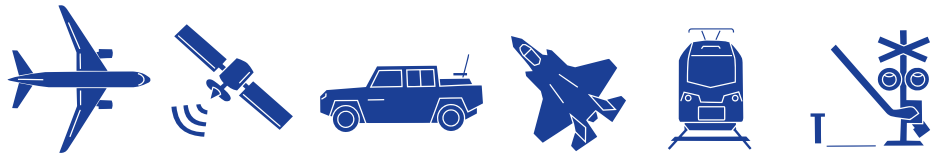
ADSE

20+ years in operation

ENGINEERING
Design & Certification

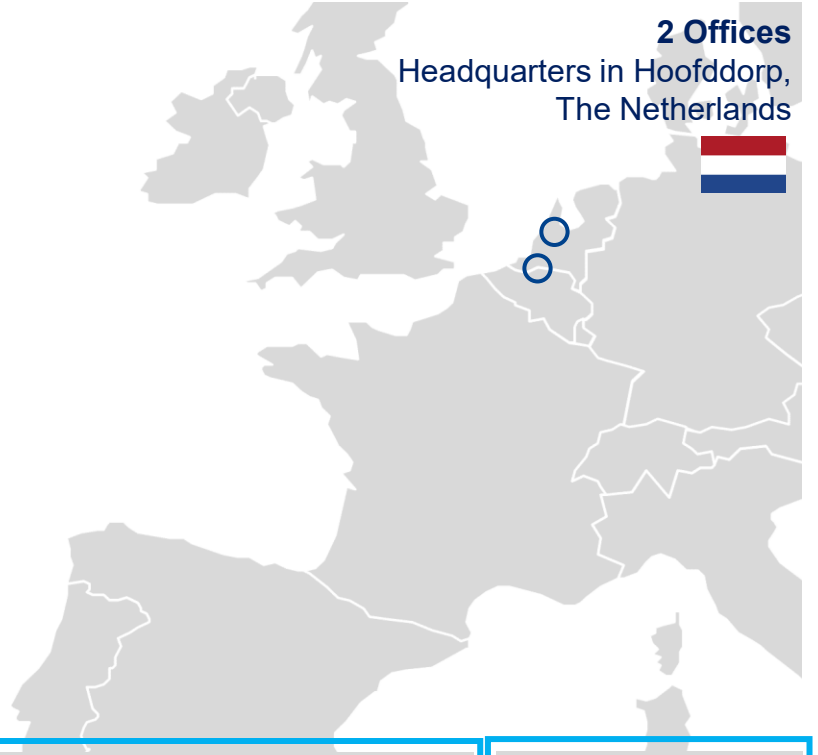
CONSULTANCY
Process improvements

EXPERTISE | IMPROVEMENTS | SOLUTIONS | INNOVATIONS



Transportation systems

Aerospace | Defense | Mobility



2 Offices
Headquarters in Hoofddorp, The Netherlands

75+ Highly Skilled Engineering Professionals

€ 8 M Turnover

Worldwide Customer Base
(OEMs, Suppliers, Operators, MROs, Authorities)

EASA **DOA**.21J.481

Sister company:

- Moving Dot offering ATM policy and R&D deployment services to ANSP's – using ATM experts and procedure development expertise

ADSE

ENGINEERING
Design & Certification

CONSULTANCY
Process improvements

Large customer base	→	Lots of experience
System Engineering DNA	→	Holistic view
Active across the whole development cycle	→	From concept to validation

\+ ----------

Excellent integrator of knowledge with high regard to stakeholder behavior and interest

Operator Technology Impact Simulator

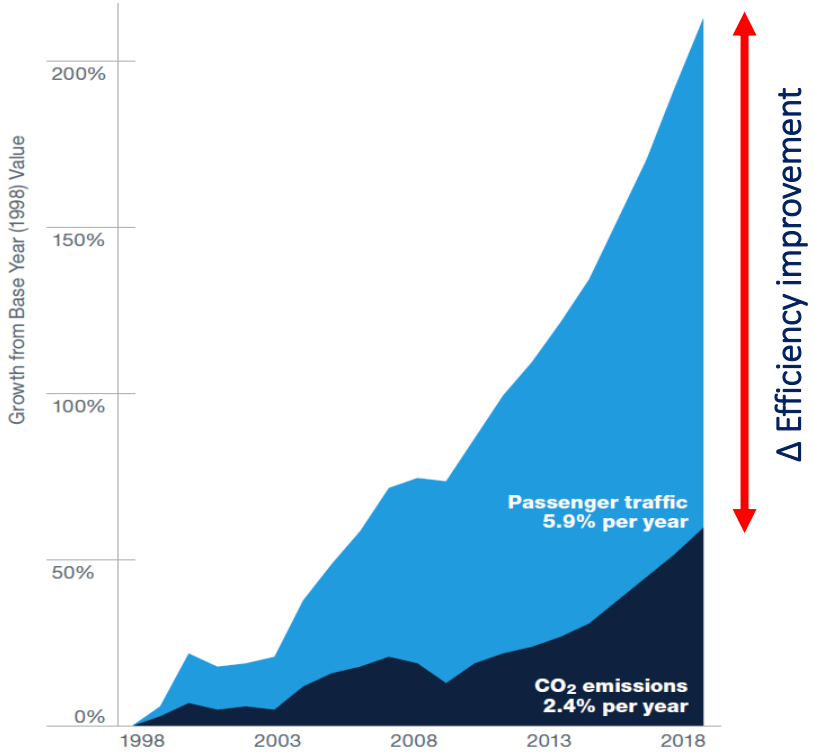
Numerical coupling of Design, Operation and Climate

ADSE experts in the loop for critical assumptions and analysis

Content

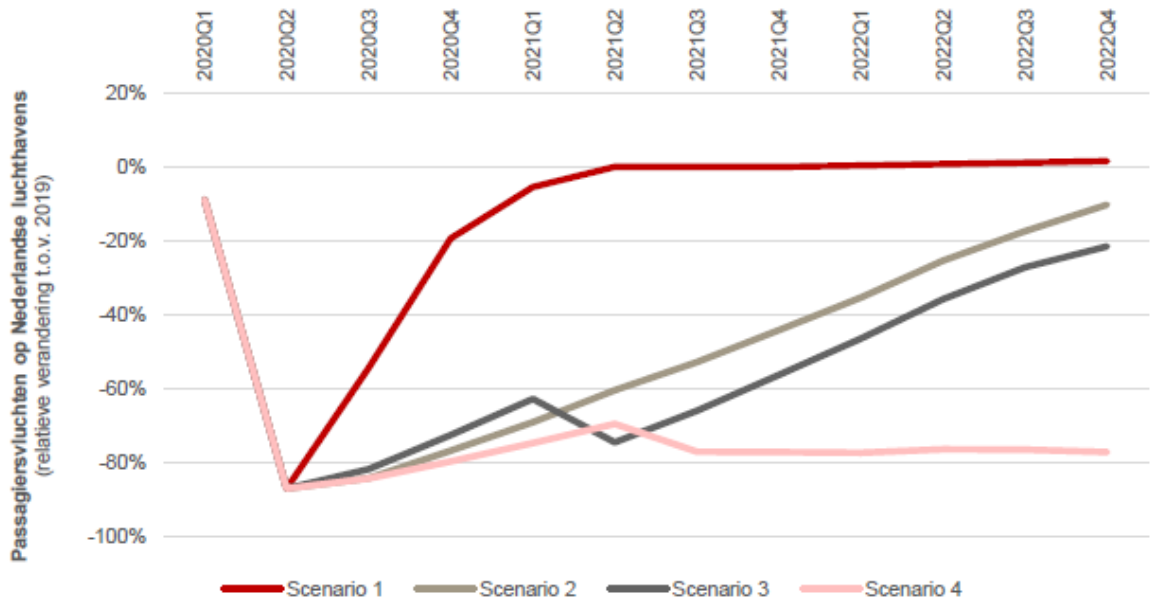
- Need for disruption in aviation
- Our look on realistic innovation
- Our solution for modeling the effects of innovation
  - Operator Technology Impact Simulator (OTIS)
  - Case study
- Conclusion

Sustainable aviation growth



Source: Boeing

- Historically traffic growth has been larger than the improvement in efficiency -> **call for disruption**



Bron: SEO Economisch Onderzoek

- COVID-19 has dampened aviation growth, but for how long?
  - In 3 out 4 scenario's aviation has not recovered fully by 2023
  - But in 10 years….
  - COVID-19 has increased aviation's per pax km CO2 production!

OK a disruption in the aviation sector?

Electrification of aircraft – across the spectrum

- A lot is happening regarding electric flight worldwide - disruption or evolution?
- ADSE takes a realistic view at what is possible and what is needed to make this happen: factual w.r.t physics, credible w.r.t scenarios and assumptions

Flying taxis: Uber partner reveals design

Uber on track to deliver aerial rideshare network by 2023 as manufacturer Bell Helicopter unveils full-scale model in Las Vegas

▲ Aerial rideshare ambition ... an artist's rendering of Bell Helicopter's Nexus in the air. All photographs: Bell Helicopter

Technology

London-Paris electric flight 'in decade'

22 March 2017 | Share

A mock-up of the Wright One, Wright Electric's plan for short-haul, electric-powered flight

Sources: BBC news, Guardian, CNN

Eviation Aircraft

Eviation: A nine-passenger all-electric aircraft.

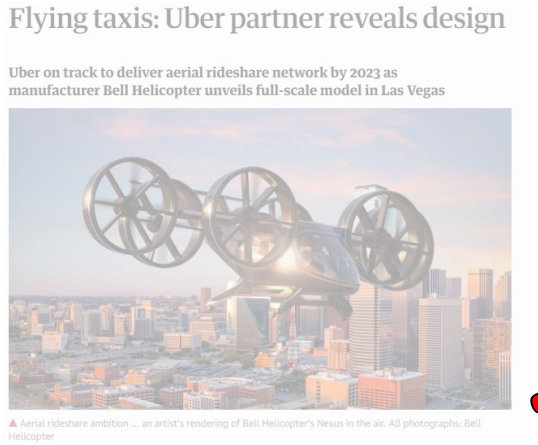
Courtesy Eviation Aircraft

Aviation behemoth Boeing has invested in Seattle-based startup Zunum Aero.

Zunum Aero

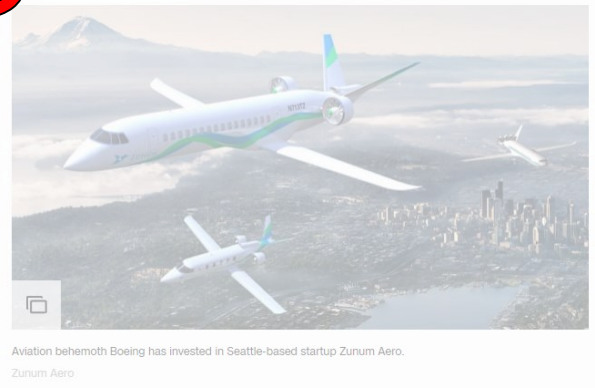
Electrification of aircraft – across the spectrum

- A lot is happening regarding electric flight worldwide - disruption or evolution?
- ADSE takes a realistic view at what is possible and what is needed to make this happen: factual w.r.t physics, credible w.r.t scenarios and assumptions



There is no silver bullet!

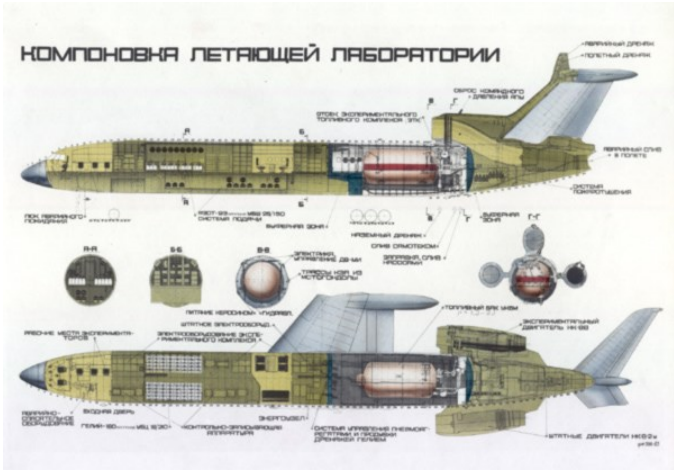
Sources: BBC news, Guardian, CNN



Need for demonstrators

Modification/retrofit of existing aircraft as a realistic first step to certifiable innovation.

Basis to de-risk program decisions for future programs/new versions



Modest innovations on the short term – Demonstratable

- ADSE believes candidates to offset aviation emissions in the present to near term to be:
  - Sustainable aviation fuels (Plant based, green H_2)
  - Operational improvements -> routing to minimize climate impact
  - Increased use of electrification -> More Electric Aircraft

- Likely mid term candidates, that require modest adjustment of the aviation arena are:
  - H_2 combustion in gas turbine
  - Improved propulsion architecture, propellers & Boundary Layer Ingestion (BLI)
  - Initial electrification of the aircraft drive train

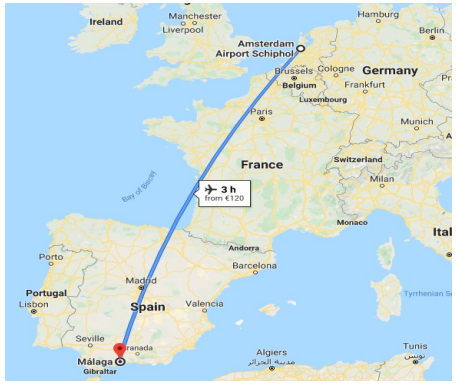
Modest innovations on the short term – Demonstratable

- These low impact, realistic innovations are interesting to examine, from an Operators point of view:
  - What does adjusting the routing for minimal climate impact mean for the operations?
  - How does an innovation in propulsion architecture translate to operational cost and revenue potential?
  - How does the utilization of an aircraft impact the Operator?

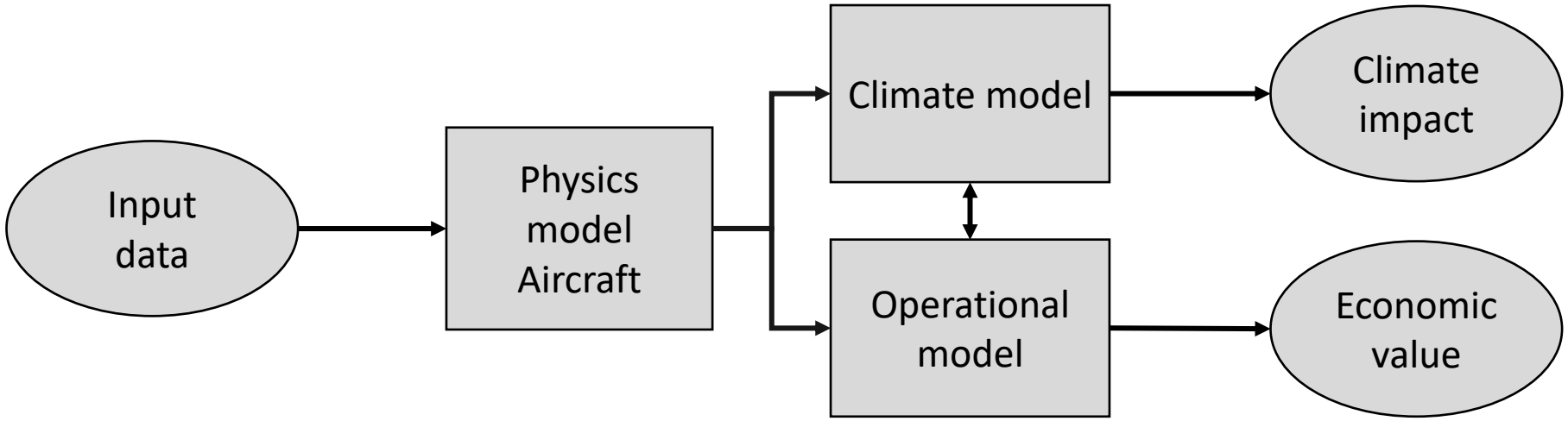
Operator Technology Impact Simulator

Operator Technology Impact Simulator, OTIS

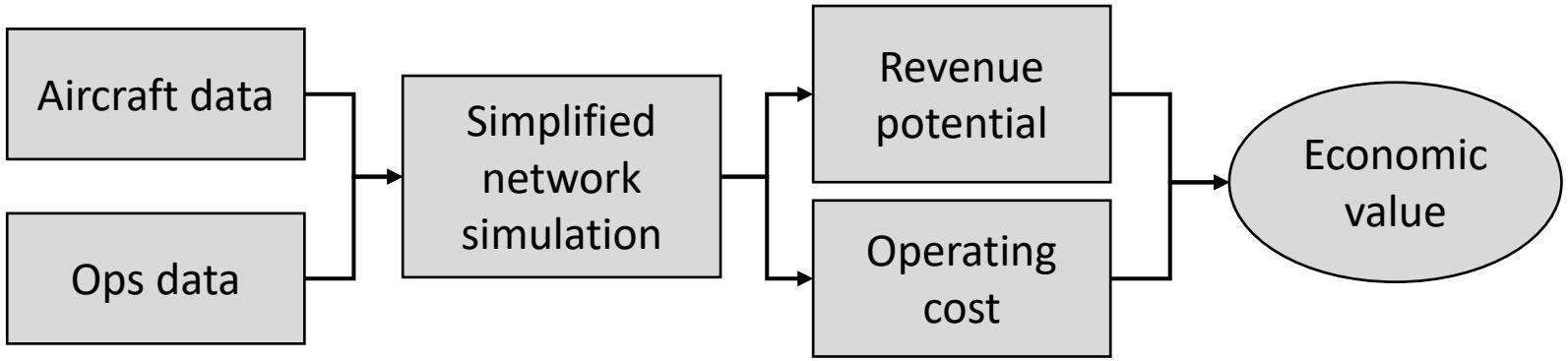
- OTIS high level modelling structure and working
  - Overall
  - Operations module
  - Climate module
- Case study – BLI
- Results
- Conclusion OTIS and Electric Aviation



High over architecture:

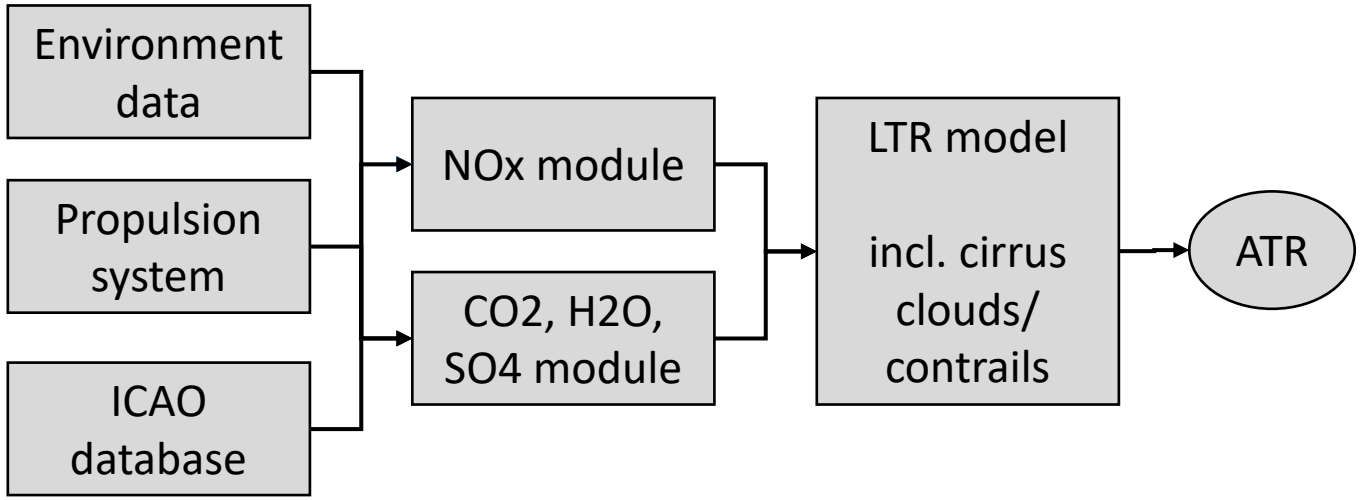


Operator Technology Impact Simulator - Operations

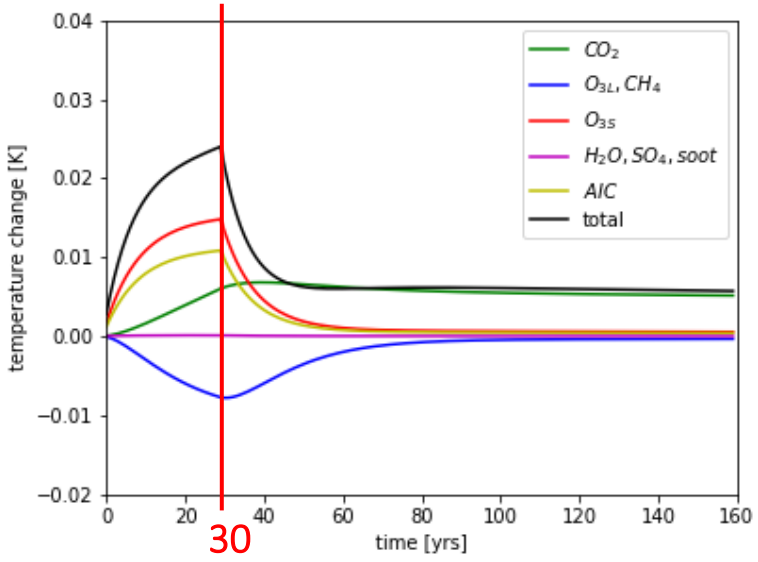


- Utilization e.g. under change in flight speed, or battery charging time.
- Aircraft performance e.g change in max range, multi-hops, more max range missions.
- Revenue management e.g load factor or ticket price.

Operator Technology Impact Simulator – Climate Impact



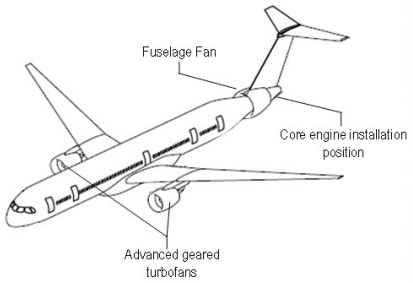
- Average Temperature Response (ATR)
- Climate integrated over lifetime and beyond (500 yrs)
- Flight height and speed
- LTR model from Stanford [1]

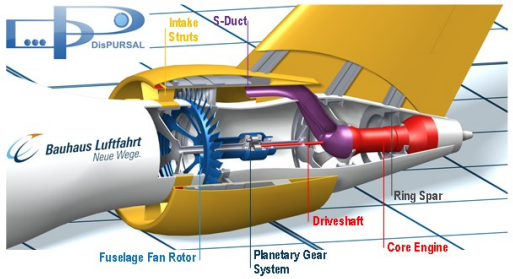


[1] Dallara, E. & Kroo, I.. (2011). Aircraft Design for Reduced Climate Impact. 1-20. 10.2514/6.2011-265.

Case Study - Regional aircraft with Boundary Layer Ingestion

Several BLI projects going on worldwide – various organizations working on it in US and Europe



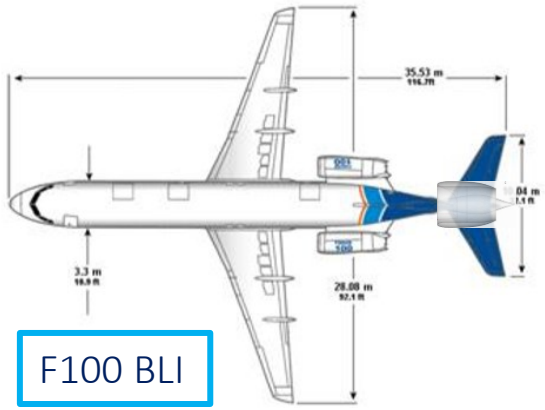


Case Study – Regional aircraft with BLI

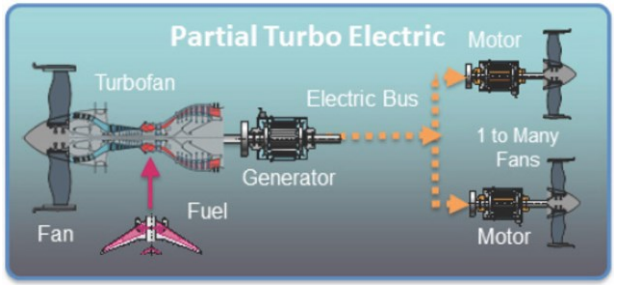
- Baseline aircraft chosen to be the Fokker F100 based on Fokker heritage – OTIS aircraft design and performance inputs modeled using AdAstra, other inputs current best estimates

Parameter	Value
Pax capacity [-]	109
Total PL capacity [kg]	11740
Max. range @ max payload [NM]	1130 (2093 km)
Delivery price (new) [$]	60M
OEM [kg]	25000
MTOM [kg]	44450
Annual avg. availability [-]	95%
Avg. block time [hr]	1.5
Avg. turnaround time [hr]	0.67
Engine [-]	2x Tay-650
TO thrust (Total) [kN]	67
Engine price (new) [$]	2.5M

- Two variants of F100 considered for analysis:
  i. **F100 BLI:** An F100 augmented with BLI via an extra centerline gas-turbine engine
  ii. **F100 e-BLI:** A turboelectric hybrid version using generators onboard driving an electrically driven fan



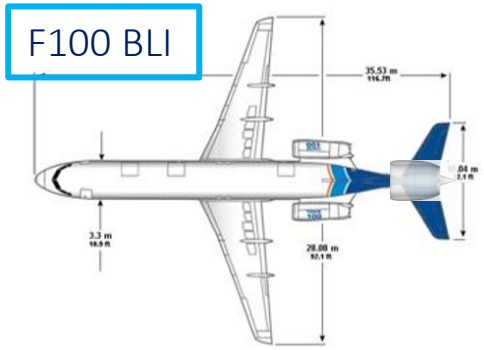
F100 BLI



F100 e-BLI

Case Study – Regional aircraft with BLI

F100 BLI



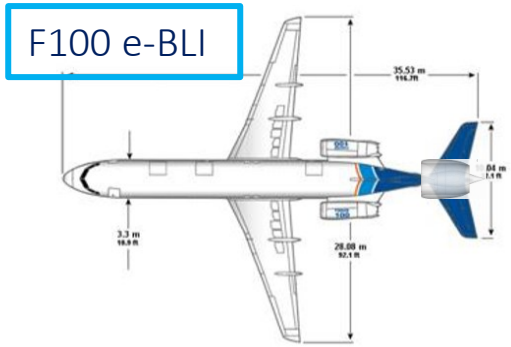
Parameter	Value
Pax capacity [-]	109
Total PL capacity [kg]	12090
Max. range @ max payload [NM]	1047 (1940 km)
Delivery price (new) [$]	63M
OEM [kg]	24650
MTOM [kg]	44450
Annual avg. availability [-]	94.5%
Avg. block time [hr]	1.5
Avg. turnaround time [hr]	0.67
Engine [-]	2x 2/3 scaled Tay-650+ 1x 1/3 scaled center engine
TO thrust (Total) [kN]	67
Engine price (new) [$]	2.5M

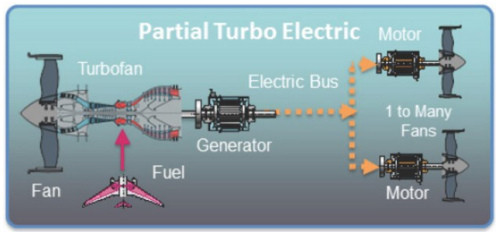
- Adding third engine allows all engines to be scaled down to produce required overall thrust
- This leads to a net OEW reduction of ~350 kg
- BLI provides ~5% improvement in trip fuel due to wake reenergization
- Presence of third engine and related additional power transfer systems leads to increase in aircraft price
- Additional periodic maintenance on new engine yields a reduction in annual availability of aircraft by 1 day

Case Study – Regional aircraft with e-BLI

- Current electric machinery of MW capacity (e.g. generators, motors) as well as associated cabling quite heavy for aviation purposes
- This leads to a net OEW increase of ~1000 kg
- BLI improvement in fuel efficiency reduces to 4%
- New electrical fan, machinery, cabling and associated systems will lead to further increase in aircraft price ~10% as a conservative case
- Electrically driven fan may need less frequent periodic maintenance, increasing its annual availability

F100 e-BLI

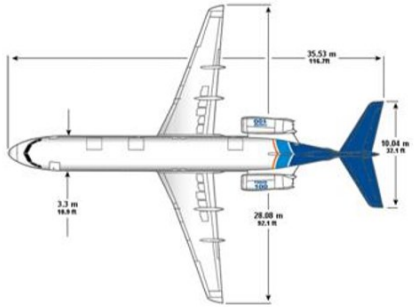




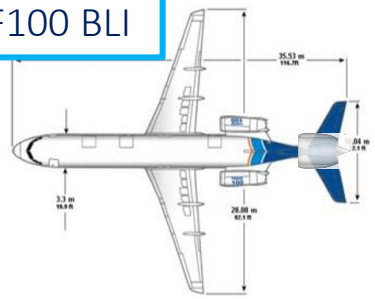
Parameter	Value
Pax capacity [-]	109
Total PL capacity [kg]	11090
Max. range @ max payload [NM]	851 (1576 km)
Delivery price (new) [$]	66M
OEM [kg]	25650
MTOM [kg]	44450
Annual avg. availability [-]	94.7%
Avg. block time [hr]	1.5
Avg. turnaround time [hr]	0.67
Engine [-]	2x 2/3 scaled Tay-650+ 1x electric driven fan
TO thrust (Total) [kN]	67
Engine price (new) [$]	2.5M

Case Study – Regional aircraft with BLI

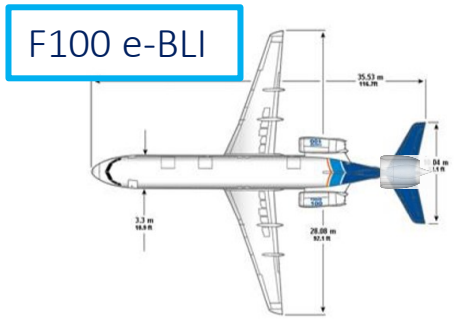
- All aircraft compared on two routes:

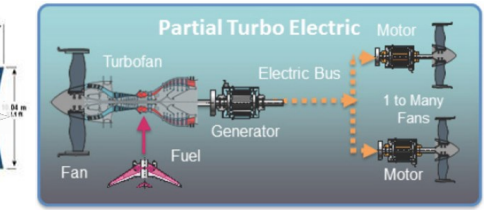


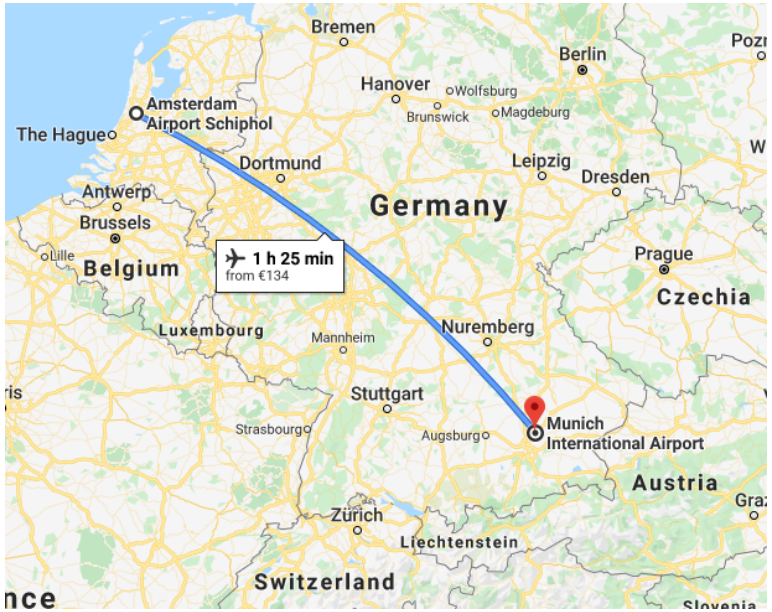
F100 BLI



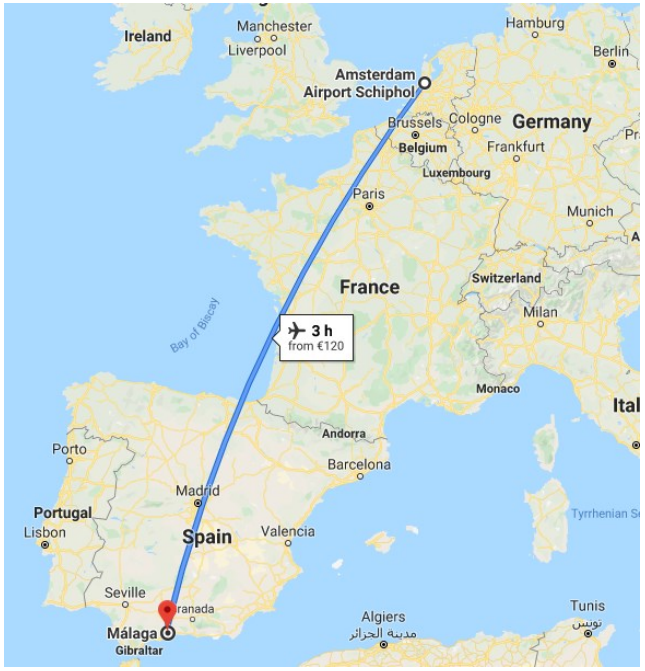
F100 e-BLI







Amsterdam - Munich
371 NM



Amsterdam - Malaga
1013 NM

Results - Regional aircraft with BLI

- Impact on operator costs, revenue and CO2 for AMS-MUC (371 NM):

Component	F100	F100 BLI	F100 e-BLI
Pax transported [-]	109	109	109
Block fuel [kg]	2521	2369	2395
Annual revenue [$]	33.5M	32.7M	32.8M
Total cost [$/BH]	8914	8985	9074
Cost per flight [$]	12034	12130	12250
Annual costs [$]	31.85M	31.1M	31.5M
Block CO2 [kg]	7960	7486	7571
RF at year 30 [µW/m2]	3.27	3.19	3.20
ATR [µK]	1.19	1.14	1.15
Annual profit [$]	1.65M	1.6M	1.3M

- F100 BLI and e-BLI versions both have higher depreciation and maintenance costs than F100
- Fuel costs are lower for both, although F100 e-BLI has higher fuel consumption and costs than F100 BLI
- Improvement in weight and efficiency improves fuel burn and costs, but fuel only 10-15% of total costs for short range missions
- F100 e-BLI 160 $/BH costlier than F100, with 20% lower profit at same ticket fare

Results - Regional aircraft with BLI

- Impact on operator costs, revenue and CO2 for Amsterdam - Malaga(1013 NM):

Component	F100	F100 BLI	F100 e-BLI
Pax transported [-]	109	109	**106**
Block fuel [kg]	5390	5101	5165
Annual revenue [$]	45.0M	44.7M	44.8M
Total cost [$/BH]	6900	6864	6933
Cost per flight [$]	19458	19356	19551
Annual costs [$]	43.4M	42.8M	43.5M
Block CO2 [kg]	17026	16119	16321
RF at year 30 [µW/m2]	9.8	9.62	9.67
ATR [µK]	3.31	3.21	3.24
Annual profit [$]	1.6M	1.9M	1.3M

- F100 e-BLI unable to transport same payload as F100 over 1000 NM
- Improvements in specific power of electric machinery for longer ranges essential for competitive operation
- Reduction in CO2 observed but not extreme due to hybrid architecture (aircraft still partly uses gas-turbines)

Conclusions

- Hybrid-electric flight can reduce carbon emissions but needs to be matched to practical and realistic insights from integrator and operator perspectives
- The Operator Technology Integrator Simulator is an excellent tool for assessing innovations in aircraft design – showing the Operator direct implications
- Lot of work still needed to achieve aircraft that can out-compete conventional aircraft – light weight and more efficient integration in aircraft designs
- Challenge to get 'clean' aircraft with same payload-range capabilities – practical combinations only possible with right development in technologies
- Hybrid-electric aircraft will not be cheaper than current aircraft – neither to buy nor to operate (at least not in the beginning)

Contact details

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