Impact of hybrid electric aircraft on contrail formation

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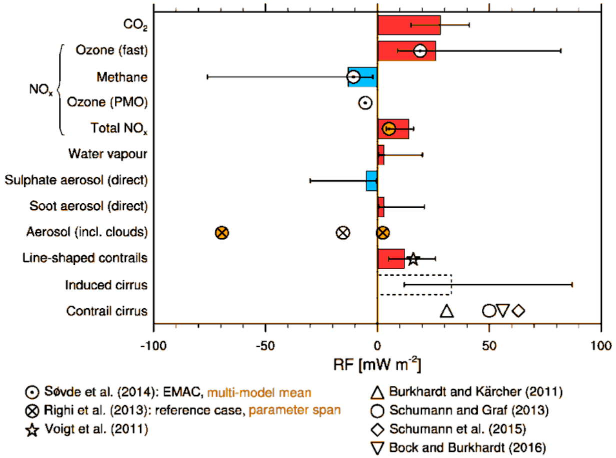
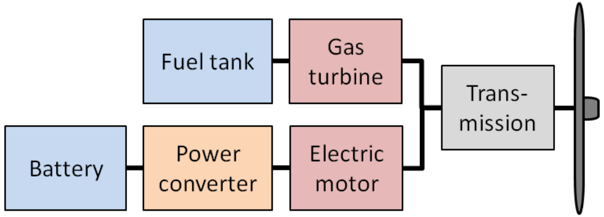
Introduction

- Aviation contributes 5% to the anthropogenic warming effects
- Contrails' effects are short but large
- Operational flexibility of parallel hybrid electric concept provides possibility to reduce contrail formation in contrail-sensitive regions



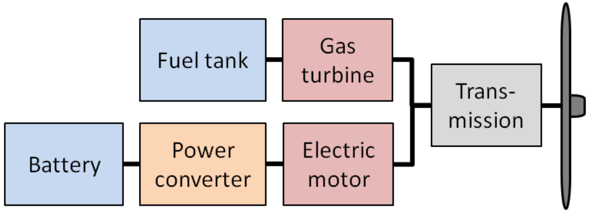
Grewe et al, 2017



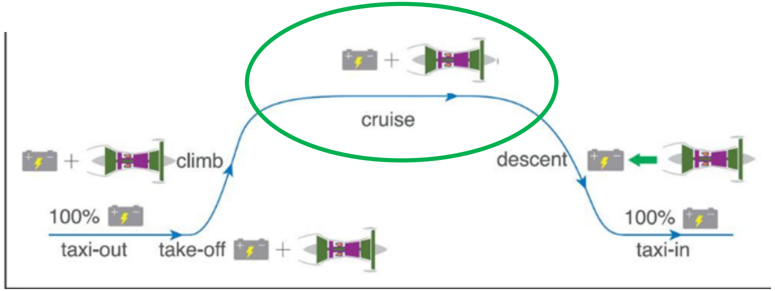
Parallel architecture

Baseline aircraft/engine

- Airbus A320neo type
- CFM LEAP-1A engine
- Technology level 2030 for electric system
- Cruise condition with given thrust



Parameter:	**2030**
Battery energy density	600 Wh/kg
Maximum electric motor efficiency	97.5%



van Holsteijn et al, “Finding the Operating Limits and Optimal Configuration of an Electrically Assisted Turbofan”, ASME TurboExpo 2020, Sep 2020.

Methodology overview

Inputs

Hybrid electric aircraft (HEA):
- Turbofan engine
- 2030 battery technology
- Power management strategy

EMAC/CONTRAIL submodel*

Derive Schmidt Appleman Criterion (SAC) for HEA

Calculate potential contrail coverage (PCC) vs. hybridization

Earth system model (EMAC)**:
- Horizontal grid of 310 km
- Vertical resolution of 1 km
- Time step 12 mins

Results

Analyze changes of PCC by HEA:
- Local effects
- Climatological effects
- Seasonal effects

*supplement of Grewe et al., 2014
**Jöckel et al. 2010

Derivation of Schmidt Appleman Criterion for HEA

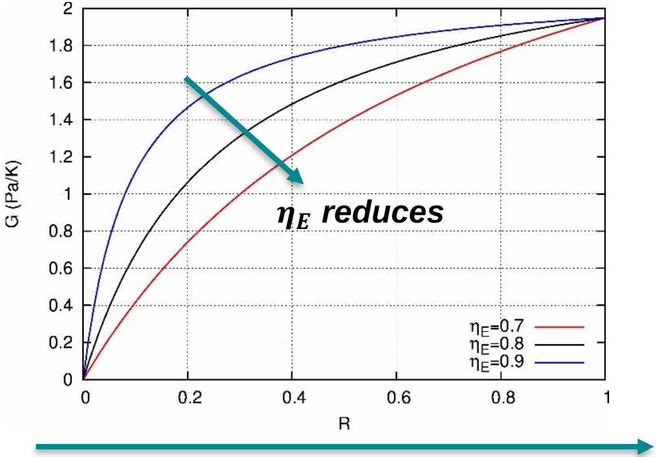
- $F \cdot V = \underbrace{\eta_k \cdot \dot{m}_f \cdot Q}_{\text{Kerosene}} + \underbrace{\eta_E \cdot P_E}_{\text{Electricity}}$

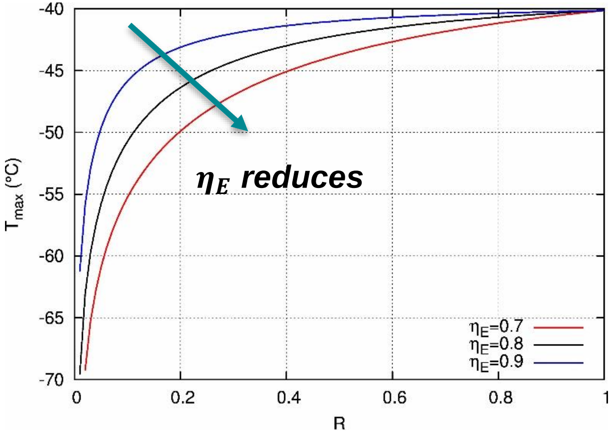
- $G = \frac{c_p p_a}{\varepsilon} \frac{R \cdot EIH_2O}{R \cdot (1-\eta_k)Q + (1-R)(1-\eta_E)Q_E^0}$

- $R := \frac{\dot{m}_f}{\dot{m}_{fmax}}, Q_E^0 := Q(\eta_k/\eta_E)$

Variable	Value	Variable	Value
Baseline propulsion efficiency (η_k)	0.4	Water emission index (EIH2O)	1.25
Lower heating value (Q), MJ/kg	43.2	Molar mass ration of water vapor and dry air (ε)	0.622

Threshold of contrail formation by SAC at 250 hPa



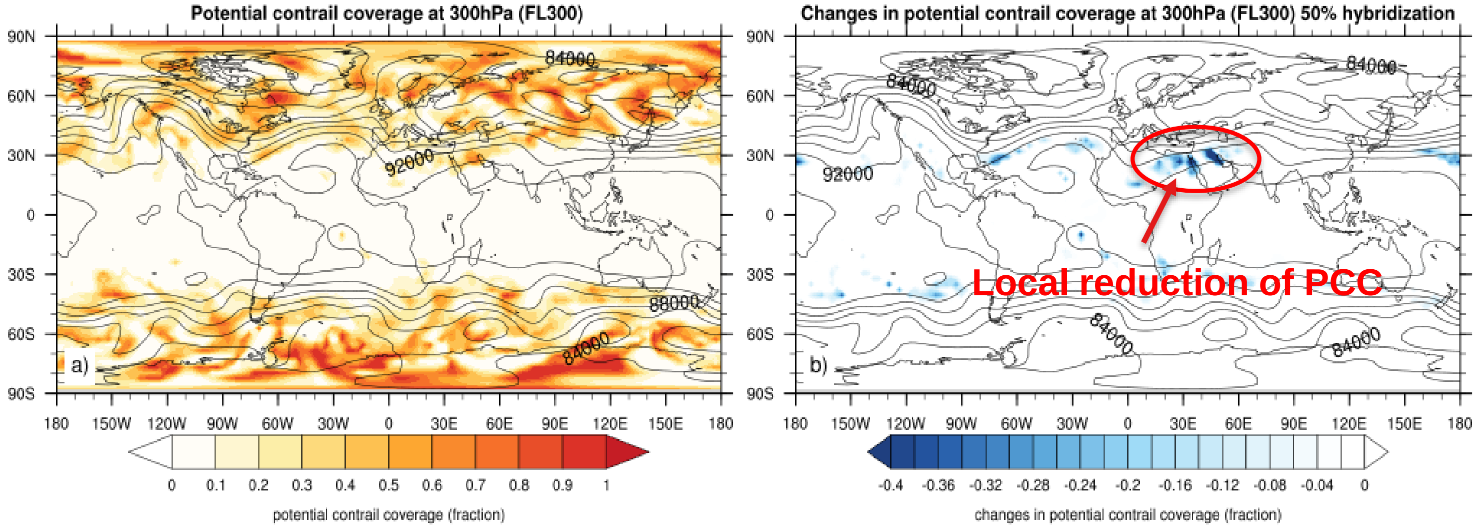


Pure electric propulsion

Pure kerosene propulsion

- η_E is the efficiency of the electrical powertrain
- The slope (G) decreases as increasing the electrical power
- The temperature threshold (Tmax) of HEA to form contrails reduces as increasing the electrical power
- In most situations, a large percentage of electric power is required for contrail avoidance

Local changes of potential contrail coverage (PCC)


Potential contrail coverage at 300hPa (FL300)

Changes in potential contrail coverage at 300hPa (FL300) 50% hybridization

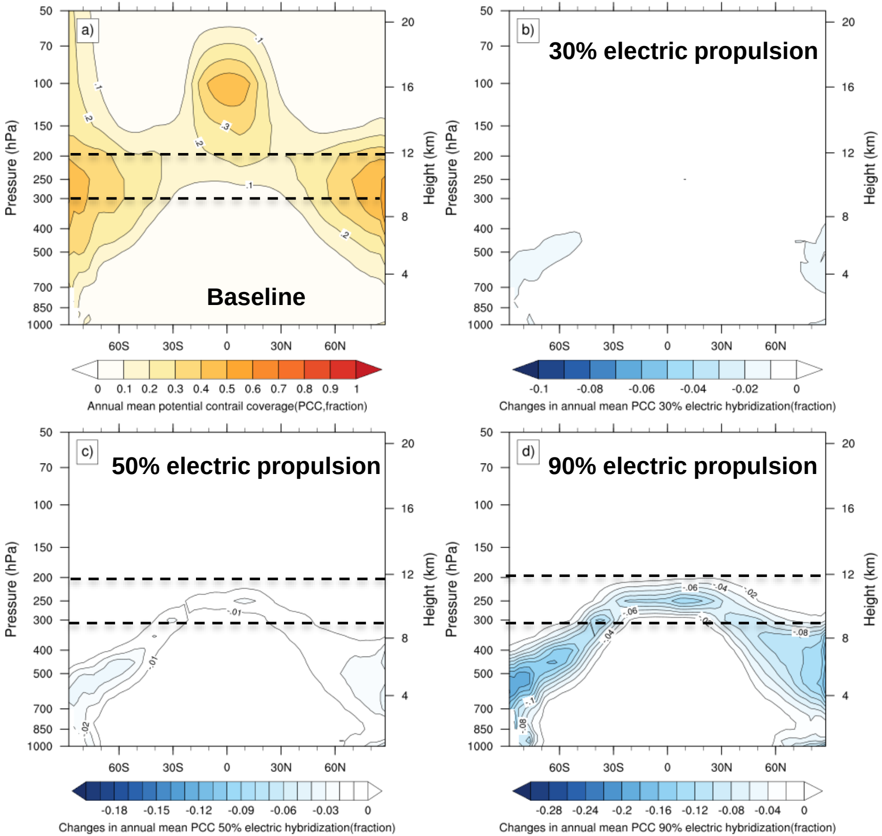
Local reduction of PCC

Baseline

50% electric power

- At FL300, 50% hydration: the reduction in PCC is at 30°N and 40°S and localized

Climatological effects on PCC



- Annual mean of one year simulation results
- Figure a)->d): baseline aircraft->30%->50%-90%
- Hybrid electric aircraft tends to form contrails at higher altitude

Conclusions

- The operational flexibility of hybrid-electric aircraft (HEA) offers opportunities in contrail avoidance.
- The HEA requires lower atmospheric temperatures to form contrails than the conventional aircraft.
- To avoid contrails at cruise altitude, a large fraction of electric power (more the 50% in the current study) is required.
- The reduction in PCC can be achieved locally.

Discussions and future work

- The current work doesn’t not consider the actual flight routes, which will be included in the subsequent research
- The derivation of SAC is valid for hybrid electric system with battery. For other forms of hybridization, e.g., fuel cell, a different SAC should be derived
- In case of designing a HEA system for contrail avoidance, a proper power management strategy is required at the first place.

Thank you!

Questions?