A realistic view on sustainable aviation

“There is no quick fix”

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- TU Delft
- TU Eindhoven
- Maastricht
- Tilburg
- Utrecht
- Rotterdam
- Amsterdam
- Leiden
- Wageningen
- Nijmegen
- U Twente
- Groningen
Delft University of Technology was founded in 1842 by King William II. It is the oldest and largest University of Technology in the Netherlands. The 8 faculties offer 16 Bachelor’s courses and 29 Master’s courses in comprehensive programmes of education and research.
Aerospace Engineering

2,700 students (BSc + MSc)
400 PhD students
11 research groups
Extensive experimental infrastructure
Nr. 4 in the Shanghai Academic ranking of world Universities
Spot the differences

1967

1987

2017

Sources: airliners.net, @zhangmx969, Shimin Gu
Content

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• The cost of an extra kg
• Developments so far
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Snowball effect in aviation

1 kg more mass
- 1 kg more lift required
  - lift is not for free -> more aerodynamic drag
  - more drag -> more thrust
  - more thrust -> bigger engines
    -> more fuel

- more mass
Snowball effect in aviation

Quick estimate numerical value snowball factor Airbus A380:

\[
\frac{\text{Maximum take-off weight}}{\text{Payload}} = \frac{548,000 \text{ kg}}{83,000 \text{ kg}} = 6.60
\]
Cost of an extra kg

Data Airbus A380

Maximum take-off mass 548,000 kg
Payload 83,000 kg
Fuel capacity 190,000 kg
Range 14,000 km
Cruising speed 945 km/hr

usage 16 hr per day
365 days per year
30 years of service
= 175,200 hrs of service
Cost of an extra kg

Data kerosene

- density: 0.81 kg/liter
- fuel tank capacity: 234,568 liter
- price: 0.52 US$/liter
Cost of an extra kg

Data fuel consumption

Flight duration 14.8 hr

Fuel consumption 15,833 liter/hr

Fuel consumption 0.0289 liter/hr.kg
(in liters per hr per kg of aircraft)
Cost of an extra kg

Multiplication factor

$$6.60 \times \text{(snowball factor)}$$
$$16 \times \text{(hr per day)}$$
$$365 \times \text{(days per year)}$$
$$30 \times \text{(years in service)}$$

$$1,156,742 \text{ hr}$$
Cost of an extra kg

=> 1,156,742 hr x 0.0289 liter/hr.kg x 0.52 US$/liter

= 17,383.52 US$/kg

This is equivalent to 406 grams of pure gold
Developments so far – fuel consumption
Developments so far – fuel consumption

![Graph showing fuel consumption over the years.](image)

- Short haul (900-1200 km)
- Short haul (1900 km)
- Medium haul (4000-5560 km)
- Long haul (9300-14100 km)

Equation: $y = -0.0266x + 55.696$

$R^2 = 0.6558$
Developments so far – fuel consumption
Developments so far - noise

Lateral noise level standardised to 500 kN in EPNdB

-25 dB
(-80%)

Year of certification


80 90 100 110 120

707-120 727-100 A300 737-300 A340-600 A380-842 787-8
Developments so far - manufacturers

Competitive widebody positioning

- 747-8 (Boeing)
- 777-9X
- 777-300ER
- 777-8X
- 787-10X
- 787-9
- 787-8
- A380 (Airbus)
- A350-1000
- A350-900
- A350-800
- A330-300
- A330-200
Developments so far - manufacturers

Boeing product line-up vs. the competition

Superior value, efficient market coverage

Airbus
- A380
- A350-1000
- A350-900
- A330-300
- A330-200
- A321neo
- A320neo
- A319neo

Future Boeing
- 747-8
- 777-9X
- 777-8X
- 787-10
- 787-9
- 787-8
- 737 MAX 9
- 737 MAX 8
- 737 MAX 7
Developments so far - airlines

Net profit per ticket

Source: IATA
Electric Aircraft

Source: Pipistrel, Airbus
Electric Aircraft

Source: Hartzellprop.com
Electric Aircraft

![Graph comparing volumetric and gravimetric energy densities of various fuels](image)

- **Volumetric Energy Density (MJ/liter)**
  - Jet A / Jet A-1
  - Biodiesel
  - F-T kerosene
  - Ethanol
  - LNG
  - Methanol
  - Lithium Battery
  - Liquid hydrogen

- **Gravimetric Energy Density (MJ/kg)**
Electric Aircraft

Electric flight will be there!

However:
- It will not be the next generation aircraft
- It will come via two routes
  1. General aviation
  2. Hybrid passenger aircraft
Alternative fuels

Source: KLM
Alternative fuels

Area-averaged probe
Measurement of ICAO LTO emissions by DLR
Direct particle size and number

- Cessna Citation II - P&W JT15Ds
- GTL 0-50% in two base fuels for ground testing
- GTL 0-90% in flight testing
Alternative fuels
Alternative fuels

- Cessna Citation II - P&W JT15Ds
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Area-averaged probe
Measurement of ICAO LTO emissions by DLR
Direct particle size and number

Soot filters in undiluted sampling line
Alternative fuels
Alternative fuels

90% GTL
Alternative fuels

Is hydrogen an option?

Yes, you can use hydrogen in jet engines. But you will need some modifications.

A better alternative would be to make use of hydrogen fuel cells and electric motors.
New configurations
New configurations

Source: DLR
New configurations
New configurations
New configurations

Sources: GE, NASA, Entrevoisins, NLR
New configurations

Sources: NASA
New configurations – quick fixes
New configurations – quick fixes
New configurations – quick fixes
New configurations – quick fixes
Conclusions

There is no quick fix

We need more research and development

We replace old aircraft sooner (fleet renewal)

We need to look into alternative “drop-in” fuels

We need better procedures (Single European Sky)

We need to compensate (CORSIA and beyond)

We need stronger incentives (legislation + societal pressure)

We need to limit the growth, preferably reduce soon