Framtidens flygmotorer – hur miljövänliga kan de bli?
Flyget i en klimatneutral framtid
Anders Lundbladh Adj. Prof. Framdrivningsteknik 2017-01-20
What is the best aircraft & engine?

**Airbus A320NEO**

**MIT Daedalus**

<table>
<thead>
<tr>
<th>Powerplant</th>
<th>2 PW Geared Turbofans</th>
<th>1 x Kanellos Kanellopoulos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>38%</td>
<td>17%</td>
</tr>
<tr>
<td>Weight/seat</td>
<td>527 kg</td>
<td>104 kg</td>
</tr>
<tr>
<td>Lift/drag</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td>Range</td>
<td>7400 km + reserves</td>
<td>115 km</td>
</tr>
<tr>
<td>Speed</td>
<td>830 km/h</td>
<td>29 km/h</td>
</tr>
<tr>
<td>Fuel energy</td>
<td>720 J/m/pax</td>
<td>130 J/m/pax</td>
</tr>
<tr>
<td>Safety</td>
<td>2 500 000 000 km/hull loss</td>
<td>115 km/hull loss</td>
</tr>
</tbody>
</table>
Aviation’s sustainability challenge

More than 99.9% of all aircraft fuel today came from fossil sources 2015

> 6.6% of crude oil to refineries is used to produce jet fuel

2.6% of anthropogenic carbon dioxide and 3 - 8% of climate forcing 2005 came from aviation

Noise affected areas around existing airports decreased substantially 1970-2000, and have since been relatively constant in size

Nitrogen Oxide emissions adds to regional acidification, in Sweden 4.2% from aviation

Metals for aircraft and engines only exists in finite extractable amounts.

Of the world production aviation industry uses:

> rhenium: 60% for turbines in jet engines

> cobalt: 30%, nickel: 4%, aluminum, vanadium: approx. 1%

• Air travel is expected to increase 2-3 times in the next 20 years

> Historically the jet fuel consumption has increased 2-3% per year.

A Vision to Limit the Climate Impact of Aviation

Global Warming Potential 100 years

- Air transport annual growth
- Constant efficiency
- Biofuels from 2020. Amount as below.
- Efficiency +1.5% per year
- Altitude adaption implemented 2025-2035
- Biofuels implemented 2020-2070

CO₂-eff. billion tonnes

CO₂ alone

Including altitude effects 1.9 x CO₂

10% of 2.4°C goal

5% of 1.5°C goal

4.5%

3%

2%

1990 2010 2030 2050 2070

Air transport annual growth

Efficiency +1.5% per year

Altitude adaption implemented 2025-2035

Biofuels implemented 2020-2070
The Turbofan Propulsion System

Action: Momentum Increase

Reaction: Thrust

Data: GKN modeling TRENT XWB at cruise
Illustration: © Airbus 2016 (modified)

250 m/s

350 m/s

440 m/s

350 m/s

250 m/s
Turbofan Functions

Illustration: © Rolls-Royce 2016 (modified)

Fan (Propulsor)  Compressor  Combustor  Core  Turbine
Major Innovations for Transport Propulsion

8 out of 10 major innovations added design parameters via decoupling of functions

Turbojet
Axial Compressor, Two Spool
Single Stage Fan
Geared Fan
Bypass Turbofan, Cooled Turbine
High Bypass Turbofan
Three Spool
Carbon fiber fan

Passenger & freight aircraft >50 Seats

First flight on production A/C

Core technology
Propulsor technology

Geared Fan w. High Speed Booster

Specific fuel consumption @cruise mg/Ns

1940 1960 1980 2000 2020
How does aviation energy need compare over time?

Aviation improving faster … than road traffic

Trains are more efficient but at status quo …

unequalled for freight

Data for Sweden from the Swedish transportation authorities.

Myndigheten för Trafikanalyser: Uppföljning av de transportpolitiska målen Rapport 2014:5
ULTIMATE: innovations to reduce fuel consumption by 34% (engine alone) 75% (engine/aircraft/operations)

Exergy: the potential to do work

Fuel (100%)

Thrust 40%

Exhaust thermal loss ~20%

Exhaust kinetic loss ~10%

Turbomachinery loss ~10%

Combustor thermodynamic loss ~20%

Data: GKN modeling of TRENT XWB & estimated from Grönstedt et.al. 2014, illustration © Airbus 2016 (modified)
Piston Turbofan Hybrid

Topping cycle with free running piston engine and compressor

- Three 130 degree V12-engines
- Four rear cylinders are fired and provide high pressure air to a conventional combustor and turbine.
- Turbine drives fan through a star gearbox.
- 35% lower fuel consumption than year 2000 technology
- 40% heavier than geared turbofan

Part Speed Operation?
Reliability?

From Kaiser, Seitz, Donnnerhack & Lundbladh 2016
Improve aircraft – energy integration

Turboelectric propulsion

- Transfer power from main engines to a rear propulsor
- Rear propulsor options: propeller or a ducted fan
- Reduce kinetic losses by accelerating boundary layer air
  - More thrust accelerating from lower velocity
- Potential for 5-15% reduced fuel consumption

From Lundbladh, Larsson & Grönstedt 2013, Petrusson 2016

2 x Turbofans with integrated generators
4 MW Electric motor

Boundary layer low momentum air

Wake acceleration

Ground clearance? Electric system weight?

Mach

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