Development Challenges of Distributive Propulsion Systems for Advanced Aeroplanes

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**Alternative variants of DPS**

**architecture № 1** – mechanical drive of propulsive fans 
power offtaking from free power turbine, installed on the core exit, transfers through transmission (shafts and gearboxes, if necessary) to fan rotor (similar architecture is used in helicopters)

**architecture № 2** – gas drive of propulsive fans 
gas offtaking from core exit transfers through gas lines to individual free power turbines, connected with their fans

**architecture № 3** – electrical drive of propulsive fans 
electrogenerator, producing electricity for driving of individual electromotor, connecting by shafts with their fans, is installed on the shaft of free power turbine, located on the core exit. Power transmission for motors is carried out by electric wiring (similar architecture is realized on ground gas-turbine power stations)
**Outboard engine core (OEC)**

Structurally outboard engine core is conventional pure turbojet with one- or two-shafts (depending on required compressor pressure ratio of OEC).

**Propulsive outboard fan (OF)**

OF depending on method of power transmission for it may be represented as:

- outboard fan is implemented as well as conventional turbofan, but is located out of core and has individual casing with bearings, intake, nozzle and nacelle (if necessary). Relative to bearing the fan may be installed in cantilever, and at that opposite fan shaft extension is connected with output shaft of intermediate gearbox, changing the power transmission direction by $90^\circ$. Such fan is used for architecture № 1

- outboard turbo-fan, represented as fan and turbine driving the fan, installed out of core and completed in one module to decrease the length and mass of shaft between fan and individual power turbine. Gas, required for driving of fan turbine, is offtaken from outboard engine core and is transferred to it by gas line. Such turbo-fan is used in the architecture № 2. Also architecture with turbine installed on the fan tip may be considered

- outboard electrofan, converting electrical power in engine thrust and consisting of in fact fan and electric motor for fan driving, also located out of core and realized in one module to decrease of transmission mass. Electrical power required for electromotor drive is generated by electr ogenerator, installed on the free power turbine shaft after exit of outboard core and is transferred to it by electric line. Electrofan is used in the architecture № 3
## Preliminary comparison

- **Mechanical driven DPS architecture is the most feasible from point of view of minimal technical risk of implementation of different variants of propulsive fans drive.**

### Pros and cons of different type of drives

<table>
<thead>
<tr>
<th>Type of drive</th>
<th>Pros</th>
<th>Cons</th>
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</table>
| **Mechanical** | Proven engineering solutions | • Losses in gear pairs and shaft bearings  
• Complicated oil system  
• Total pressure losses behind of fan (because of location of driven shaft in the duct behind of fan) |
| **Gas** | Decrease of core length | • Losses in long and big gas ducts  
• Gas ducts with high temperatures (up to ~1400K)  
• Complicated turbine and fan structures (at location of turbine on the fan blades tip)  
• Complicated structure due to complex control system |
| **Electrical** | • Optimal rate of core  
• Simple control  
• Independent location of core and OF on the aeroplane | • High weight of electrical units (total weight of PS approximately is 3 times higher than one of the mechanical driven PS)  
• Complicated cooling system (cryogenic with heat exchangers)  
• Presence of redundant power sources  
• Power inverters and distributers |

Predicted for 2025–2030 time period specific performance of electrical equipment (electrogenerators and electromotors for electrical driven DPS) with power about $\sim 10^{1–2}$ MW don't provide competitiveness of DPS with electrical driven OF - such DPS was found about $\sim 3$ times heavier than mechanical driven DPS, that is why fuel efficiency of aeroplane with this DPS will be worse than existing aeroplanes. Electrical driven DPS will be competitive relating to mechanical and gas driven DPS in case of significant decreasing of specific weight of electroequipment.
Possible mechanical driven DPS architectures

- architecture with outboard engine core and fans («OF+Core», a)
- architecture with turbofan and offtake from it the mechanical power to drive two OF («OF+turbofan», b) - core is “embedded” in turbofan, and operates as generator of mechanical power for driving of three OF

As gearing losses are about 1-2%, it will require to install oil cooling system (pumps, heat exchangers, oil tanks)

- Transmission sufficiently high power through single gearing is impossible, therefore different variants of power training are considered
- DPS with OF will require bearings of fans and free power turbine, taking high axial loadings, because of they are installed on the different shafts which results PS weight increase.

*core is indicated on the Figure small device, in reality it has big size turbine, because of full power are offtaken from the turbine.
Alternative variants of DPS location

Relative location of propulsive fans nacelles of DPS

a) - isolated location with short distance of each other
   (in the train shafts between OF pass through the pylons)
b) - sided fans
c) - fans joined with core in a common nacelle

Different location OF and turbofan

Choice of the variant depends on both obtaining losses with length and weight of whole structure

In case of failure of a one fan inlet flow distortion may be extend to neighboring modules
Maximal impact on engine SFC has losses at fan inlet, because of fan generates most part of thrust

Losses has not impact on core due to high core pressure ratio

Problems relating to development of aeroplanes with DPS for separate discussion

- complexity of cabin design taking into account its emergency escape
- definition of aircraft lift surfaces
- complication of passenger capacity sizing of vehicle
- ...

DisPURSAL - Distributed MultiFan Concept – Design Description

- **Airframe aerodynamic and DP features**
  - $C_L \approx 0.3$ due to low wing loading (332kg/m²)
  - Pragmatic improvement of aerodynamic efficiency (10% rel. to 2035R)
  - Same level of SFC as 2035R

- **Outcome**
  - -3.8% block fuel relative to 2035R and -32% relative to SoAR

<table>
<thead>
<tr>
<th></th>
<th>2035R</th>
<th>DMFC*</th>
<th>Δ [%]</th>
</tr>
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<tbody>
<tr>
<td>Fuselage Length</td>
<td>m</td>
<td>67.0</td>
<td>37.0</td>
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<tr>
<td>Wing Span</td>
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<tr>
<td>MTOW</td>
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<tr>
<td>OWE</td>
<td>kg</td>
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<tr>
<td>Wing Ref. Area $S_{ref}$</td>
<td>m²</td>
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<tr>
<td>MTOW$/S_{ref}$</td>
<td>kg/m²</td>
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<td>Lift-to-Drag Ratio</td>
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<td>24.0</td>
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<tr>
<td>M0.80 $C_L=0.5$</td>
<td></td>
<td>(5)</td>
<td>(3)</td>
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<tr>
<td>$C_L=0.0$</td>
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<td>24.0</td>
<td>6.7</td>
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<tr>
<td>Block Fuel Burn,</td>
<td>kg</td>
<td>41690</td>
<td>40100</td>
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<tr>
<td>4800 nm, 340 PAX</td>
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*if BLI / wake-filling effects are not accounted
New CO2 emission Standard (Annex 16, Vol.III) metric value (MV) [1]

\[ \text{MV}_{\text{CO2}} = \frac{1}{(\text{SAR} \times \text{RGF}^{0.24})} \] [1]


<table>
<thead>
<tr>
<th></th>
<th>SoAR (2000)</th>
<th>2035R</th>
<th>PFC</th>
<th>DMFC</th>
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<tr>
<td>(1/SAR)\text{mean}</td>
<td>1</td>
<td>0.65</td>
<td>0.53</td>
<td>0.6</td>
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<tr>
<td>RGF</td>
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<td>1</td>
<td>1</td>
<td>0.79</td>
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<tr>
<td>MV\text{CO2}</td>
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<td>0.65</td>
<td>0.53</td>
<td>0.63</td>
</tr>
</tbody>
</table>

\[ \text{MV}_{\text{CO2}} \text{ reduction} \]

- PFC - 47%          DMFC - 37% (relative to SoAR)
- PFC - 18.5%        DMFC - 3% (relative to 2035R)
Growing stringency of requirements of environmental and fuel efficiencies demands discovery of new engineering solutions. Development of aeroplane like HWB with DPS is a one of them.

DPS is well-handled just for HWB due to having large surfaces from which boundary layer may be ingested.

Mechanical driven DPS architecture is the most feasible from point of view of minimal technical risk of implementation of different variants of propulsive fans driving.

Final selection of method of power training from core (or turbofan) to OF requires comprehensive experimental investigations and 3D calculations.

Application of turboelectric and full electric DPS are seemed in the far-term outlook, when will be available and sufficiently studied superconductivity technologies, including superconductor cooling, improved electrical equipment, etc.