CENTRAL AEROHYDRODYNAMIC INSTITUTE NAMED AFTER PROFESSOR N.E. ZHUKOVSKY

# TsAGI RESEARCH CAPABILITIES TO ADDRESS AVIATION ENVIRONMENTAL IMPACT ISSUE


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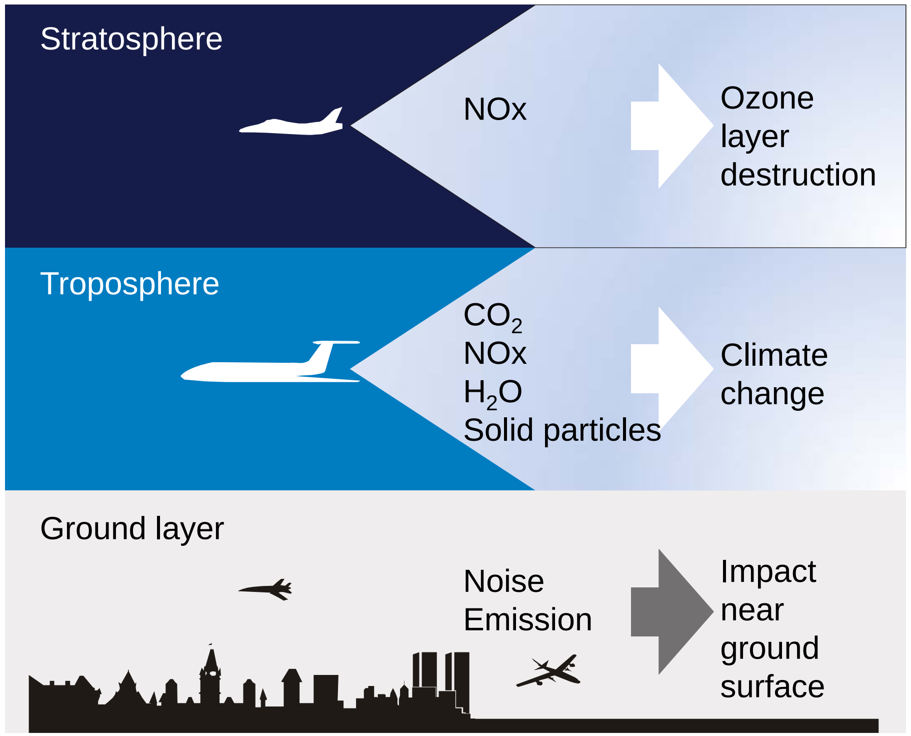
# Contents

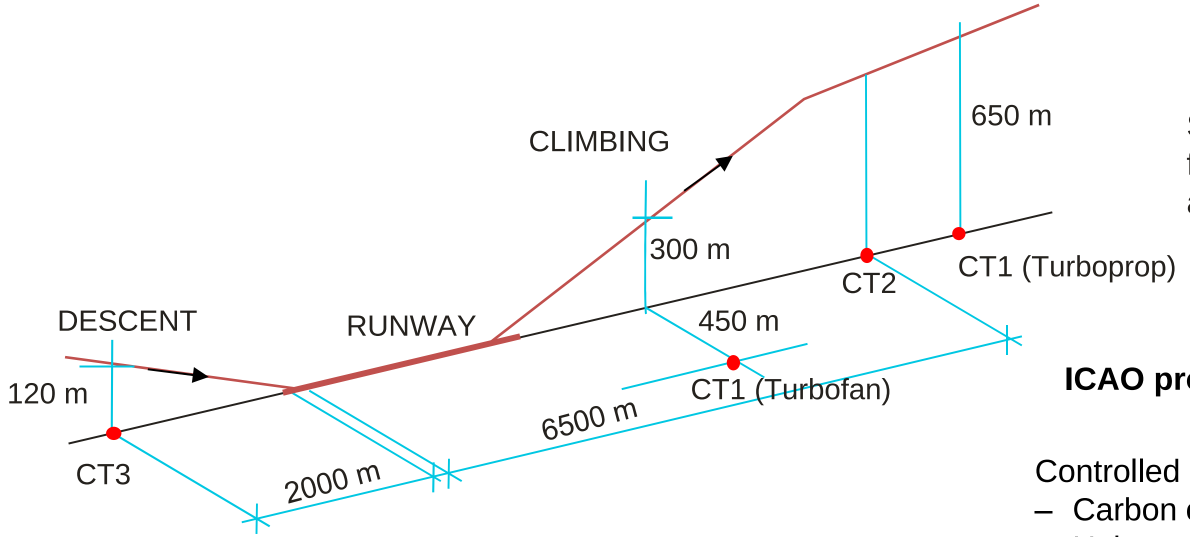
- AVIATION ENVIRONMENT ISSUES
- NOISE
- SONIC BOOM
- EMISSION
- ALTERNATIVE AVIATION FUEL


# Aviation Impact on Environment

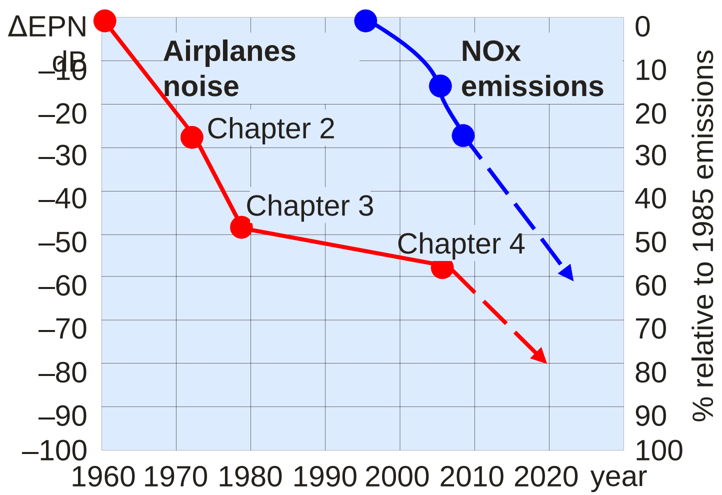
| | | |
|---|---|---|
| Aircraft Environment Issues | Noise | ➢ Health deterioration<br>➢ Hearing impairment<br>➢ Disturbances of vocal communication |
| | Emission | ➢ Respiratory disorders<br>➢ Toxic symptoms<br>➢ Discomfort |
| | Sonic boom | ➢ Orientation response of people<br>➢ Starting<br>➢ Sleep disruption |
| | Greenhouse gases emissions, contrails | ➢ Global warming<br>➢ Climate change |
| | Airport environment | ➢ Pollution |



# ICAO Requirements in Airport Proximity



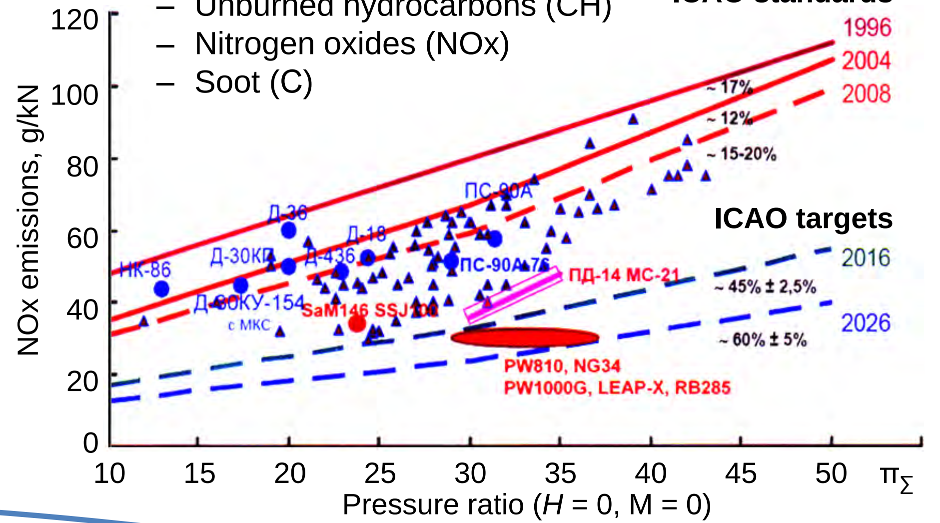

Spatial location of control points (CP) for acoustic certification of commercial airplanes



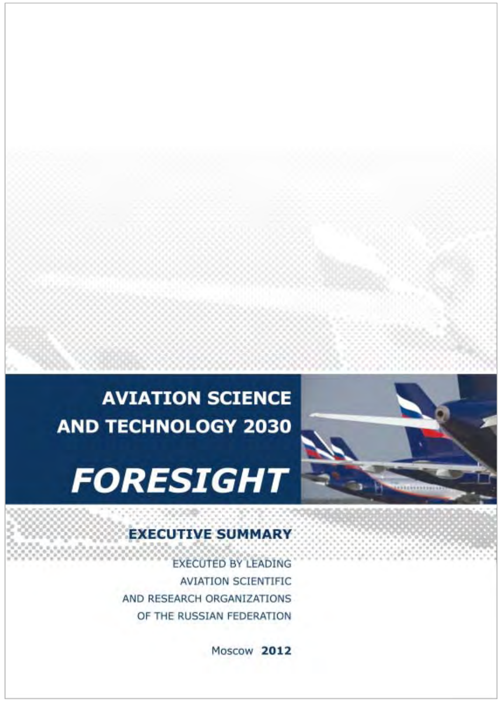

**ICAO proposals to toughen NOx emissions during take-off and landing**

Controlled combustion products:

- Carbon oxide (CO)
- Unburned hydrocarbons (CH)
- Nitrogen oxides (NOx)
- Soot (C)



# Environment Target Goals for the Russian Aviation




| Target goals | Baseline (2010) | Dynamics of target goals | | | |
|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | 2030 |
| Accidents reduction | 1 | 2.5 | 5.0 | 7.0 | 8.5 |
| Noise reduction relatively to ICAO Chapter 4 (by EPN dB) | 7 | 12 | 20 | 25 | 30 |
| $NO_x$ emission reduction relatively to ICAO 2008 standards (by %) | 100 (2008) | 20 | 45 | 65 | 80 |
| Fuel consumption and $CO_2$ emission reduction (by %) | 100 | 10 | 25 | 45 | 60 |

# Contents



# Aircraft Noise Sources

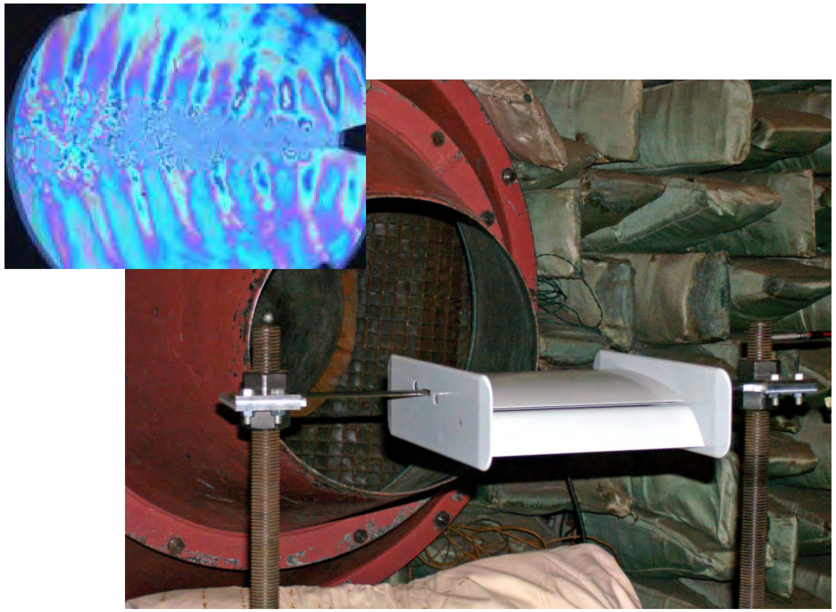
1. Jet noise 2. Inlet and aft fan noise, turbine noise 3. Airframe noise

The principal components determining the noise of a modern passenger aircraft are: fan and turbine noise, jet noise and airframe noise. All the above sources of aerodynamic noise turn out to be important at different flight stages. Only a balanced reduction of all the above sources can lead to the overall desired aircraft noise reduction.

# Acoustic Anechoic Chambers

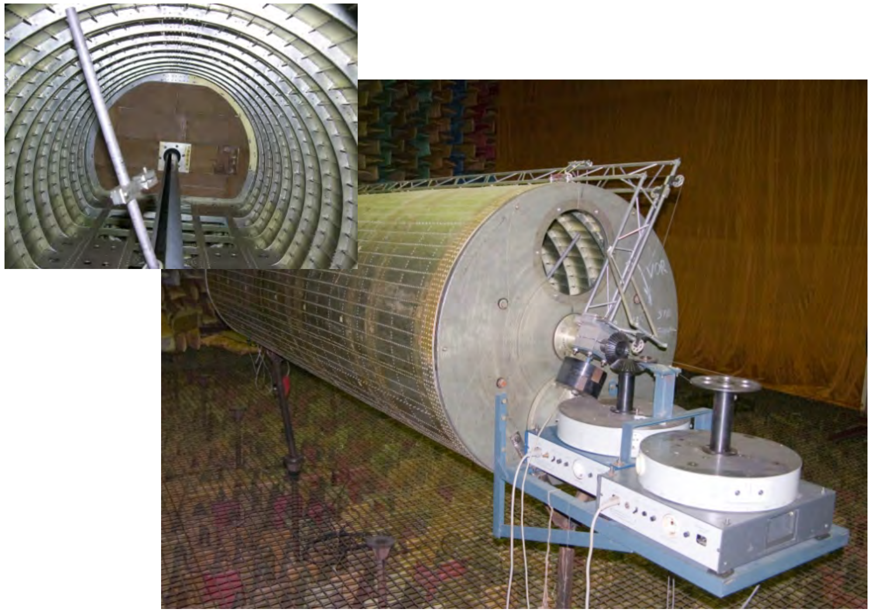
## AK-2

| | |
|---|---|
| Maximum sound pressure level | 160 dB |
| Test section volume | 211 м$^3$ |
| Test section dimensions | 9,6×5,5×4,0 м$^3$ |
| Operational frequency range | 160 – 20000 Hz |
| Stagnation temperature | 293 K |

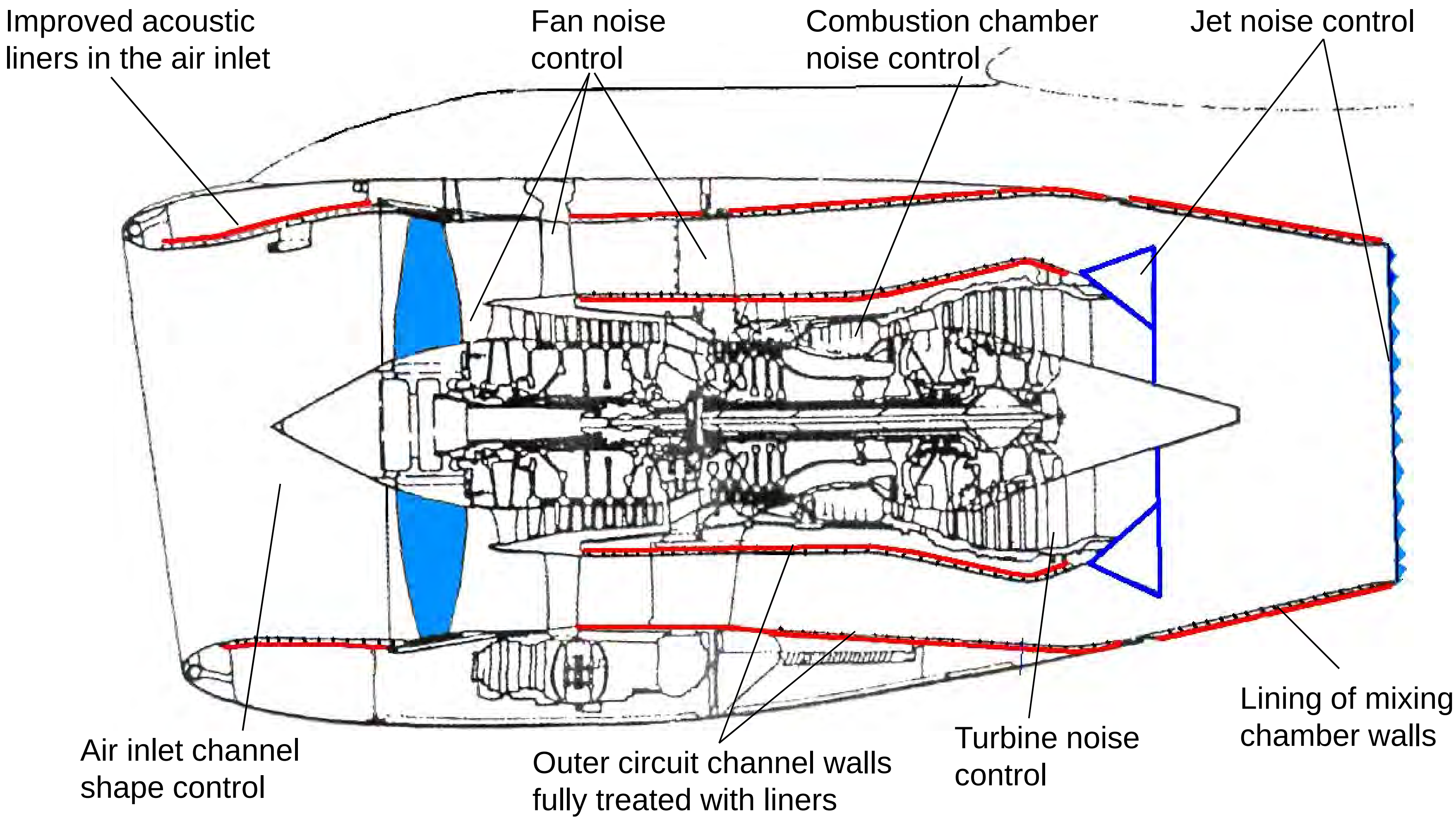


## AK-11

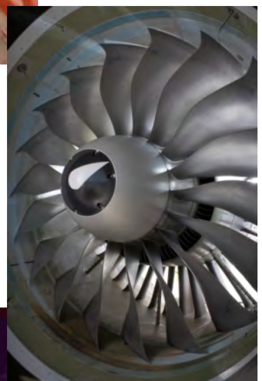
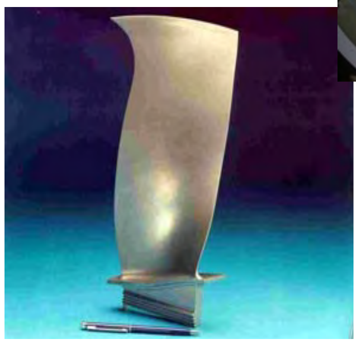
| | |
|---|---|
| Anechoic chamber (AC), m$^3$ | 14.0×11.5×8.0 |
| Free volume, m$^3$ | 12.2×9.7×6.3 |
| Reverberation chamber 1 (RC1), m$^3$ | 6.4×6.4×5.15 |
| Reverberation chamber 2 (RC2), m$^3$ | 6.6×6.4×5.15 |
| Operational frequency range, Hz | 80 … 16000 |



# Aircraft Engine Noise Reduction



# Fan Noise Reduction Methods

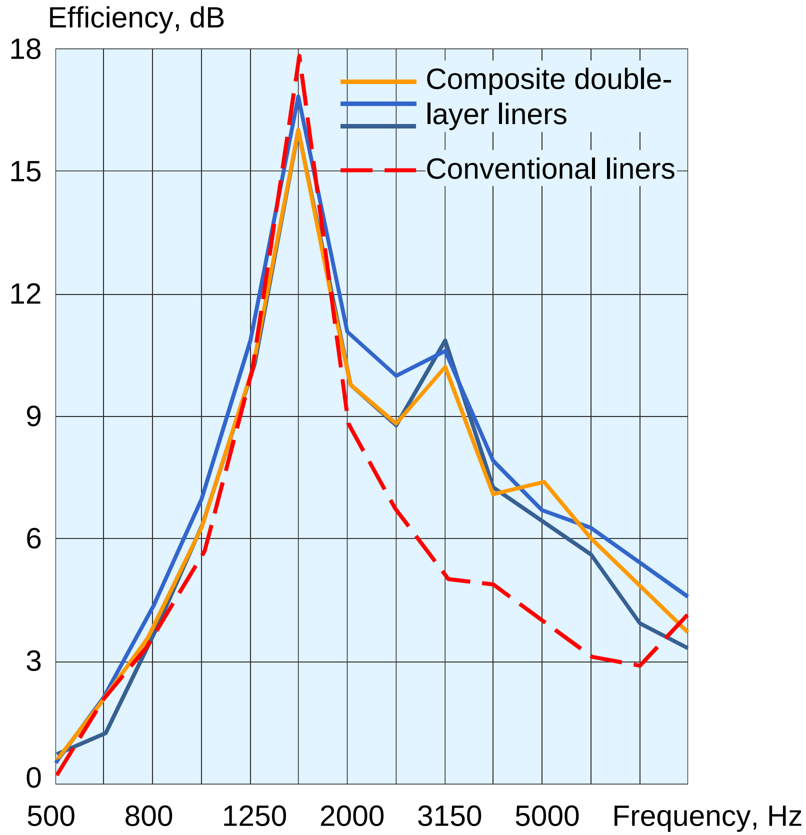




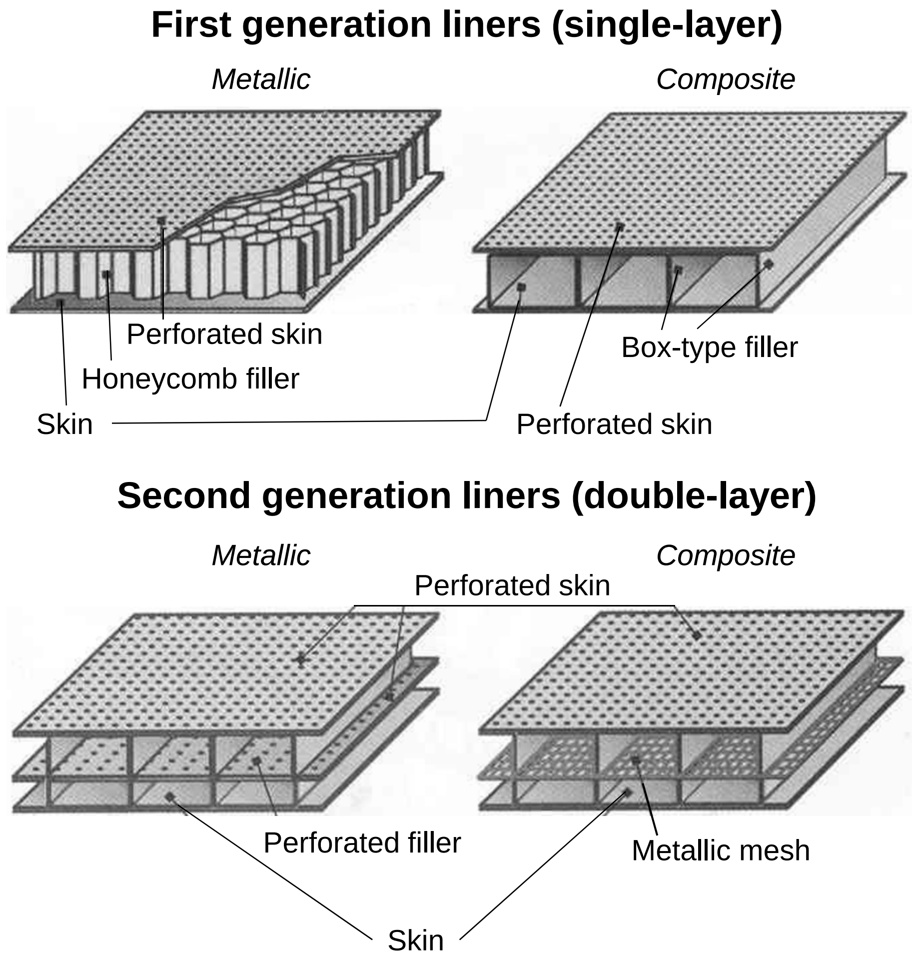
**Approach:**
- To remove or weaken shocks at the fan blades
- Simultaneous optimization of aerodynamic and acoustic performance

**Expected noise reduction:**
- Fan tone intake noise 2 to 4 dB at take-off
- Fan tone exhaust noise up to 2 dB

**Key Issues:**
- Fan aerodynamics performance
- Fan blade stability and stall margin erosion
- Manufacturing cost and complexity
- Validation of CFD prediction methods

# Engine Noise Reduction by Advanced Acoustic Liners



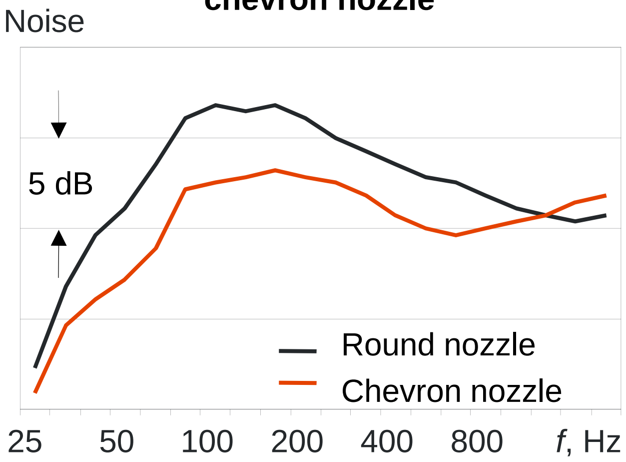
# Fan Noise Reduction by Acoustic Liners

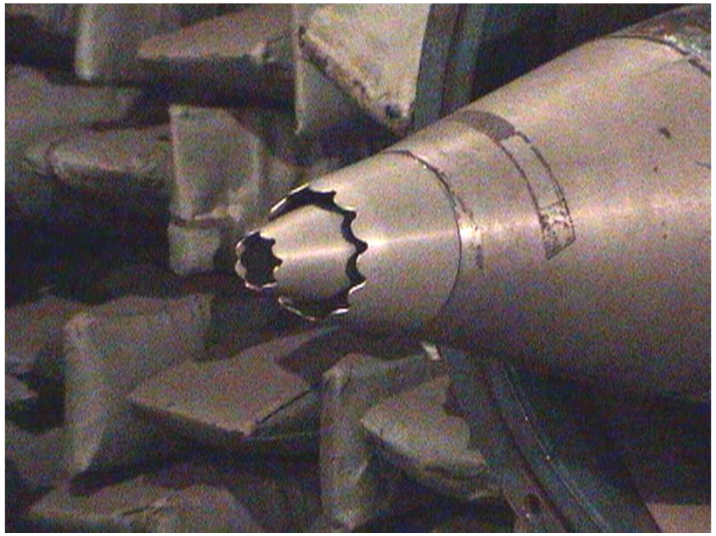
| Method | Estimated noise reduction | TRL | Main problems |
|---|---|---|---|
| Seamless air inlet liners | Suction noise: 1…4 dB<br>during approach<br>(in service with A380) | 7…9 | Improving liners manufacturing and repair technology |
| Tapered air inlets | Suction noise: ~ 3 dB | 4…6 | Aerodynamics, trade-off between cruise and climb |
| Lining of air inlet lip | Suction noise: 1…3 dB | 4…6 | Integration with anti-icing systems |
| Lining of hub surface | Acoustic power at outlet: 1…3 dB | 3…4 | Lacking full-scale verification data |

# Low Noise Nozzle Configurations

Variety of nozzle configurations are suggested for the experimental jet noise reduction

**Noise reduction of jet emanating from chevron nozzle**

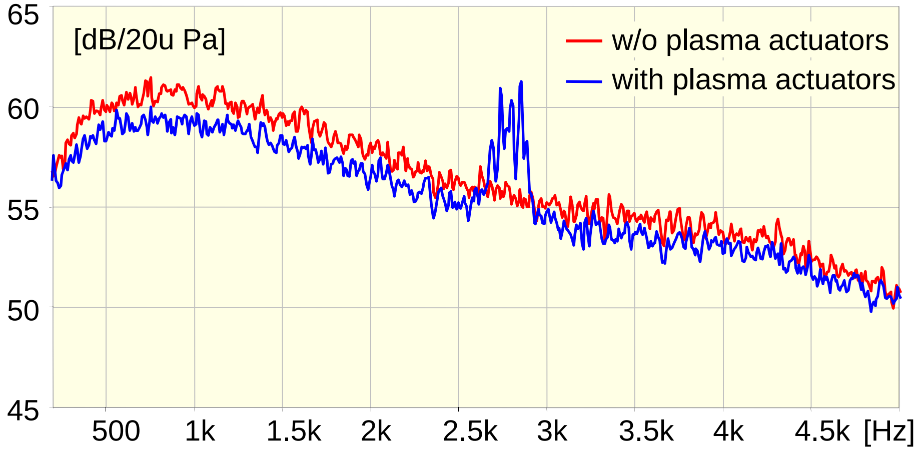


# Jet Noise Reduction Methods

| Method | Expected noise reduction | TRL | Open issues |
|---|---|---|---|
| Fixed geometry chevrons | 1…4 EPN dB during roll and climb | 6…9 | Nacelle-Pylon integration for best aerodynamic performance |
| Variable geometry chevrons | 0.5…1.0 EPN dB during roll and climb | 6 | Reliability, maintainability and manufacturability |
| Geared turbofan, m > 10 bypass ratio | Depending on operation regime | 6…7 | Higher structural weight and drag; maintainability |
| Long channel with forced flow mixing | ~ 1…2 EPN dB during roll and climb | 6…9 | long fairing nacelles for m ≈ 4…6, typically applied on regional and business aircraft |

# Noise Control by Plasma Actuators



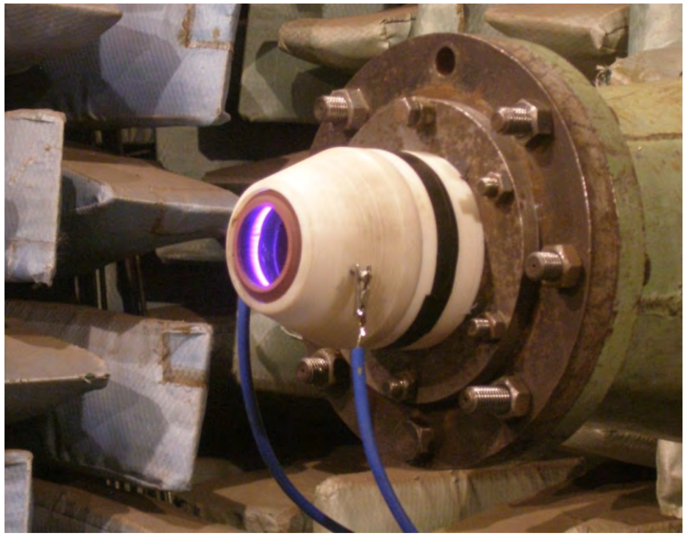

The concept is based on direct control of noise radiation by Dielectric Barier Discharge (DBD). Vlasov–Ginevsky effect.

Noise level improvement – 1.3 dB

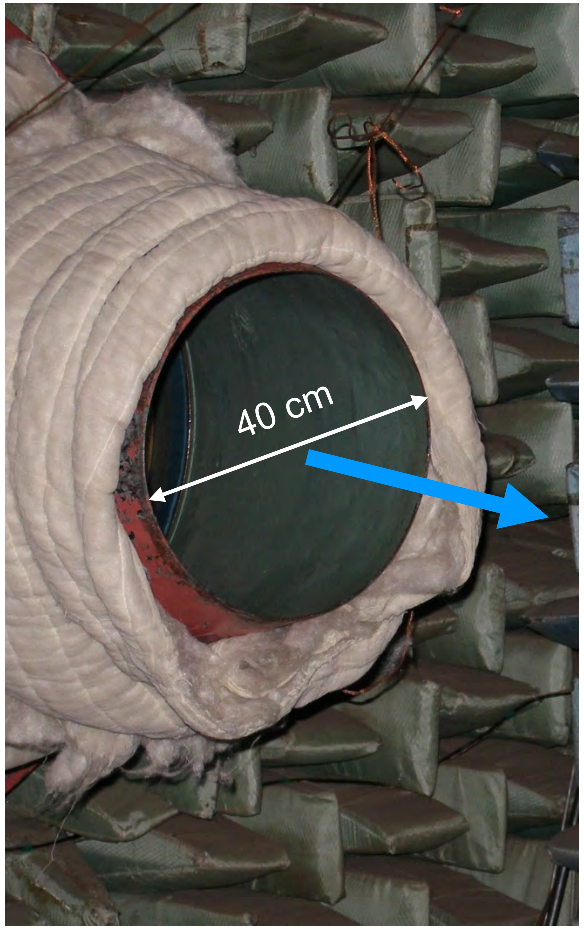
$V$ = 100…180 m/s

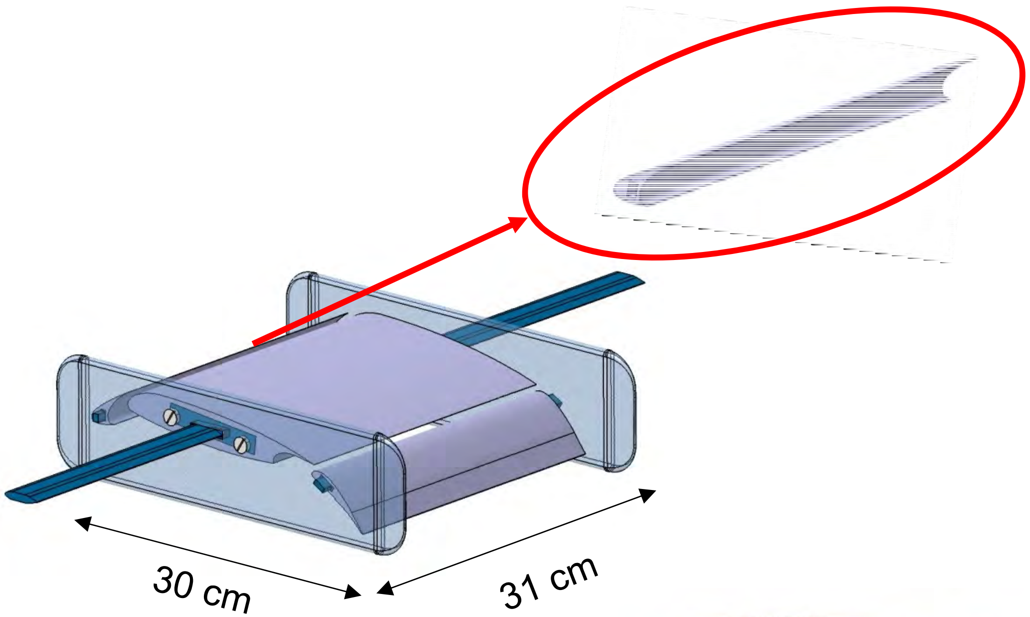
$f$ = 6…12 kHz

$D$ ~ 5 cm

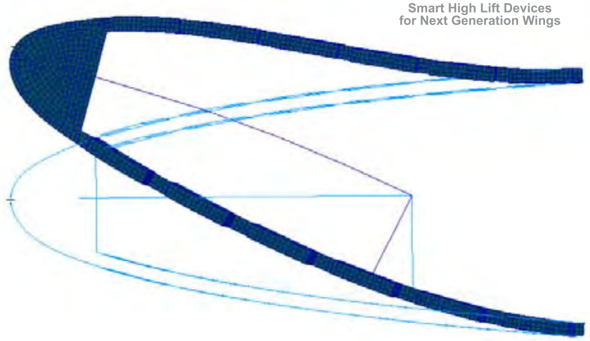


# Airframe Noise Reduction: Slats



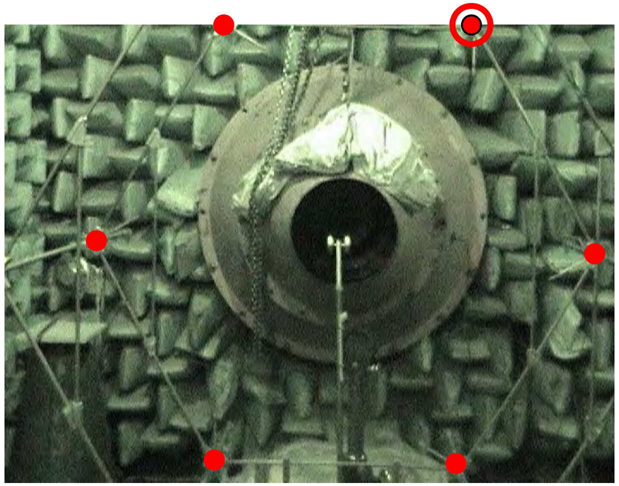



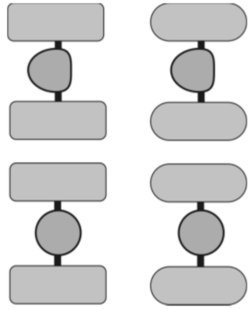

SADE
Smart High Lift Devices for Next Generation Wings

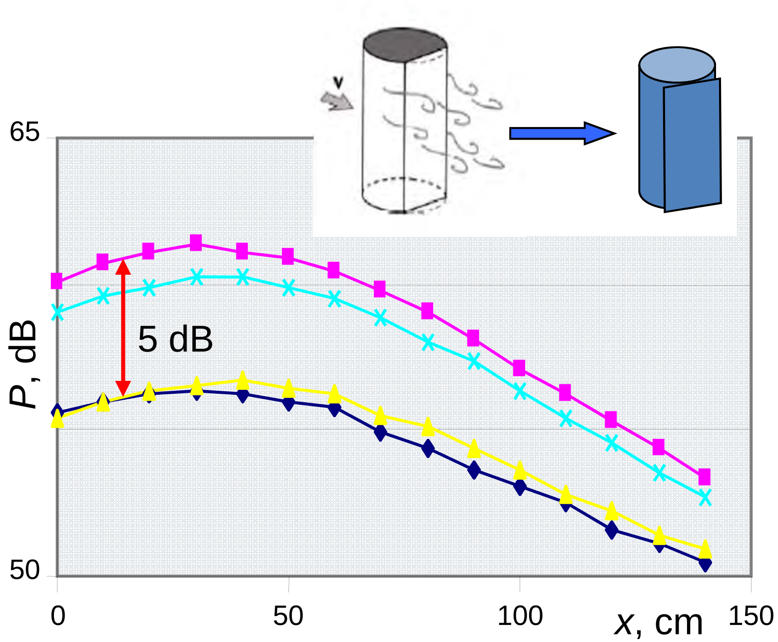


# Airframe Noise Noise Reduction: Landing Gear

microfone 1





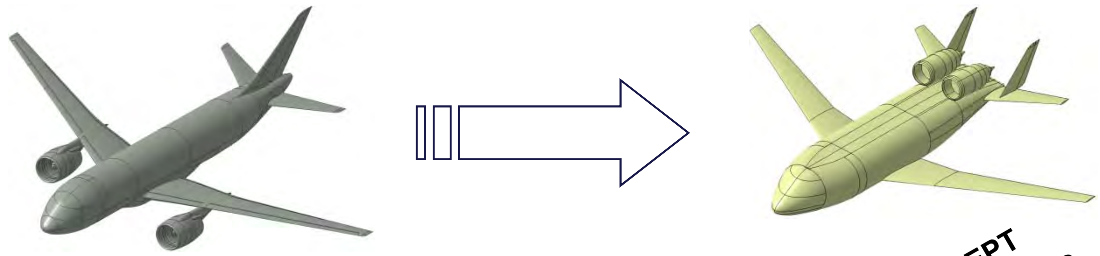


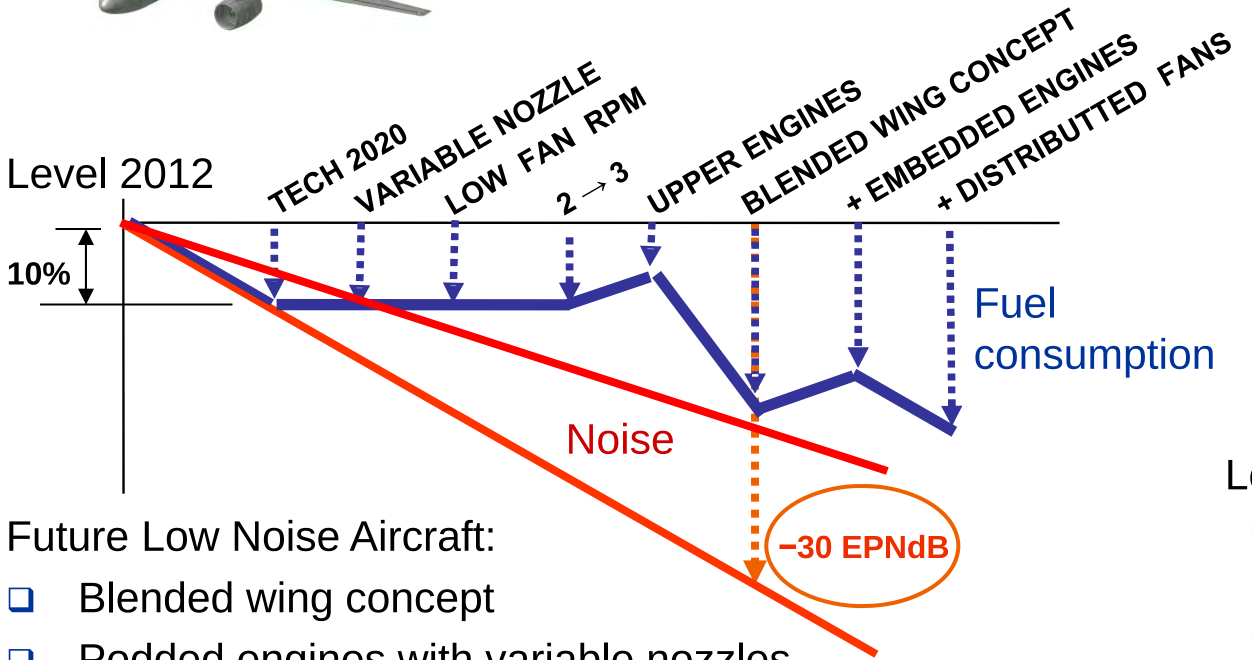

Noise control concept is based on shaped chassis rack and self-tuning system for major mode noise suppression.
Patent of TsAGI No. 2293890

# Landing Gear Noise Reduction Methods

| Method | Overall noise reduction efficiency | TRL | Expected TRL = 6 time target | Expected TRL = 8 time target | Main problems |
|---|---|---|---|---|---|
| Fairings and covers | Up to 3 dB | 6 | | | Weight, heat emission, maintainability |
| Low-noise chassis rack | Up to 5 dB | 3…4 | 2013 | 2015 | Structural and systems integration |

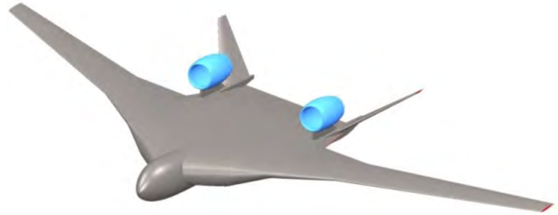
# Future Aircraft: Low Noise and Low Fuel Consumption






Future Low Noise Aircraft:

- Blended wing concept
- Podded engines with variable nozzles
- Mixed exhaust with extensive acoustic liners
- Power managed take-off



Blended wing concept

Low noise embedded propulsion

Distributed Fans

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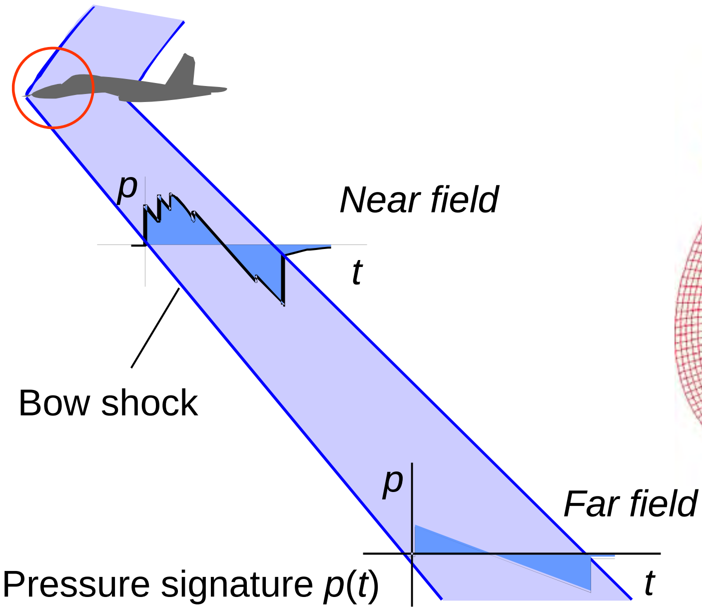
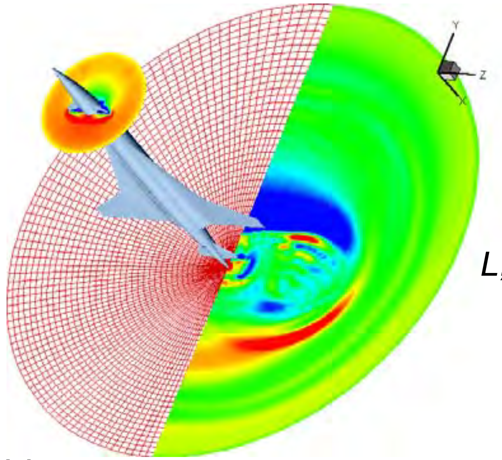
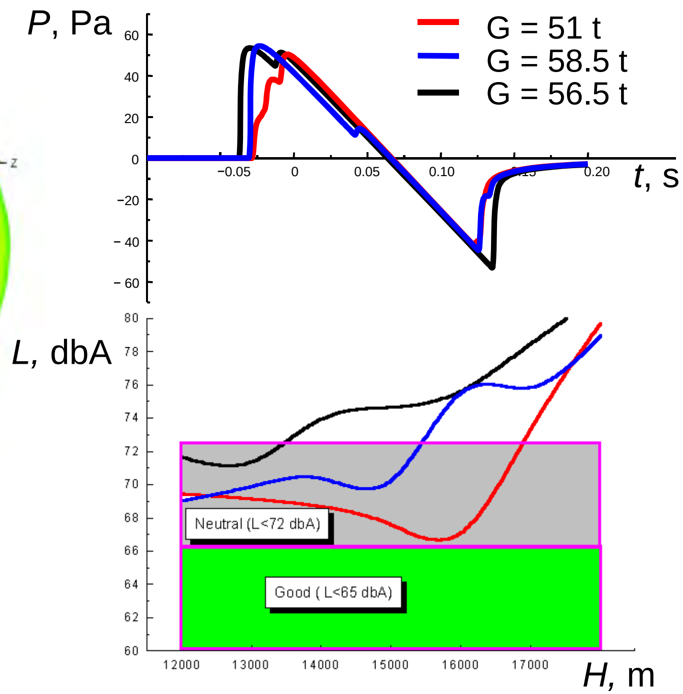
# Low Boom Super Sonic Business Jet



# Contents

- ❑ AVIATION ENVIRONMENTAL ISSUES
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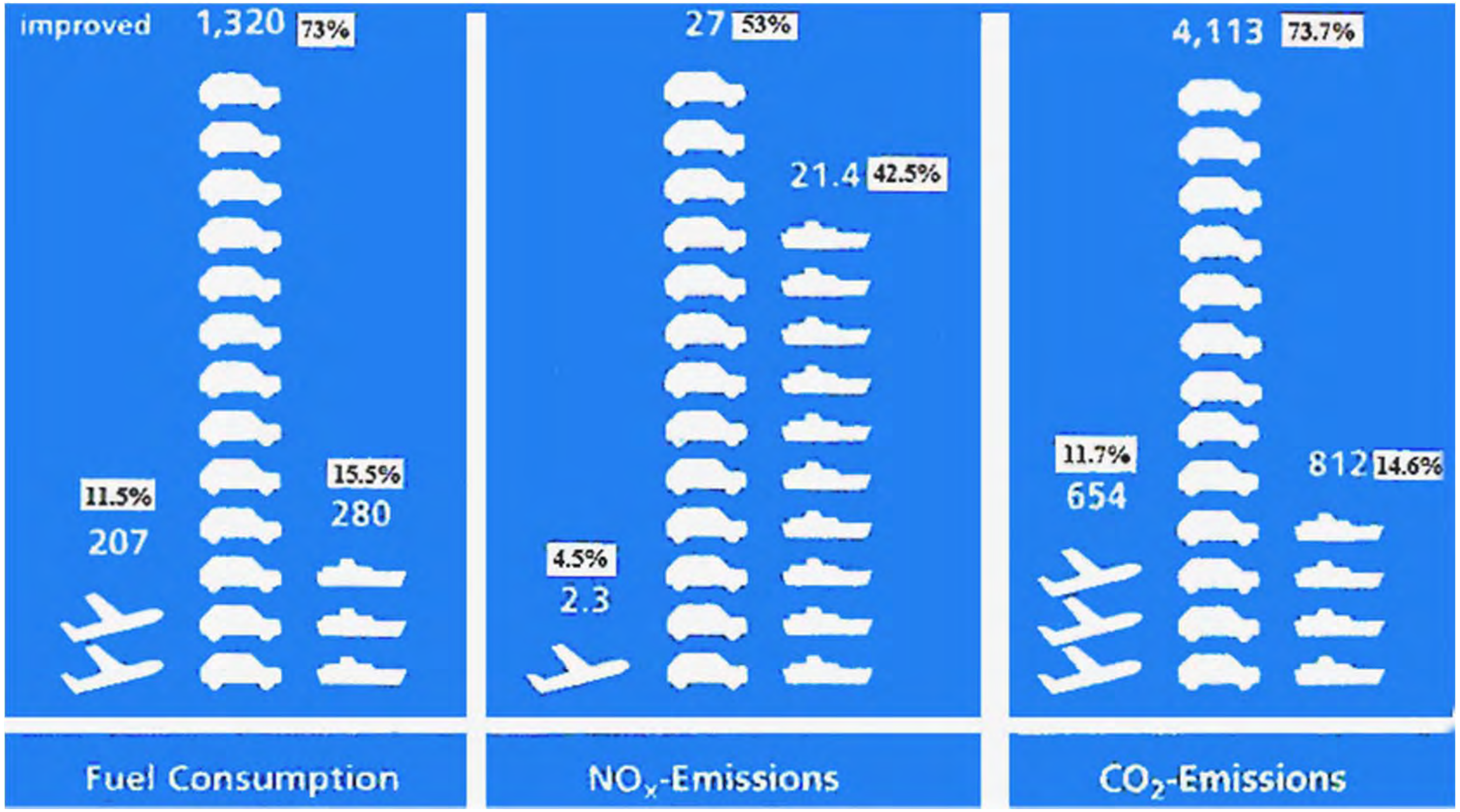
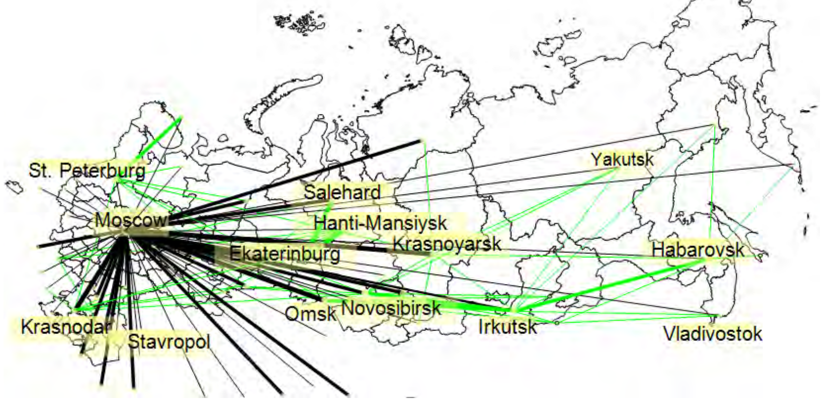
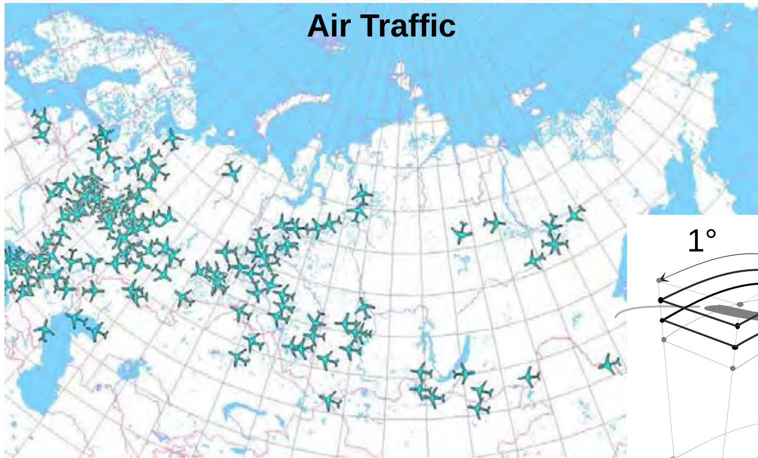
# Emission Factor OF Various Transportations
## ref. DLR, 2008

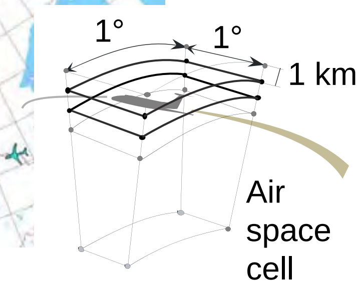


# Air Transport Emission Modeling

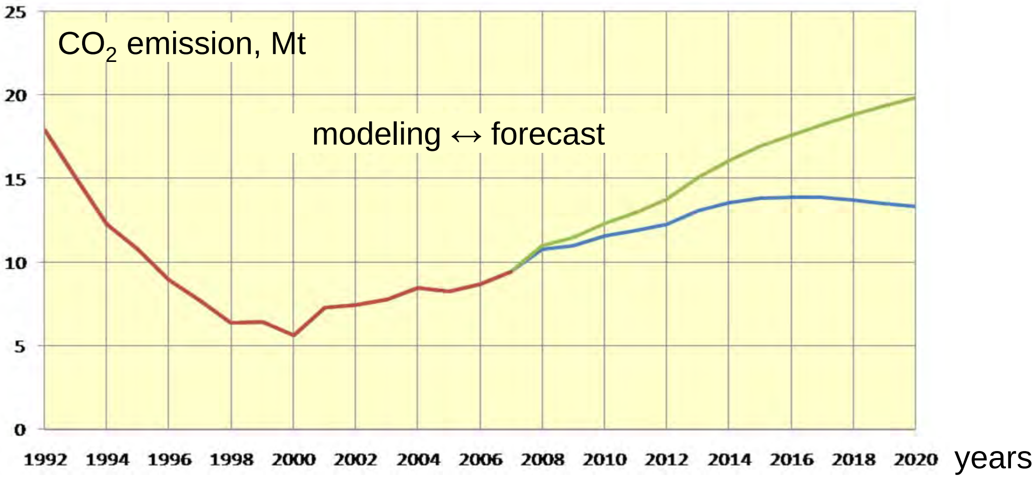
**Routes over Russia**



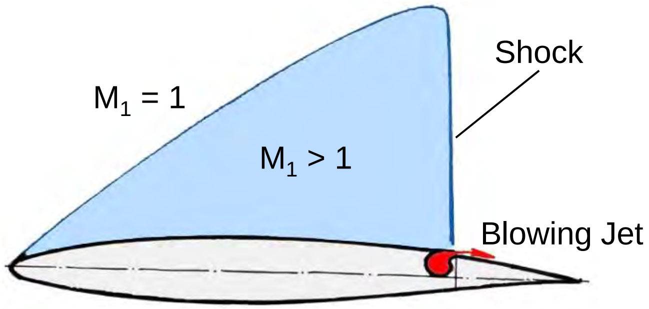



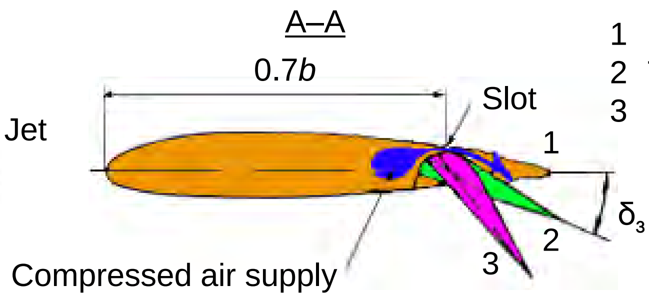




**$CO_2$ emission, including forecast**

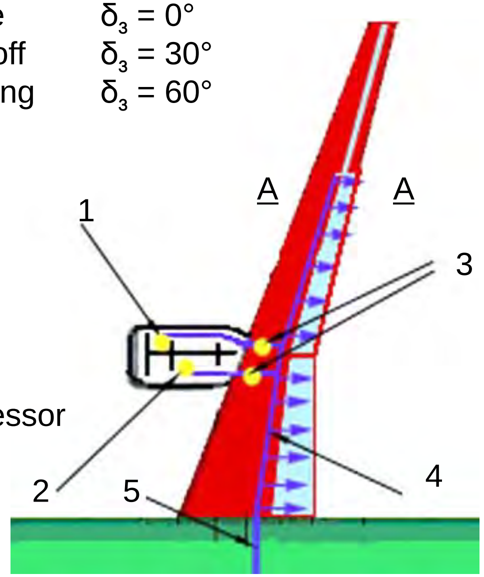


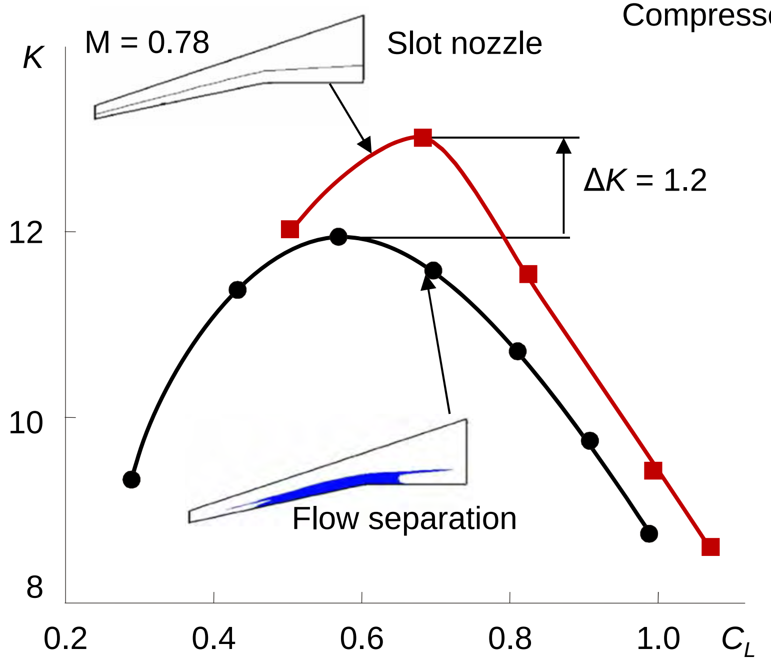

# Low Drag Due to Flow Control




1 Cruise $\delta_3 = 0°$
2 Take-off $\delta_3 = 30°$
3 Landing $\delta_3 = 60°$




1 Bleeding air from fan
2 Bleeding compressed air from compressor
3 Control and cut-off valves
4 Slot nozzle
5 Ring channel

**Using jet blowing system provides:**

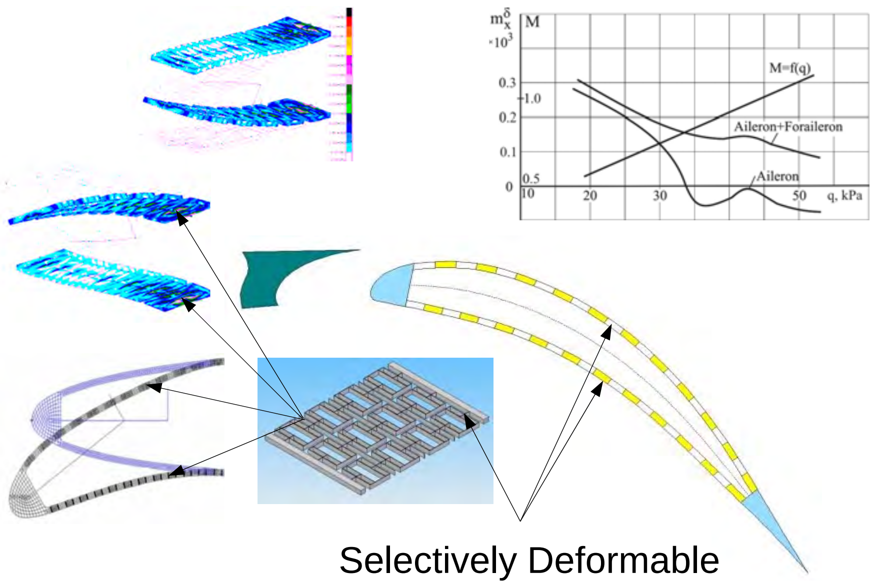
| | |
|---|---|
| Speed and range increase | 8–10% |
| Fuel burn reduction | –(5–7)% |
| Take-off and landing speeds reduction | –(10–15)% |
| Runway length reduction | –(30–35)% |

# Active Aeroelasticity Concept

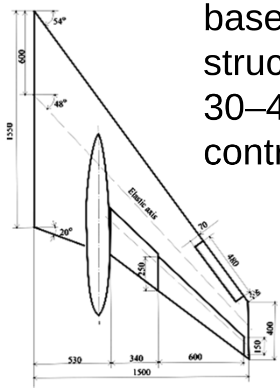
- Innovative controls having high efficiency at all flight regimes: take-off, landing, cruise
- Main tasks – engineering, materials, optimization, life

Main benefits of active structures :

- 4–6% increase in lift-to-drag ratio
- Control efficiency increase by 30–40%
- Fuel efficiency increase by 5–7%
- Structure weight reduction by 6–8%
- Noise reduction by 7–10 dB



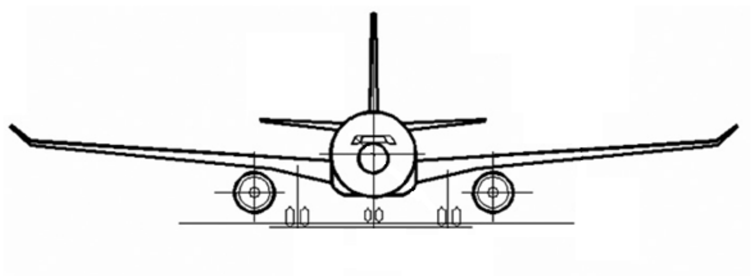

Selectively Deformable Structure (SDS)



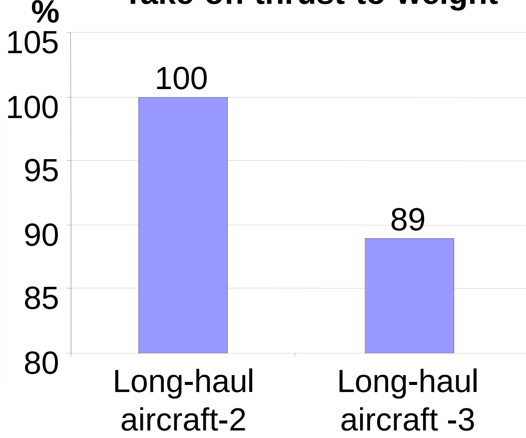
Smart controls based on SDS-structures provide 30–40% gain in control efficiency

# Number of Engines: Environment Impact

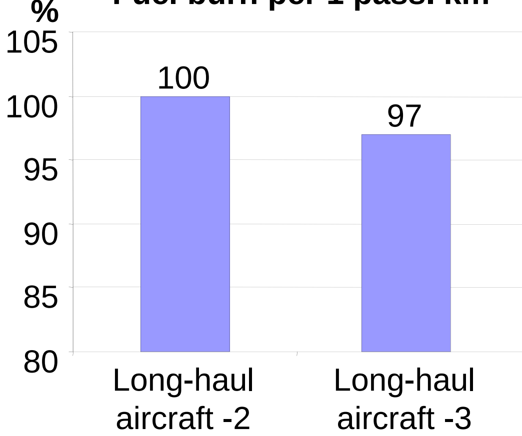
**Conventional configuration, two engines**



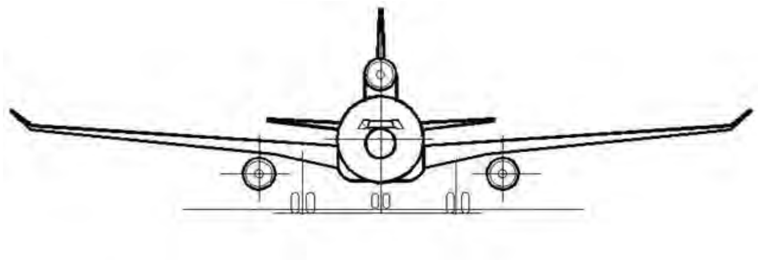
**Take-off thrust-to-weight**



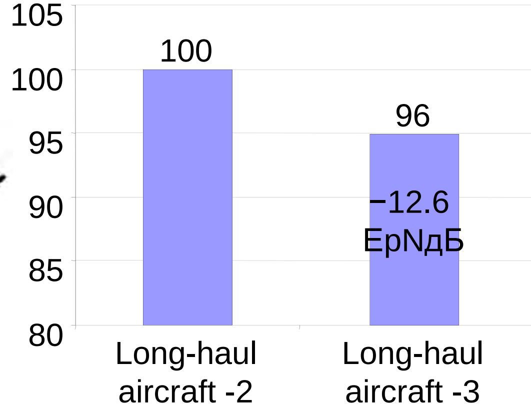

**Fuel burn per 1 pass.·km**



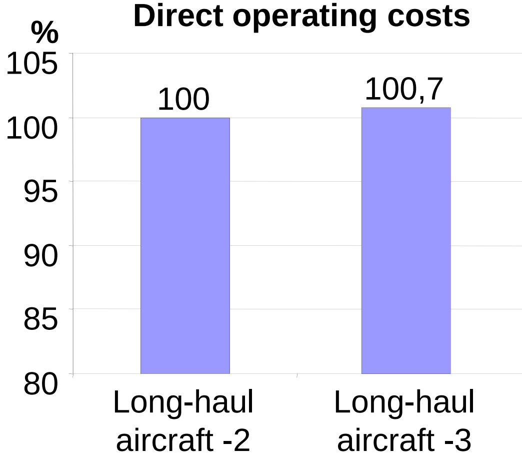

**Conventional configuration, three engines**



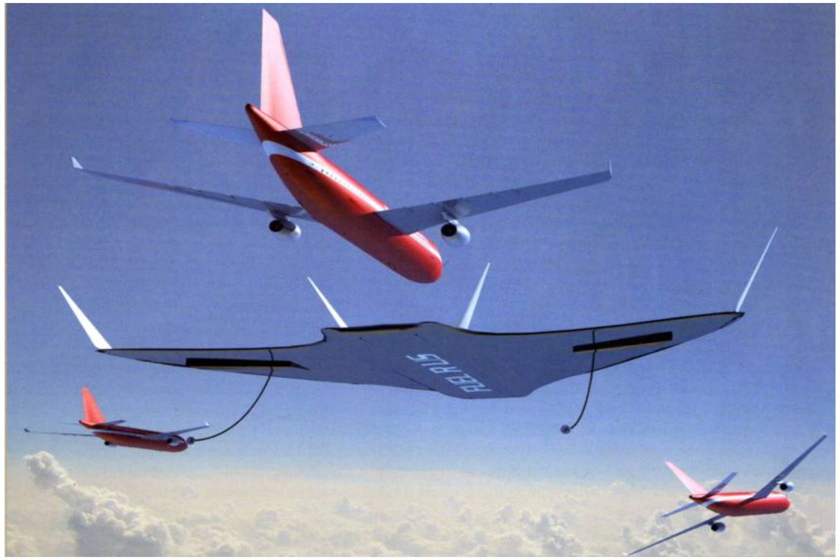
**Noise**



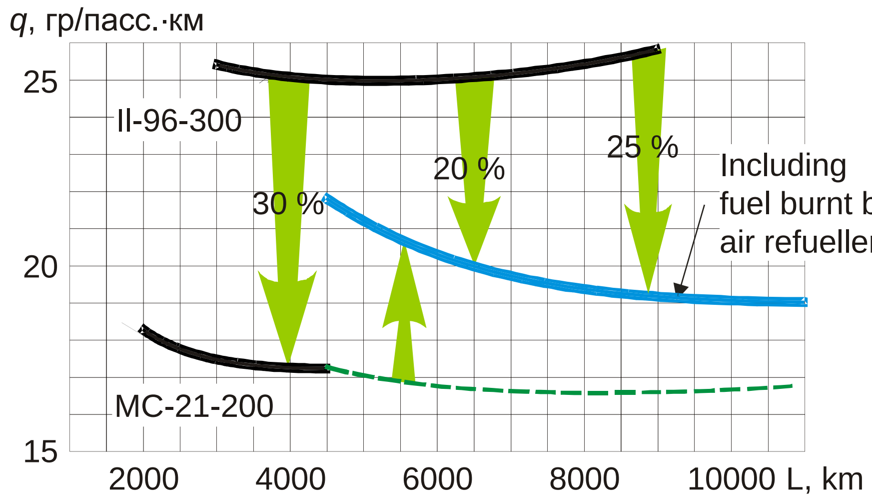

**Direct operating costs**



# AERIAL REFUELING




- Noise reduction in the airport area due to reduced aircraft weight up to 35–40% for long-haul airplanes
- Reduction of air transportation volumes due to increasing number of «point to point» routes
- 15–20% less fuel burn



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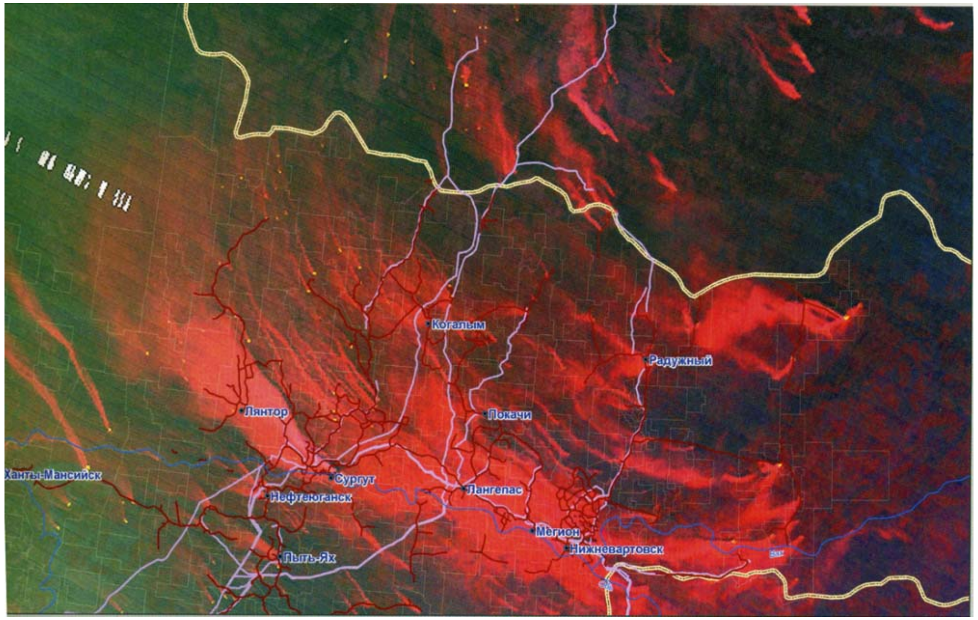
# Condensed Aviation Gas Fuel

1. Condensed aviation gas fuel is «greener» compared to conventional kerosene:

   – $CO_2$ 5–10% less emission
   – low NOx and CO
   – very low solid particles (soot)

2. Huge amounts of propane-butane gas are burned at the oil development sites contributing to greenhouse gas emission in the atmosphere.



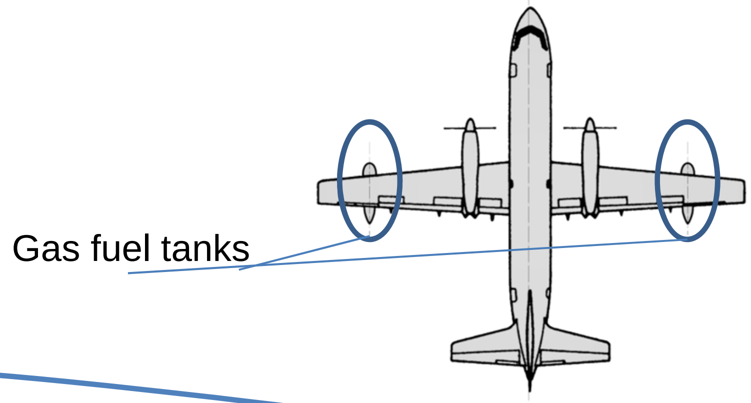

Russia territory gas torches thermal wakes

# Condensed Gas Fuel Aircraft

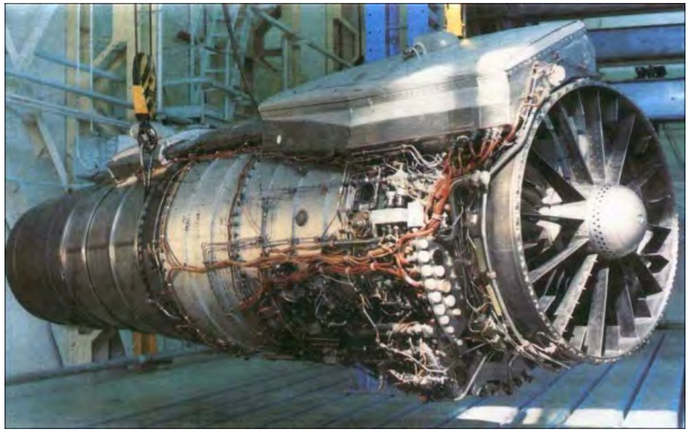

**Mi-8TT helicopter**


**Ilyushin-114 regional turboprop**

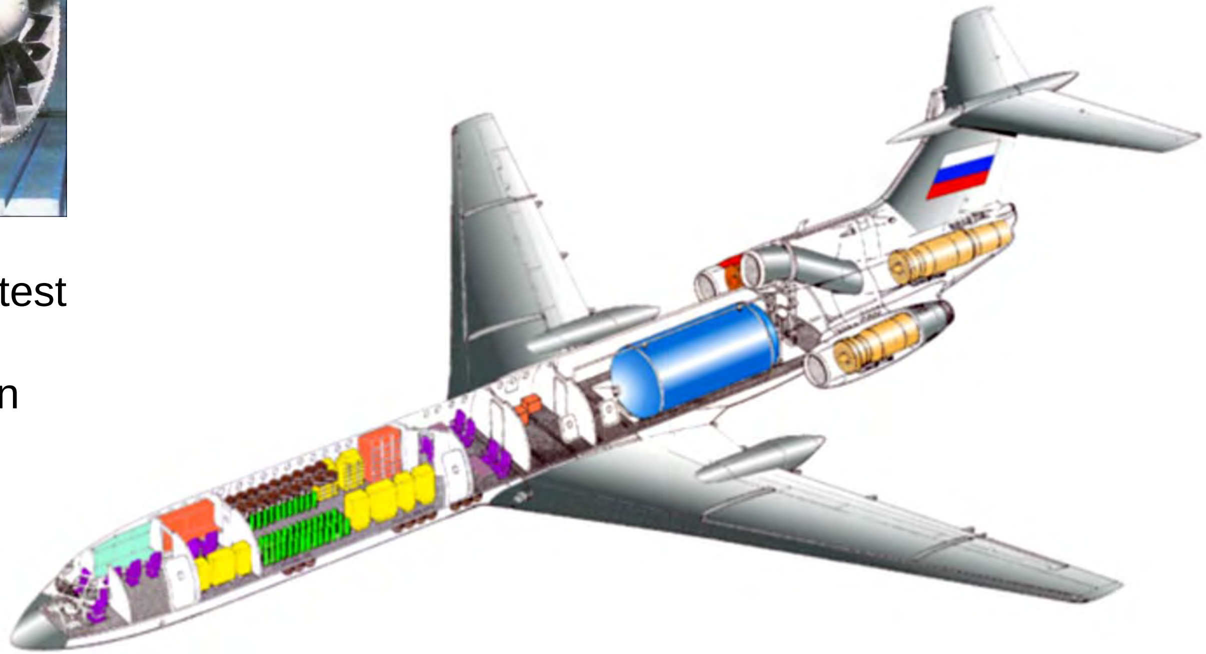
Condensed gas fuel for near and middle term fuel strategy in Russia



# Cryogenic Fuel Aircraft

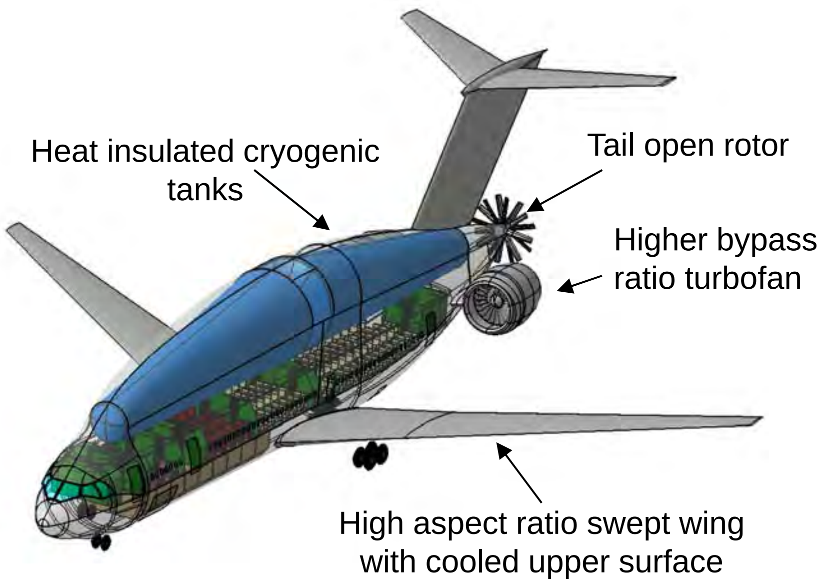


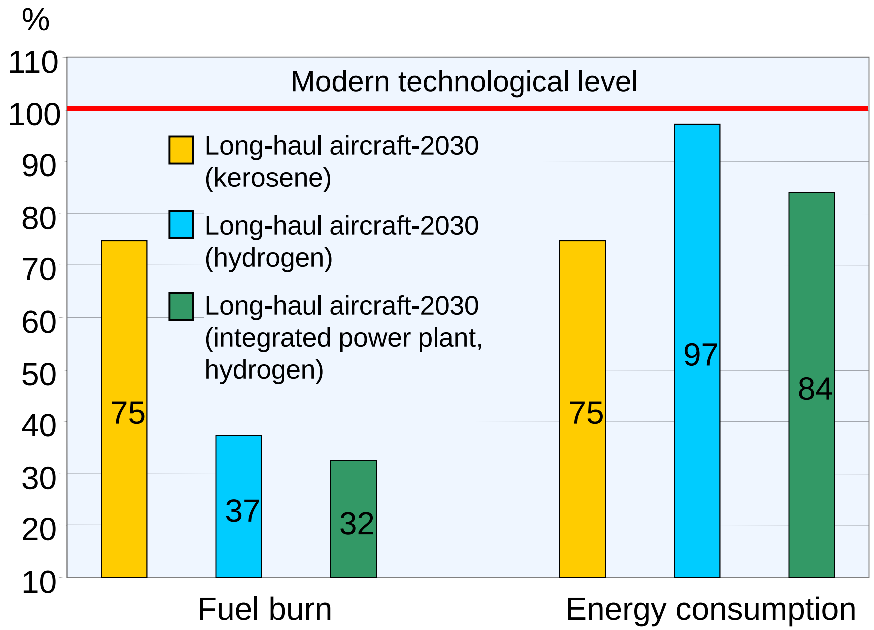
Cryogenic gas fuel Tupolev-155 test bed. Flight demonstration of cryogenic methane and hydrogen for one of its three engines



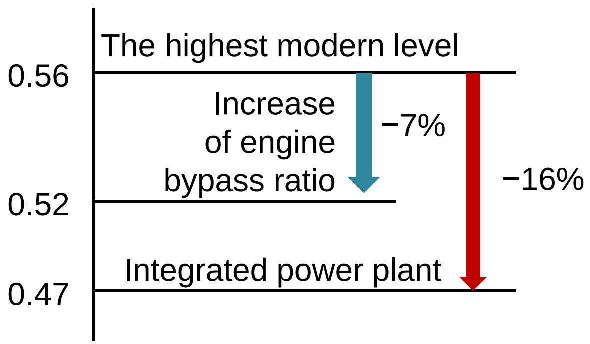
Tupolev-155 Aircraft

# Cryoplane



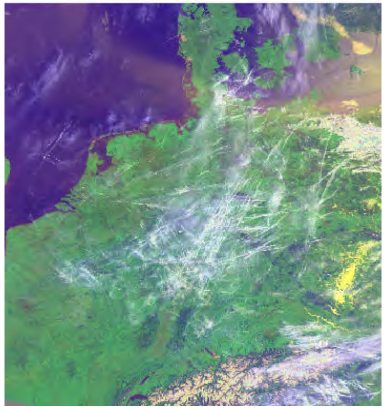




Specific fuel consumption, kg/kG·h




Critical technologies:

- High-power fuel cells (2–3 MW)
- Superconductivity electric engines, the 50–60 K working temperature may be provided by the cryogenic hydrogen fuel



## Thank You for Your Attention!