Environmental Aspects of Air Transport
- Future Technologies & Prospects -

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German Aerospace Center
Institute of Air Transportation System & Technology Assessment
Contents

- DLR
- Introduction
- Environmental Impact of Air Transport
- Air Transport Research
  - Noise
  - Emission
- Technology Trends for eco-friendly Air Transport
- Future Air Transport Concepts
- Summary
The DLR
German Aerospace Research Center
Space Agency of the Federal Republic of Germany
Sites and employees

5,100 employees working in 27 research institutes and facilities
- at 9 sites
- in 7 field offices.

Total 2006 budget
€ 1.224 million

<table>
<thead>
<tr>
<th>Category</th>
<th>Value (€ millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Total budget</td>
<td>1.224</td>
</tr>
<tr>
<td>2. Space Agency</td>
<td></td>
</tr>
<tr>
<td>2.1 German ESA contributions</td>
<td>167</td>
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<tr>
<td>2.2 National Space Program</td>
<td>552</td>
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<tr>
<td>3. Research and Operations</td>
<td></td>
</tr>
<tr>
<td>3.1 Institutional funding</td>
<td>257</td>
</tr>
<tr>
<td>3.2 Third-party funding</td>
<td>248</td>
</tr>
</tbody>
</table>

All figures in Euro millions

Additional notes:
- Total budget for 2006 is €1.224 million.
- The total is divided into two main categories: Space Agency and Research and Operations.
- Under Space Agency, the figures are for German ESA contributions (€167 million) and the National Space Program (€552 million).
- Under Research and Operations, the figures are for Institutional funding (€257 million) and Third-party funding (€248 million).
Mission

To open up new dimensions for exploring the earth and the universe, for protecting the environment and for promoting mobility, communication and security:

- Research portfolio ranging from basic research to innovative applications and the products of tomorrow
- Operating large-scale research facilities for DLR’s own projects and as a service provider for its clients and partners
- Promoting the next generation of scientists
- Advisory services to government
DLR’s strategic competencies (1)

Strategic product-related core competencies:

- Design of complex aerospace and transport systems
- Design of complex flight guidance systems
- Improving the performance and environmental friendliness of aerospace engines as well as energy systems
- Remote control and monitoring of aircraft and spacecraft
- Development and operation of remote sensing systems (Data acquisition, transmission, processing and evaluation)
- Remote sensing and telemetry
- Precautionary measures to maintain the health and capability of people in the mobile society
Strategic non-product-related core competencies:

- Development of new materials and new production methods
- Numerical simulation and experimental validation
- Management of complex projects and operation of large-scale facilities
- Advisory services to government
- Implementing the German government's integrated space program
The Problem

Air Transport in Public Perception ...

The “Anti”-Organisations
Introduction

World Air Travel Forecast

Revenue Passenger Kilometers (billions)

RPKs (Trillions)

Gulf War Crisis

9/11 Crisis

Long-Term Growth

2004-2023
GDP 3.0%
Passenger 5.2%
Cargo 6.2%

Source: Boeing Market Outlook 2005
Air Travel Forecast by Region

<table>
<thead>
<tr>
<th>Region</th>
<th>2003 traffic</th>
<th>Added traffic 2004-2023</th>
<th>Annual growth %</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td></td>
<td></td>
<td>4.1</td>
</tr>
<tr>
<td>Asia-Pacific (excl. intra-China)</td>
<td></td>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>Europe</td>
<td></td>
<td></td>
<td>4.1</td>
</tr>
<tr>
<td>North Atlantic</td>
<td></td>
<td></td>
<td>4.9</td>
</tr>
<tr>
<td>Europe - Asia-Pacific</td>
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<td></td>
<td>6.0</td>
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<td>Transpacific</td>
<td></td>
<td></td>
<td>6.1</td>
</tr>
<tr>
<td>Intra-China</td>
<td></td>
<td></td>
<td>8.1</td>
</tr>
<tr>
<td>North America - Latin America</td>
<td>5.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe - Latin America</td>
<td>5.4</td>
<td></td>
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<tr>
<td>Latin America</td>
<td>7.6</td>
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</tr>
<tr>
<td>Africa - Europe</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

World Average Growth: 5.2%

Source: Boeing Market Outlook 2005
Introduction

Reduction of Fuel Consumption

Examples:

Fuel Efficiency Improvement is a Joint Engine / Airframe Manufacturer Effort

Current Engine Improvements
BPR = High Bypass Ratio

Low BPR Turbfans
1st Generation
High BPR Turbfans
2nd Generation
High BPR Turbfans
3rd Generation Engines

Current Engine and Aircraft

Source: Boeing
Constant Level of Noise

Airport Frankfurt / DIN 45543

Leq (dB)

Number of Flights

Source: Dr. Beder Consult
Vision 2020 – Challenges and Goals

- Quality and Affordability
  - Reduced passenger charges
  - Increased passenger choice
  - Transformed freight operations
  - Reduced time to market by 50%

- The environment
  - Reduction of CO₂ by 50%
  - Reduction of NOₓ by 80%
  - Reduce perceived external noise by 50%
  - Substantial progress towards ‘Green MMD’

- Safety
  - Reduction of accidents rate by 80%
  - Drastic reduction in human error and its consequences

- The Efficiency of the Air Transport System
  - 3X capacity increase
  - 99% of flights within 15’ of schedule
  - Less than 15’ in airport before short flights

- Security
  - Airborne - zero hazard from hostile action
  - Airport - zero access by unauthorised persons or products
  - Air navigation - No misuse. Safe control of hijacked aircraft

Reference: Year 2000
Vision 2020 Targets (relating to a/c)

- Reduce CO$_2$ by 50%
  (20% by engine improvement
  25% by airframe improvement,
  5% by improved operation)

- Reduce NO$_x$ by 80%

- Reduce perceived noise by half
  (equiv. to 10 EPNdB reduction)

- Eliminate noise nuisance outside airport boundaries

- Affordability
Environmental Impact of Air Transport
Environmental Impact of Air Transport

IPCC-Report: Global Warming

Source: IPCC, 2007
Environmental Impact of Air Transport

Green House Gas Concentrations

Source: IPCC, 2007
Environmental Impact of Air Transport

Emissions Flow Chart

<table>
<thead>
<tr>
<th>Sector</th>
<th>End Use/Activity</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Road: 9,9%</td>
<td>Carbon Dioxide (CO₂) 77%</td>
</tr>
<tr>
<td></td>
<td>Air: 1,6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rail, Ship &amp; others: 2,3%</td>
<td></td>
</tr>
<tr>
<td>Electricity &amp; Heat</td>
<td>Residential Build: 9,9%</td>
<td></td>
</tr>
<tr>
<td>Other Fuel Comb. 9,0%</td>
<td>Commercial Build: 5,4%</td>
<td>Methane (CH₄) 14%</td>
</tr>
<tr>
<td>Industry</td>
<td>Unalloc. Fuel Comb: 3,5%</td>
<td>N₂O 8%</td>
</tr>
<tr>
<td>Fugitive Emiss. 3,9%</td>
<td>Iron &amp; Steel: 3,2%</td>
<td></td>
</tr>
<tr>
<td>Ind. Processes 3,4%</td>
<td>Chemicals: 4,8%</td>
<td></td>
</tr>
<tr>
<td>Land Use Change 18,2%</td>
<td>Cement: 3,8%</td>
<td></td>
</tr>
<tr>
<td>Agriculture 13,5%</td>
<td>Other Industry: 5,0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T&amp;D Losses: 1,9%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coal Mining: 1,4%</td>
<td></td>
</tr>
<tr>
<td>Waste 3,6%</td>
<td>Oil/Gas Extraction, Refining &amp; Proc.: 6,3%</td>
<td></td>
</tr>
</tbody>
</table>

Source: World Resources Institute
Environmental Impact of Air Transport

Emissions Flow Chart

Sector
- Transportation: 13.5%
- Electricity & Heat: 24.6%
- Other Fuel Comb.: 9.0%
- Industry: 10.4%
- Fugitive Emiss.: 3.9%
- Ind. Processes: 3.4%
- Land Use Change: 18.2%
- Agriculture: 13.5%
- Waste: 3.6%

Energy
- Gas: Carbon Dioxide (CO₂) 77%
- Methane (CH₄): 14%
- N₂O: 8%

Transportation
- Air: 1.6%
- Ship &: 2.3%

Source: World Resources Institute
Environmental Impact of Air Transport

Noise Exposure of Population

London - Edinburgh

Population exposed per passenger journey (average occupancy) 90dB SEL

Source: AEA Techn., CAA, 2001
Environmental Impact of Air Transport

Number of Airports with Noise Restrictions

Source: NASA Aero Blueprint 2002
Environmental Impact of Air Transport

Other Potential Effects

- Fuel Spills (Kerosene, fire fighting foam)
- Releases during terminal operation, cleaning and maintenance (e.g. Chlor-Fluor-Carbon)
- De-Icing Liquids (e.g. Glycol)
- Herbicides, pesticides and insecticides
- Habitat disruption from land-take and fragmentation
- Waste generation and disposal
- Effects from oil extraction, transportation and processing
Global warming is a proven fact

Green house gas contribution of air transport is relatively small – however, to be taken into consideration are:

- Longevity of gases at altitude
- Specific impact of green house gases at altitude
- Tripled air traffic until 2020
- Future public acceptance of air traffic dominated by noise nuisance

Noise & emission reduction of paramount importance
Main Noise Sources

- Engine System
- Airframe – Exhaust Interaction
- Landing Gear
- High-Lift System

Noise Reduction
Noise Reduction

Noise-Optimized Landing Gear

- Enlarged Landing Gear Bay Cover
- Brake Fairing
- Bogie Fairing
- Hinge Fairing
- Wheel Rim
- Fairing Fillet

max. -5 dB through realistic partial fairing
Full Scale Investigation of Noise Sources

Noise Reduction

DNW-LLF

1600Hz

800Hz

Flow
Noise Reduction Potential at Slat and Flap

-2 dB by fillets in cavities

-5 dB with brushes on slat/flap trailing edge
Slat Noise at High-Lift

-3 dB far field noise reduction

Flow

Slat-cove-cover

DLR
A319 Flyover measurements DLH / DLR

- Transfer of wind tunnel based expertise into real flight situation
- Reduction of excess noise from "acoustically detrimental" details

Vortex generators to eliminate hole tones
Sealing of slat track cutouts
Foam filler at flap side edge

2 dB(A) bbn reduction
1-2 dB(A) bbn reduction
Noise Reduction

A319 Flight Test DLR/LH (Autumn 2001)

-1 to -3 dB far field noise reduction: short term
Noise Reduction

Boeing 787 Roll-Out (Summer 2007)
Active Noise Control for Aeroengines

Noise Reduction

Principle

Experimental Rig at DLR Cologne
Noise Reduction

Low-Speed Geared (low noise) Fan

Average flow Mach number at blade tips
Today’s fans (BPR ~ 6):
\[ \text{Ma}_{\text{rel}} \approx 1.5 \]
Geared fan (BPR \( \geq 12 \)):
\[ \text{Ma}_{\text{rel}} < 1.0 \]

Demonstration with a model fan in EU-Project SILENCE(R)

up to -6 dB noise reduction at BPR 12
Potential for Noise Reduction

**Short Term (3-5 years): 2-3 dB**
- Modification of airframe and landing gear
- Chevron nozzle

**Medium Term (5-10 years): 5-6 dB**
- Noise-reduced high-lift devices and landing gear
- Aero-engine design-to-noise
- Active/passive noise reduction
- Noise-optimized flight patterns

**Long Term (15-20 years): 10-12 dB**
- Aircraft design-to-noise
- Geared fan with high bypass ratio (>14), engine integration
- Low-noise core engine
- Noise-optimized ATM
Emission Reduction
Emission Reduction

Direct Measure
- Engine Optimisation
- Recuperator
- Intercooler
- Geared Fan
- Bleedless Compressor
- Staged Combustion

Indirect Measure
- Drag Reduction
- Optimized Engine Installation
- Hybrid Laminar Flow
- V-Tail
- Weight Reduction
- New Material CFRP, Glare
- Load Control
- Single European Sky
- Optimized Flight Procedure

Drag Reduction
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Weight Reduction
- New Material CFRP, Glare
- Load Control

Drag Reduction
- Optimized Engine Installation
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- V-Tail
Development Trends for Low Emission Combustors

- Conventional single annular combustor; burners with diffusion flames
- Axially staged combustor; conventional burners with diffusion flames
- Axially staged combustor; lean burners in main stage
- Single annular combustor; lean burners and internal pilot flames

Emission Reduction
Emission Reduction

New Material WHIPOX™ (Wound highly porous oxide composite)
for Combustor Walls

- Non-re refractory failure
- Inherent oxidation resistant
- Thermal shock resistant
- Moldable and machinable
Validation of Simulation Tools

Emission Reduction

DLR Falcon behind Lufthansa Airbus A310

EI Soot, measured [g/kg]
EI Soot, calculated [g/kg]

- F100-200E, 10600 m
- F100-200E, 15200 m
- F100-200E, 16700 m
- M45H, 7925 m
- Olympus 593, 16300 m
- CF6-80C2A2, 10670 m
- CFM56-3B1, 7925 m
In-Flight Measurement of Engine Emissions

B-737
Emission Reduction

Potential for Emission Reduction

ANTLE
-12% CO₂
-60% NOₓ

EEFAE
On going programme

CLEÁN
-20% CO₂
-80% NOₓ

VITAL
On going programme
Conventional fan
mainly from propulsive efficiency
Geared fan

NEWAC
On going programme
Contra fan
mainly from thermal efficiency

2000’s engine
Datum
CO₂ & NOₓ

Potential for Emission Reduction

-20% CO₂

-20% CO₂

-20% CO₂
Technology Trends

- 1698
- 1783
- 1804
- 1886
- 1903
- 2005
Paradigm Shift

From

Further, Faster, Higher

To

Cheaper, Leaner, Greener
Technology Trends

Options for Cheaper, Leaner, Greener

More efficient, e.g. through:

- Automation
- New materials
- New processes
- Improved operation
- Adjustable Standards (Level of Service)
- Integrated system (System of Systems/Holistic Approach)
Example “Automation”: Structural Health Monitoring

Direct Operating Cost Breakdown

- Flight Ops: 28%
- Maintenance: 11%
- En-Route/Airport: 18%
- Depreciation: 6%
- Passenger services: 11%
- Ticketing, Sales & Promotion: 14%
- Admin & Other: 12%

Source: ICAO, Airbus
Example “Automation”: Structural Health Monitoring

- Human nerve system:
  - The brain detects intensity and location of pain and judges when to go to the doctor.

- SHM system:
  - The SHM System checks the structure (diagnosis) and evaluates the follow up actions for maintenance (prognosis).

Source: ICAO, Airbus
Example “New Materials”: CFK/Titanium

Boeing 787

Mass reduction

Mass fraction of material [%]

Δ component mass [%] compared to Al component

CFRP
Titanium

Source: Boeing, TU Braunschweig
Example “New Processes”: Friction Stir Welding

- Joining through frictional heat without reaching the melting point
- Advantages:
  - Good mechanical properties in the as welded condition (no material softening)
  - Easily automated on simple milling machines: low set-up costs
  - Minimal thickness under/over-matching, thus reducing the need for expensive machining after welding
### Example “Improved Operation”: Single European Sky

<table>
<thead>
<tr>
<th>Category</th>
<th>Europe</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Space (million km²)</td>
<td>10,5</td>
<td>9,8</td>
</tr>
<tr>
<td>ATC Service Provider (civil &amp; mil.)</td>
<td>47</td>
<td>1</td>
</tr>
<tr>
<td>Centers</td>
<td>58</td>
<td>21</td>
</tr>
<tr>
<td>Operating Systems</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>Programming Language</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Flights (million)</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>ATC Cost per Flight (EUR)</td>
<td>742</td>
<td>386</td>
</tr>
</tbody>
</table>

Source: Lufthansa
Example “Adjustable Standards”: No-Frills Airlines

EasyJet KLM

- these seats don’t exist because of business class.
  KLM’s Boeing 737-300 only has 109 seats!
- in-flight catering
  extra cabin crew to serve business class & travel agent commission
- ticketing costs
- computer reservation fees & expensive airports
- lower aircraft utilisation because of delays at congested airports
- same costs as EasyJet

Source: EasyJet Website 2005
Example “Holistic Approach”: Modern Logistics
Future Air Transport Concepts

Source: NLR, Ad de Graaf
Future Air Transport Concepts

Aircraft Retirement Age (based on current fleet)

Retirements

Total retirements  Pax ret age  Frt ret age  Frt conv age  Average age

<table>
<thead>
<tr>
<th>Year</th>
<th>Total retirements</th>
<th>Pax ret age</th>
<th>Frt ret age</th>
<th>Frt conv age</th>
<th>Average age</th>
</tr>
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<tbody>
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<td>1980</td>
<td>50</td>
<td>10</td>
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<td>10</td>
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<td>130</td>
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<td>2004</td>
<td>290</td>
<td>120</td>
<td>140</td>
<td>130</td>
<td>130</td>
</tr>
</tbody>
</table>

Avg. Retirement Age

- Business Jet: 40
- Regional Jet: 24
- Single Aisle: 28
- Twin Aisle: 25
- Freighter: 35-40
Aircraft Retirement Age (extrapolated)
Low-Noise Concepts

- On-Wing Engine Installation (Noise Shielding: 5-9 dB improvement)

<table>
<thead>
<tr>
<th></th>
<th>VFW614</th>
<th>ERJ-145</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-Off [EPNdB]</td>
<td>90,5</td>
<td>89,0</td>
</tr>
<tr>
<td>Sideline [EPNdB]</td>
<td>92,2</td>
<td>94,0</td>
</tr>
<tr>
<td>Approach [EPNdB]</td>
<td>97,1</td>
<td>98,0</td>
</tr>
<tr>
<td>First Flight [Year]</td>
<td>1971</td>
<td>1996</td>
</tr>
</tbody>
</table>

Source: civil-aviation.org
High Efficiency Cargo Concepts (1)

- Ground Effect Vehicles

Source: NLR, Ad de Graaf
High Efficiency Cargo Concepts (2)

- Blended-Wing-Body Freighter/Airliner

Source: Airbus & NLR, Ad de Graaf
Future Air Transport Concepts

New Airport Concepts

- Off-Shore Airports for 24/7 Operation
- Alternative subterranean Terminals

Source: NLR, Ad de Graaf
Future Air Transport Concepts

New Concepts for Propulsion/Energy Supply

- Fuel Cell
- Solar Power
- Distributed Power
- Hydrogen/Bio Fuels
- Geared Fan & Inter Cooler/Recuperator

Source: NASA, NLR, Ad de Graaf
New Concepts for Operation

- Aerial Refueling
- Formation Flight
- Paired Approach/paired Departure

Source: NLR, Ad de Graaf
Future Air Transport Concepts

New Concepts for highly automated Operation

- Unmanned Aerial Vehicle
- Data Link
- Sense or See & Avoid

Source: NGATS, NLR, Ad de Graaf
Future Air Transport Concepts

New Concepts for Personal Air Transport

- Tilt-Rotor Concepts
- Personal Air Vehicle

Source: NLR, Ad de Graaf
National Research on Air Transportation

Research establishments and academia doing research on:

- components of air transportation system
- complete air transportation system
Future Air Transport Concepts

DLR Research on Air Transportation

Institute of

Air Transportation Concepts & Technology Assessment

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         D-21073 Hamburg
Mission

Development/design and assessment of new aircraft concepts, airport infrastructures, air traffic technologies, and aircraft operations
within the scope of the entire air transportation system
Future Air Transport Concepts

Focus

Air transportation system

Future concepts and scenarios

- Aircraft design systems, cabin
- Environment and social aspects
- Air traffic management
- Airline operations
- Airport and access

Technology assessment within the scope of the entire air transportation system

Team and infrastructure
Research Areas

3 Main Areas of Research:

- Development of an integrated modelling- and simulation system to demonstrate the entire air transport process including the capability to zoom into detailed aspects, e.g. aircraft/airport interface, subsystem performances and interactions within an aircraft in flight.

- Development of future air transportation concepts addressing:
  - new aircraft concepts / configurations
  - air transport processes
  - environmental, social and competitive scenarios

- Development of methods and assessment of new technologies in the overall context of air transport regarding, e.g.
  - techn. performances and limitations,
  - economical benefit for manufacturer, airliner, ATC
  - ecological value
## DLR Technology Assessment Process

- **Technical Technology Assessment**
  - Viability/Feasability
  - Functionality
  - Potential

- **Ecological Technology Assessment**
  - Environmental Burden

- **Monetary Technology Assessment**
  - Net Present Value
  - Internal Rate of Return

![Diagram](Diagram)
Monetary Technology Assessment (Airbus Method)

Source: Airbus, Hans Schnieder, DGLR
Future Air Transport Concepts

Monetary Technology Assessment (Airbus Method)

Source: Airbus, Hans Schnieder, DGLR
Due to tripling capacity the air transportation will gain significant impact on climate

Future public acceptance of air transportation is dependent on noise and emission levels

Promising technologies for noise and emission reduction have been identified

Prompt action and holistic approach is mandatory for future R&D

With its wide range of expertise DLR is ready to contribute to the future air transportation system
Questions