Noise reduction by aircraft innovations

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Die Fracht braucht die Nacht (Freight needs night)
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6500 Employees work in 29 Research Institutes and Units in 13 Locations.

Offices in Brussels, Paris, Washington

- Locations of the Institute of Propulsion Technology and its external units
- Further Locations with research activities in air-traffic noise
DLR locations with research in air traffic noise

- Berlin, Cologne  Propulsion noise
- Braunschweig  Airframe noise, flight procedures
- Göttingen  Airframe noise, cabin noise, noise immission
- Oberpfaffenhofen  Sound propagation in the atmosphere
Assessment of achievements in aircraft noise reduction with the aid of certification noise levels
Noise certification according to ICAO, Annex 16

Take-off, sideline 450 m lateral distance from runway Engine
Take-off, flyover 6.5 km after start of roll Engine and climb performance
Approach 2 km before landing threshold Engine and airframe
Achievements in noise reduction shown in terms of normalized sideline noise levels

- Seitenlinienpegel für Flugzeug/Triebwerkconfigurationen
- normiert auf konstanten Schub

23 dB
23 dB noise reduction in 50 years.

Reduction of normalized sound power by a factor of 200 to only 0.5% relative to Boeing 707-100.

Apparently no significant noise reduction since 1985. Cause: ICAO noise limits are satisfied, quieter aircraft would have higher operating costs.

Reduction of noise emission in the last 6 years is indicated by comparing A340-500 with A380-800. The latter is 4 dB quieter. 2 dB are the credit of one airline, which required this to avoid night-flying limitations in London.

The engines of the A380 emit practically no tones.

This will hopefully also be the case for all new aircraft with turbofan engines:
Boeing 787, Boeing 747-8, Bombardier C-Series, Airbus A350
Survey of noise sources of a turbofan
Noise sources of Turbofans

Fan
- Tones at various frequencies
- Broadband noise
- “Buzz saw” noise

Compressor
- High-frequency tones
- Broadband noise

Turbine
- High-frequency tones
- High-frequency broadband noise

Jet
- Low-frequency broadband noise

Combustion chamber
- Low-frequency broadband noise
Additional sound source with increasing importance: Bleed valves

- Bleed valves are necessary at part power (e.g., during landing)

- Pressure in core engine is continuously increased in modern turbofans

- Part of the mass flow has to be bled.

- Pressure is relieved in hundreds of small jets.

- Sound emission large
Airframe noise sources

- High lift devices
  - Slats
  - Flaps
  - Landing gear
- Cavities of any kind may generate tones (like by an overblown bottle)

Quiet air intake

Very loud tone

Flow direction

De-ice air outlets on nacelle generate tone
Which technical innovations have achieved today's noise reduction?
Technical innovations for the reduction of engine noise

1. Introduction of the turbofan engine (bypass engine) and continuous increase of the bypass ratio to current values above 10 (since 1960)
Innovations on engine

- Increase of bypass ratio (mass flow in bypass over mass flow in core)
- Technically more correct: reduction of fan-pressure ratio, resulting in
  - smaller jet speeds (see lower left)
  - higher Mass flows to maintain thrust (larger fan diameter, see lower right)

Reduction of jet speed from 306 m/s to 272 m/s reduces jet noise by approx. 4 dB.

Requires increase of engine size for given thrust, expensive!
Technical innovations for the reduction of engine noise

1. Stepwise increase of bypass ratio to values above 10.
2. Relocation of fan guide vanes to position downstream of rotor.
First turbofans with inlet guide vanes

Rolls-Royce Conway
Inlet guide vanes cause very loud tones,
Bypass ratio 0.3
First turbofan in air transport

Further turbofans with inlet guide vanes:
JT3D, military version on Lockheed Starlifter C-141B, audible in Frankfurt until 2005
Spey, very ubiquitous on BAC 1-11
JT8D, Boeing 727, 737-100/200
Technical innovations for the reduction of engine noise

1. Stepwise increase of bypass ratio to values above 10.
2. Relocation off guide vanes downstream of rotor.
3. Forced mixer for bypass ratios up to 7.
Forced mixer

- Forced mixer increases thrust and reduces noise.

Early example (top figure):
JT8D (B727, B737-100/200)

Current examples:
- BR710, BR725 (various business jets)
- BR715 (Boeing 717), figure left
- CFM56-5C (A340-200/300)
- PW6000 (A318)
Technical innovations for the reduction of engine noise

1. Stepwise increase of bypass ratio to values above 10.
2. Relocation off guide vanes downstream of rotor.
3. Forced mixer for bypass ratios up to 7.
4. Increase of stator vane count (cut-off design).
Cut-off design

- Careful selection of the stator vane count results in cut-off of the tone at the blade-passing frequency (waves cannot propagate out of the engine)
- Relates to interaction between rotor and stator.
- Theory of Tyler and Sofrin (1962)
Technical innovations for the reduction of engine noise

1. Stepwise increase of bypass ratio to values above 10.
2. Relocation off guide vanes downstream of rotor.
3. Forced mixer for bypass ratios up to 7.
4. Increase of stator vane count (cut-off design).
5. Increase of distance between rotor and stator.
Current turbofans

Undisturbed inflow to fan rotor

Both engine types of A320 feature struts downstream of stator.
Newest engines with very large distances between rotor and stator

GP7200
(Engine of A380)

No more struts. Mounting of engine solved in a technically different way.
Technical innovations for the reduction of engine noise

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2. Relocation off guide vanes downstream of rotor.
3. Forced mixer for bypass ratios up to 7.
4. Increase of stator vane count (cut-off design).
5. Increase of distance between rotor and stator.
6. Reduction of tip Mach number of fan blades
Reduction of Mach number of circumferential tip speed of fan

Reduction of fan tip Mach number

- **past** \( M = 1.45 \)  
  Airbus A340-500/600 (Trent 500)
- **present** \( M = 1.28 \)  
  Airbus A380 (Trent 900, GP7200)
- **future** \( M = 1.15 \)  
  Boeing 787 (Trent 1000)

- Buzz tones apparently vanished on A380
- The smaller \( M \), the larger is swirl in flow between rotor and stator.
- Swirl reduces rotor-stator interaction tones.
- Cut-off design might no longer be required, noise reduction potential of broadband noise.
Technical innovations for the reduction of engine noise

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6. Reduction of tip Mach number of fan blades
7. Serrated nozzles (Chevrons)
Reduction of jet noise

- Jet is external sound source, thus only limited reduction potential for given jet speed.
- Serrated nozzle (chevrons) sole method with small thrust loss.
- Serrated outer nozzle improves mixing between jet and ambient air.
- Serrated inner nozzle improves mixing between hot core-flow (inner nozzle) and cold bypass flow (outer nozzle).
- Retrofit of existing engines possible.

Chevrons on Boeing 787 mainly for reduction of cabin noise in cruise
Technical innovations for the reduction of engine noise

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8. Improvement of acoustic liners
Passive acoustic liners

- Acoustic liners very important.
- Reduce sound emission of internal sound sources by up to 18 dB.

Progress:
- Surface of perforated plates replaced by wire meshes: sound absorbing performance less dependent on operating point of engine.
- Two layers of honey combs in some areas: better performance over larger frequency range.
- Liners in inlet manufactured in one piece without splices.
- Close to rotor no liner is better than liner with splices.

Sources: google; Rienstra; Pratt & Wittney; Hennecke
Innovations for reduction of airframe noise
Technical innovations for the reduction of airframe noise

1. Design measures for eliminating cavity tones.
2. Reduction of slat noise
Cavity tones are the loudest sound sources during the approach of some aircraft.

Cavity tones can be localized before certification.

Measuring technique: phased microphone array
Up to 240 microphones on ground record flyover noise. Data reduction yields positions of all sound sources.
Reduction of slat noise

- Noise reduction of high lift devices on leading edge:
- Replacement of slats by drooped leading edges on part of wing (also results in better climb performance)
- Further known measures for airframe noise reduction not yet applied, for example
  - Width reduction of slat gap reduces slat noise
  - Fairings reduce landing gear noise
Measures to be expected in the near future
Further increase of bypass ratio

Further increase of bypass ratios

Technical measures

- Slow fan driven by fast turbine via gearbox (Pratt & Whitney with MTU), will be installed on Bombardier C-Series

- Variable area nozzle ensures flutter-free operation of fan (installed on C-Series)
  - Reduction of engine noise during take-off by approximately 2 dB
  - Improvement of climb performance after take-off.
Variable fan nozzle

Advantages:
- Lower jet speeds
- Higher propulsive efficiencies
- Larger thrust
- Smaller fuel consumption
- Lower noise

Disadvantages:
- Higher mass
- Higher maintenance costs
New concepts for far future
EU goals for reduction of emissions until 2020: Advisory Council for Aeronautics Research (ACARE)

-10 dB for each of the three certification points
Very challenging Goal.
Making available required technology
New engine concepts necessary
  Further development of geared turbofan
  Counter rotating fan

Ultra High Bypass Ratio Fan
With gearbox (PW, MTU, DLR)

Counter rotating fan
(General Electric/Snecma)

Pratt Whitney PW 1000G
New aircraft concepts

- Noise reduction by shielding of noise radiation from engine inlets
- Jet noise cannot be reduced with this concept

Source: Silent Aircraft Initiative, Cambridge-MIT Institute

Source: Airbus
New engine concepts:
Open counter rotating rotors

- A substantial reduction of fuel consumption is only possible through introduction of open rotors. High flight Mach numbers require counter rotating propellers.
- Noise reduction much more difficult in comparison to turbofan. Large research requirement.
Conclusion

- Engines have already become very quiet.
- Tones in airframe noise are eliminated.
- Current noise limits can be satisfied with existing technologies.
- More quiet aircraft under the current boundary conditions can only be realized, if this can be achieved without higher costs.
- A large part of the noise reduction at source in the past years was offset by increases of air traffic.
- Technical solutions and ideas exist to use noise reduction potentials in the future.
- Political support in form of continuous and lasting research funding is necessary.
- New engine concepts with large fuel savings potential will lead to a great challenge for noise research.