Acoustic liners for modern aero-engines

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The Noise Challenge

Friends of the Earth Birmingham

Photo Opportunity: Start Sat 23rd Nov, 9.30am, BANG! and BFOE protesters with banners, placards masks, and a truck with loud speakers

Aircraft Noise – It Takes The Peace!

IVE LIV BBC NEWS CHANNEL

Last Updated: Monday, 10 March, 2003, 21:36 GMT

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Family sue over jet noise

The owners of a 17th Century house are claiming £9m in compensation from the Ministry of Defence (MoD) over "unbearable" aircraft noise from RAF Harrier jets.

The planes fly over the house when they are coming in to land

The Future of Air Transport – 2003 UK White Paper

UK air travel has increased five-fold over the last 30 years

Air travel will continue growing over the next 30 years

Half the population now flies at least once a year

We need a balanced approach which recognises the importance of air travel, but which also tackles environmental issues

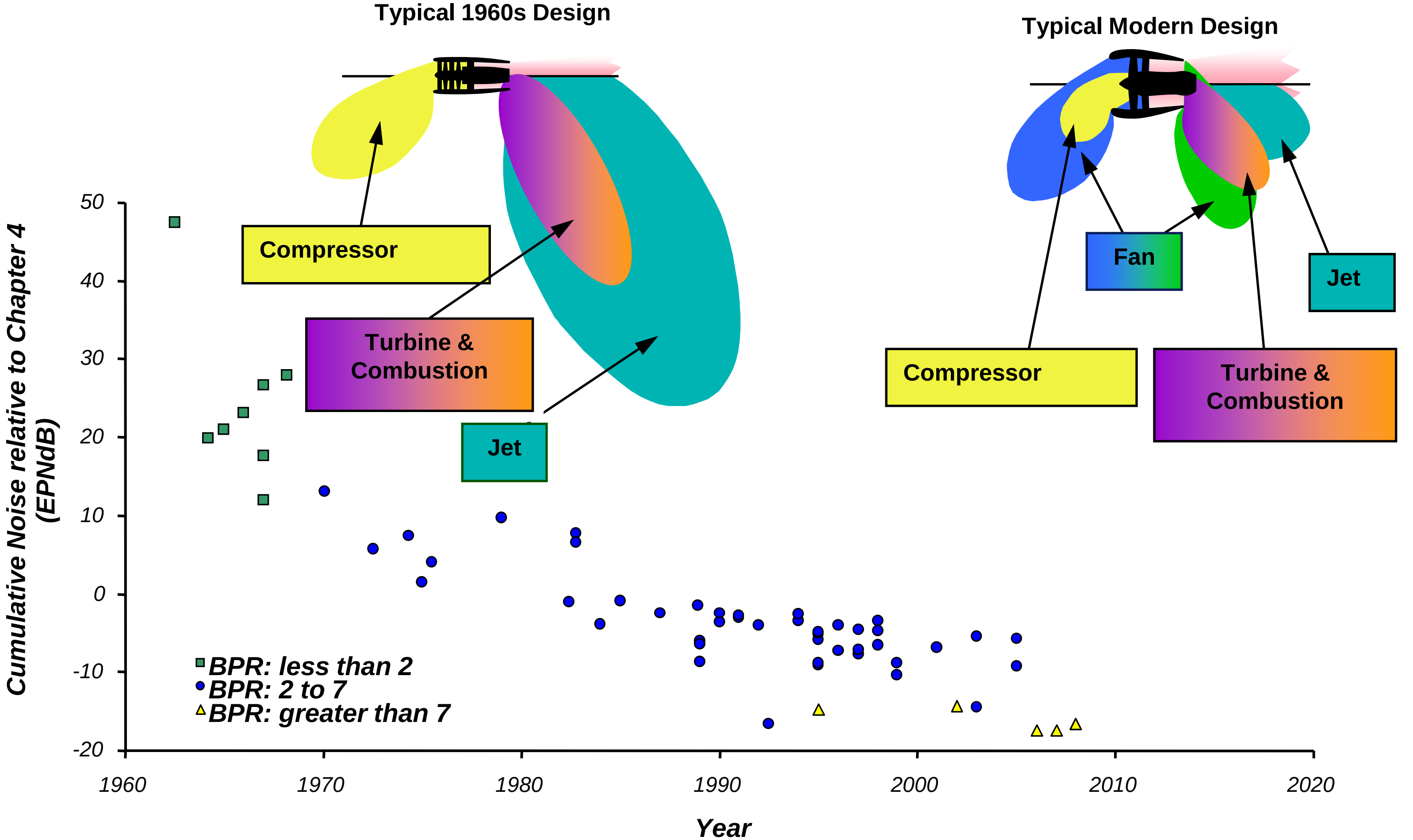
Aviation helps people stay in touch with friends and family around the world.

Airports are important to the economies of the regions

The aviation industry directly supports around 200,000 jobs.

Rolls-Royce

Significant progress in reducing aircraft noise

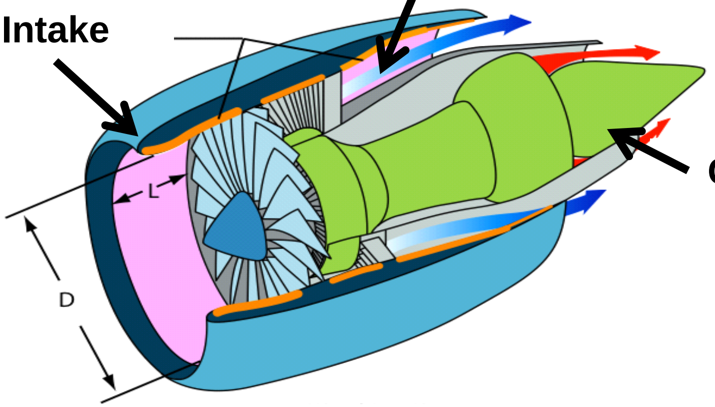


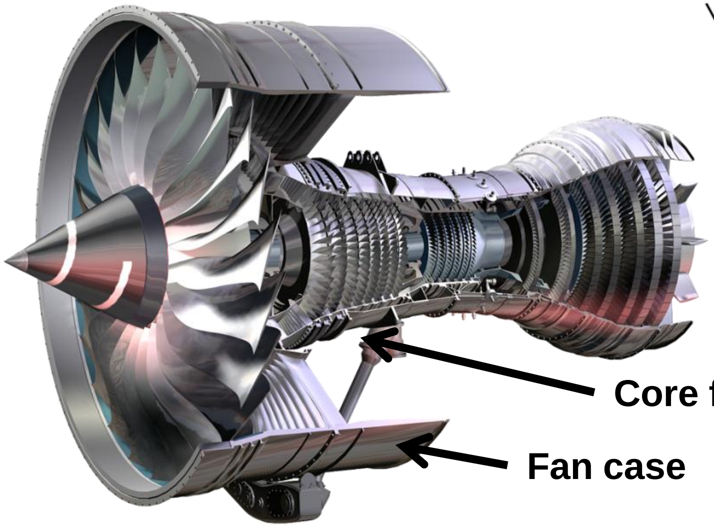
Very significant progress in reducing jet noise was achieved by the introduction of high-bypass-ratio engines

Presentation Content

- Acoustic liner requirements
- Zero-splice intake liners
- Intake lip liners
- Bypass-duct liners
- Core-duct liners
- Liner types
- Measurement of liner attenuations
- Measurement of liner impedance
- Liner impedance models

Aero-Engine Liners





Acoustic Liner Requirements

Acoustic Liners are fundamental in ensuring jet aircraft are quiet, but they must also satisfy many other requirements:

- **Must be effective over a wide range of engine operating conditions and frequencies (reducing both tones and broadband noise)**
- **Must fit into the restricted space available (liner depth and area)**
- **Must be light to ensure that fuel burn is not penalised**
- **Must be cost effective to buy their way onto the aircraft**
- **Must be specified when many details of the airframe and engine design have not been finalised, so the liner design must be robust**
- **Must be integrated with other engine design requirements**
- **Must survive rain, ice, oil leaks, maintenance staff ...**
- **Must satisfy manufacturability and maintainability requirements, for decades of in-service life in the exacting aero-engine environment**

Progress towards zero-splice intakes

Rolls-Royce/Boeing QTD

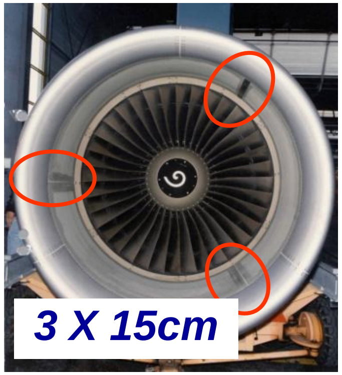
Much progress has been made in improving the acoustic performance of intake liners.
Axial splices scatter energy from nearly cut-off modes into modes not so well attenuated by liner

Rolls-Royce/Airbus SILENCE(R)

Progress towards zero-splice intakes

Improved manufacturing techniques have enabled the zero-splice intake liner now to enter service on the A380 and B787

A320



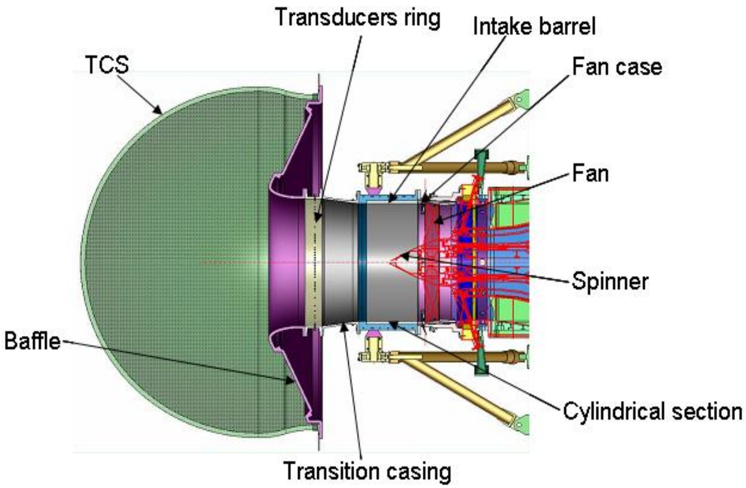
A340-600

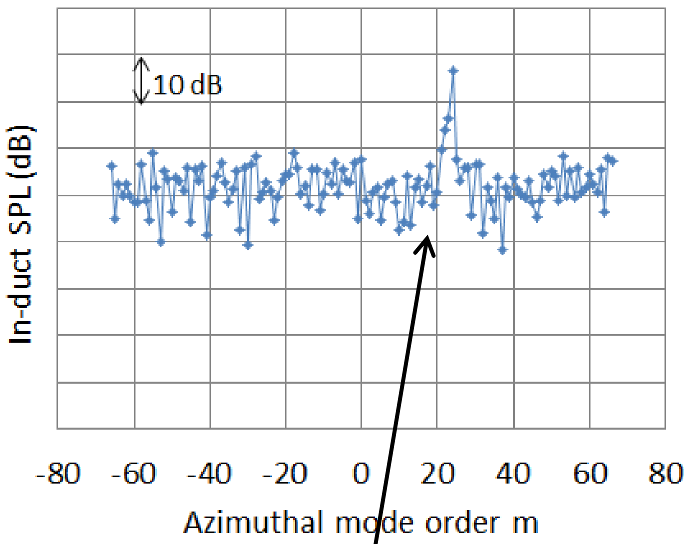
A380

Why are zero-splice intake liners so effective in reducing fan tones?

With acknowledgements to Airbus

Modal structure of fan blade-passing-frequency (BPF) tone

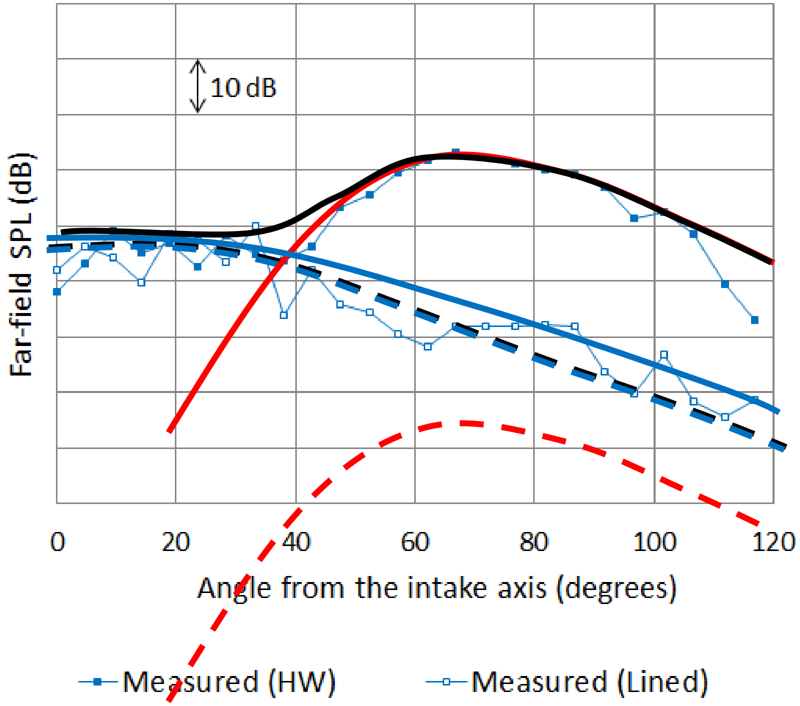




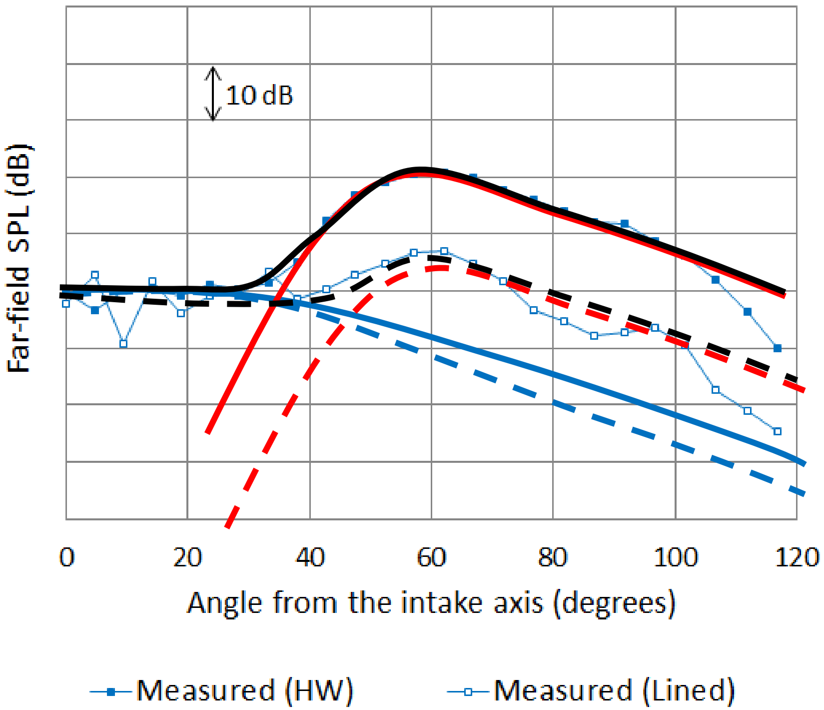
At supersonic fan tip speeds the rotor-alone tone cuts on (m=24 at BPF for 24-bladed fan)

Influence of modal structure on liner attenuations

Fan BPF tone



Tip speed just supersonic



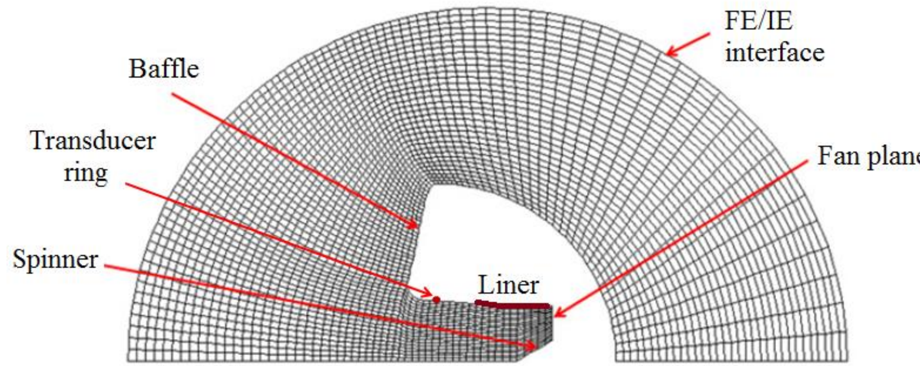
Tip speed well supersonic

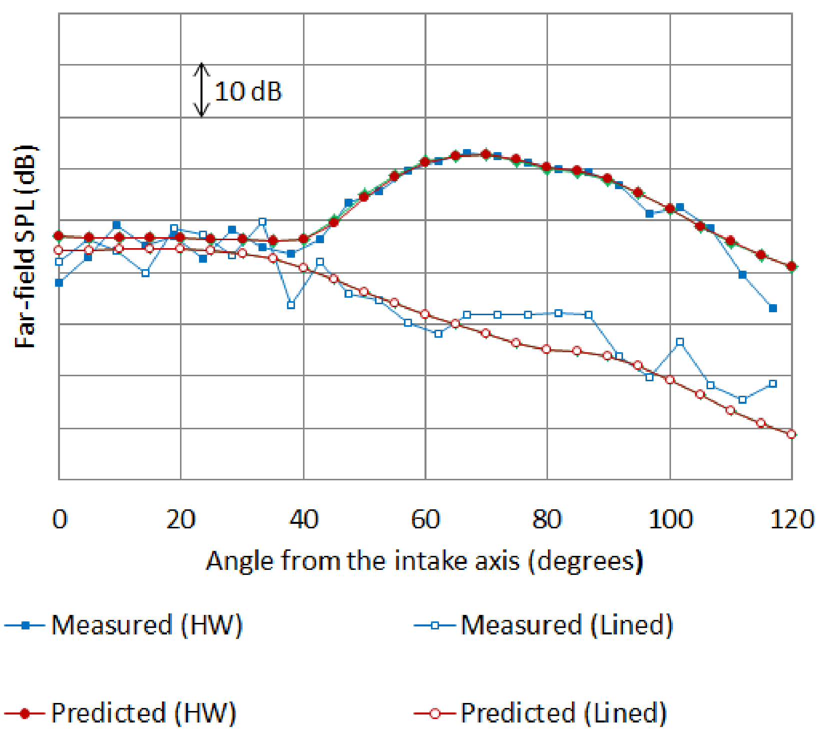
Rotor-locked **Multimodal** **Total**

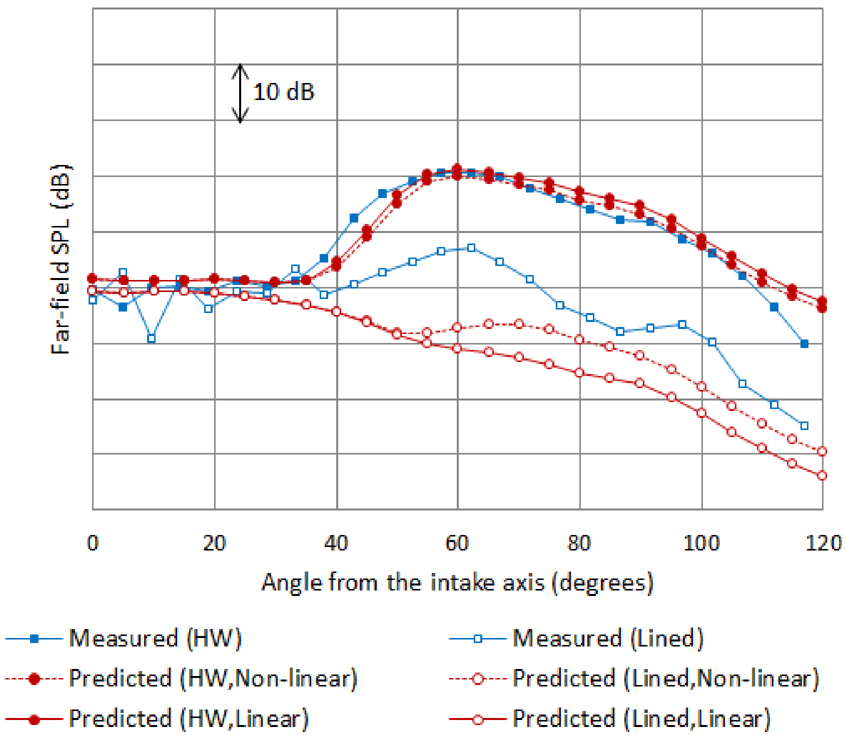
Understanding the modal structure is key to understanding the liner attenuations

Prediction of fan BPF tone

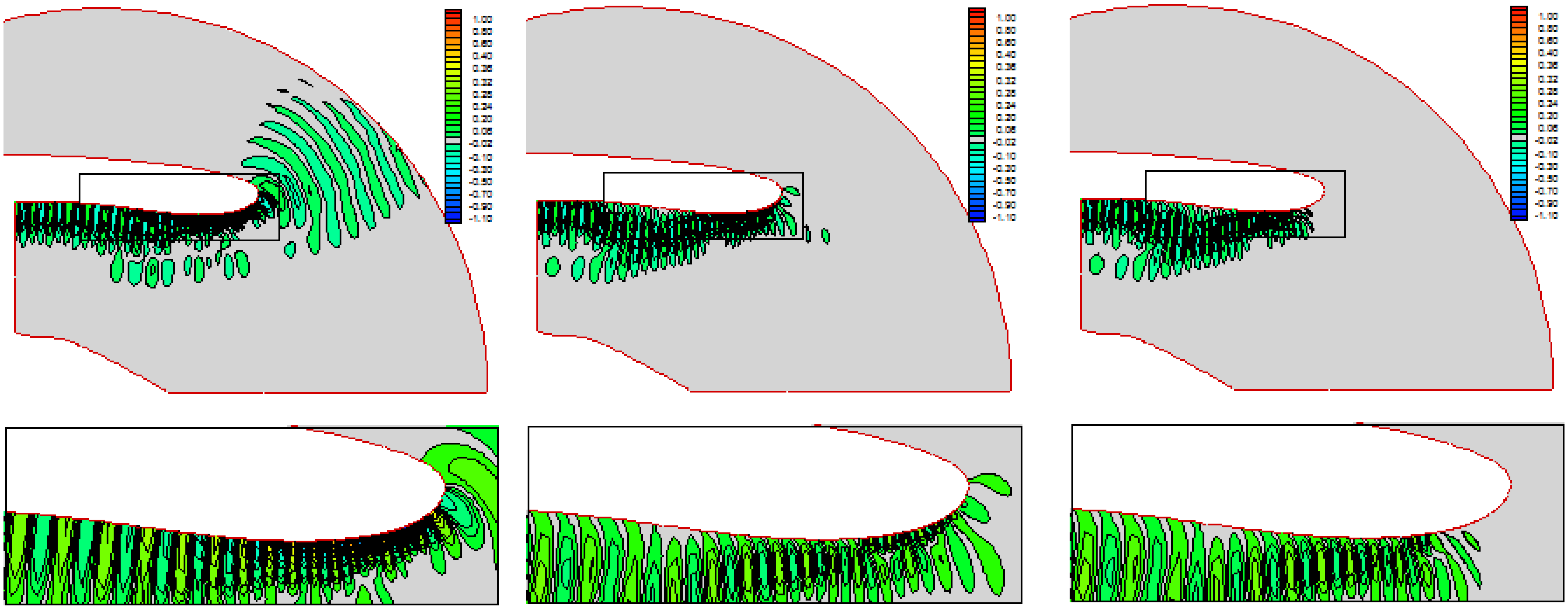
With acknowledgements to ISVR







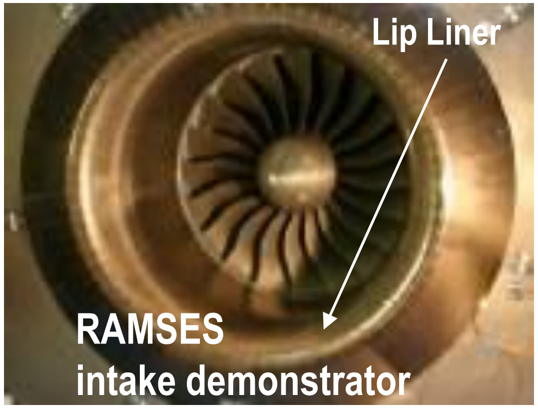
Intake Lip Liner



Hard walled **Barrel liner** **Lip & Barrel liners**

With acknowledgements to ISVR

Intake Lip Liner



- **Intake lip liners must be integrated with the anti-icing system and must not cause the intake aerodynamics to deteriorate.**

Bypass duct liners

- The three-dimensional nature of the both the duct geometry and the duct flow (including thicker boundary layers and swirl) is greatly increased, and the radiation of sound to the communities around airports is subject to refraction and frequency-broadening as it propagates across the sheared turbulent jet flow.

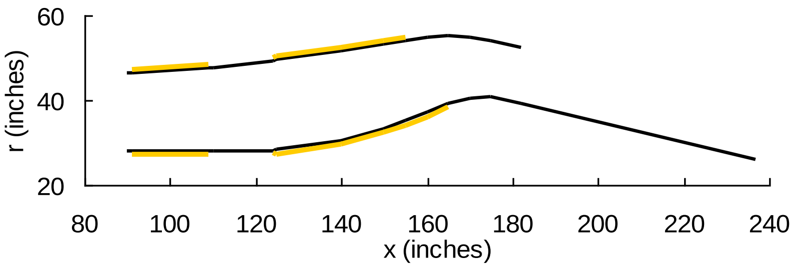
- Furthermore, the bypass duct is required to perform many duties:
  - enabling surface cooling in the engine
  - providing air to ventilate various zones in the engine
  - redirecting fan air for reverse thrust
  - allowing the bleeding of air from the engine core to improve engine handling.

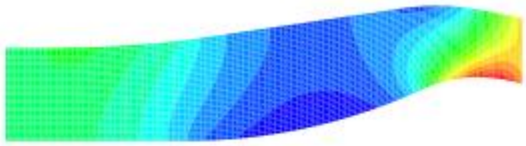
  Acoustic liners must compete for space with all these features in the bypass duct, so that the area available for acoustic liners is greatly reduced.

Multi-Disciplinary-Optimisation of Bypass Ducts

A total-system multi-disciplinary-optimisation design approach is required. For example, highly-curved short bypass ducts bring benefits in terms of aircraft weight and fuel burn but careful design is required to reduce the noise penalty associated with the reduced acoustic liner area.

Bypass-Duct Propagation Model

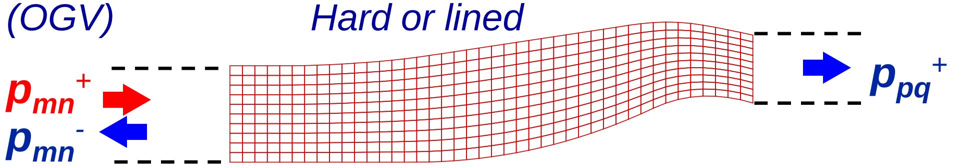


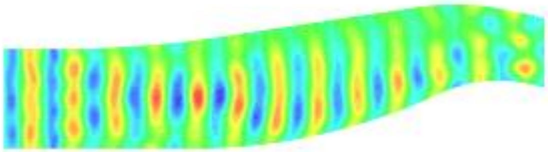


Input plane
(OGV)

Outer/inner walls
Hard or lined

Exhaust plane





With acknowledgements to ISVR

Core-Duct Liners

- **Acoustic liners in the core duct need to survive in the very hot environment.**

- **3D curvature is large, making manufacture difficult**

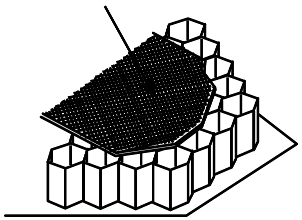
- **The liners need to attenuate simultaneously both low-frequency combustion noise and high-frequency turbine noise.**

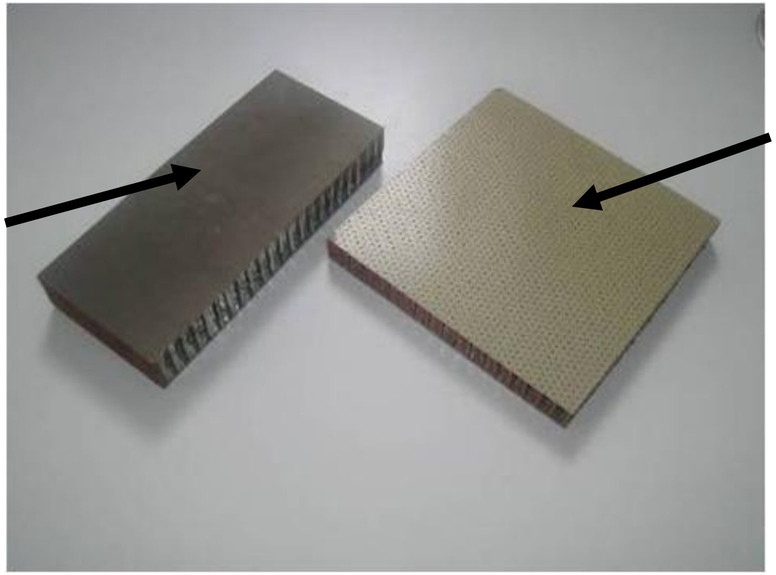
- **A total-system multi-disciplinary-optimisation design approach is required. There is a trade between penalising the turbine's weight and performance to reduce noise at source against increasing the engine weight and maintainability problems by incorporating acoustic liners in the core duct.**

Liner Types in common use

Single Layer Linear

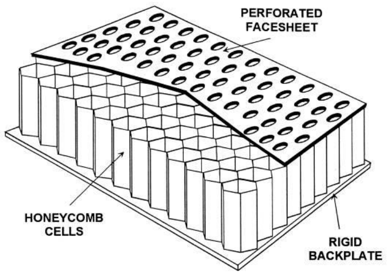
Wire mesh on perforate sheet + honeycomb + hardwall backing sheet



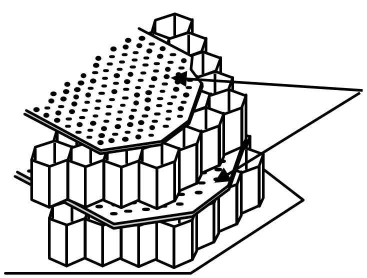


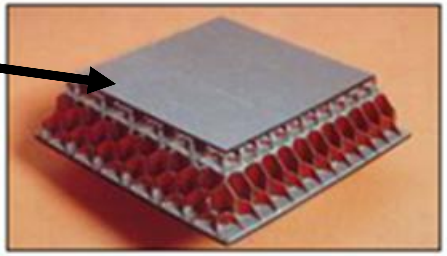
Single Layer Perforate

Perforate sheet + honeycomb + hardwall backing sheet



Double layer liners





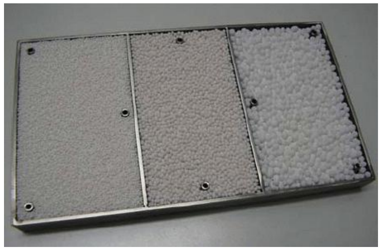
Perforated sheets

- ***Punched Aluminium***
- ***Mechanically Drilled Carbon Fibre Composites***
- ***Laser Drilled***
- ***Injection Moulded***
- ***Microperforates***

Novel Liner Materials

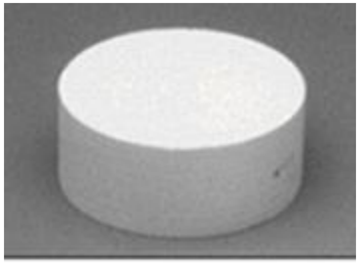
Bulk Absorber materials

Metal Casing Ceramic Hollow Spheres



Felt Fibre

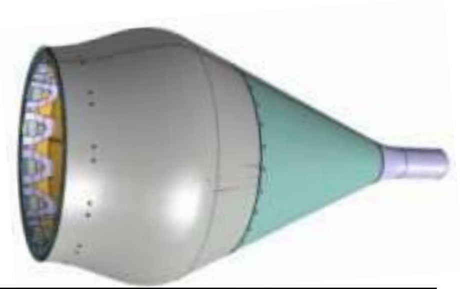
Ceramic Foam



Ceramic Fibre

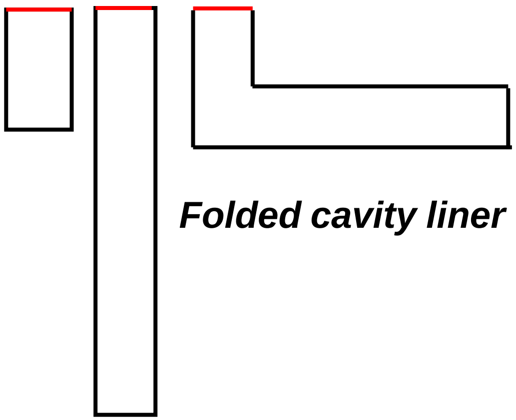
Composite Ceramics Technology

Metallic Plug



Composite Plug

Novel low-frequency liners

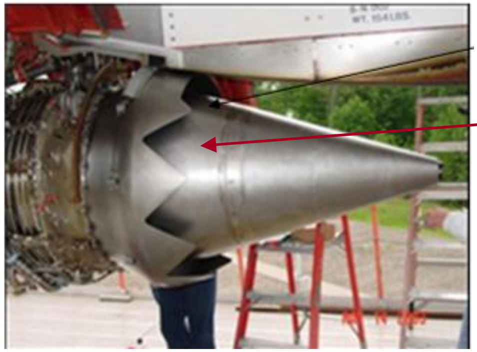


Folded cavity liner

'Special Acoustic Absorber' liner

With acknowledgements to EADS

Large Folding Cavity Plug



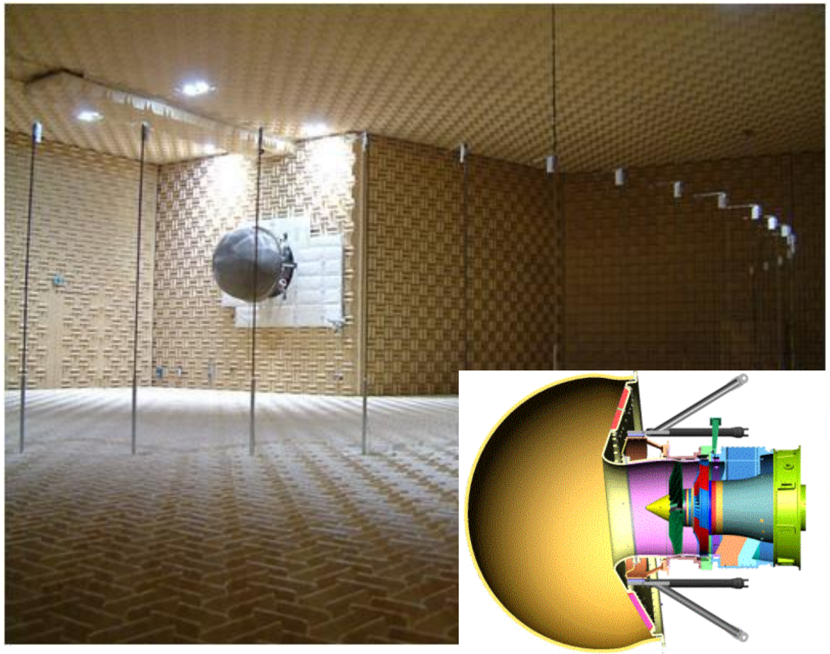
Microperforated Skin

Septum

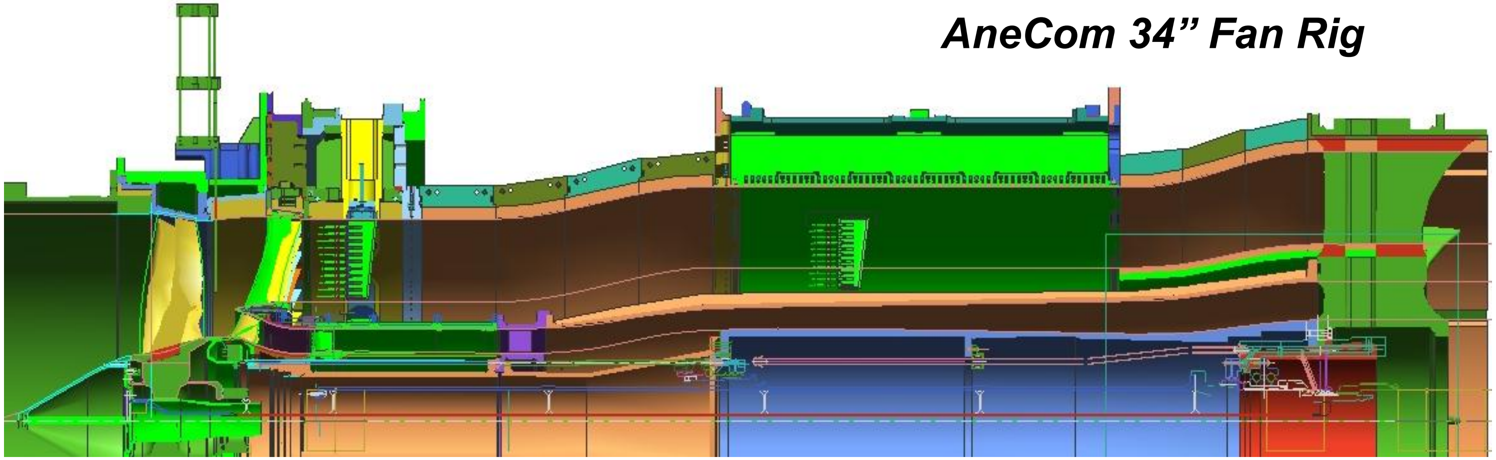
With acknowledgements to Goodrich

Liner rig tests

NASA GRC 48” Fan Rig



AneCom 34” Fan Rig



Liner engine tests

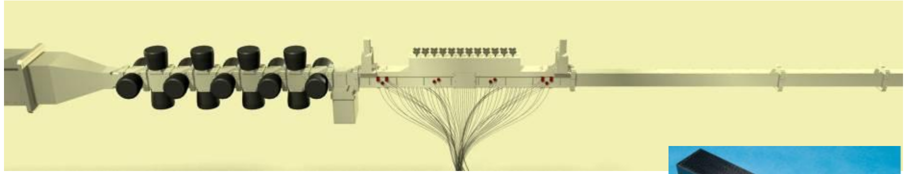
Rolls-Royce/Airbus SILENCE(R)

Rolls-Royce/Boeing QTD

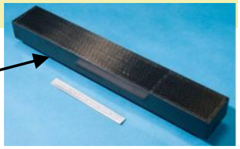
Liner Impedance Measurements

DC Flow Resistance

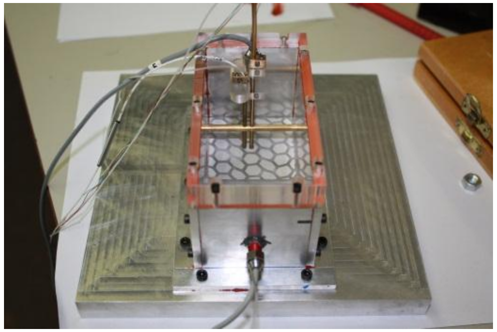
NASA Grazing Flow Impedance Tube



Test sample



Portable Acoustic Liner Meter



NLR In-Situ Impedance Measurements

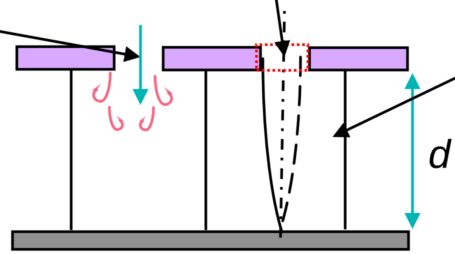
Liner Impedance Models

$$Z = R + i[km - \cot(kd)]$$

Facing sheet resistance *Facing sheet inertance* *Cavity reactance*

pressure drop

$$\Delta p = R \rho c u$$



- **Acoustic liner facing sheet resistance depends significantly on the manufacturing technique employed**
- **CFD techniques are required to inform liner acoustic impedance prediction models, in particular the resistance of facing sheets in grazing flow**
- **CAA techniques are required for impedance models of novel liners and for design features that result in liners being non-locally reacting (e.g. drainage slots)**

Summary

- Aero-engine acoustic liners are an essential feature of low-noise jet aircraft, but, in addition to noise requirements, acoustic liners must satisfy many other design constraints
- Single-layer and double-layer liners with perforate and mesh facing sheets are standard on aero-engines, but more research is required to understand their acoustic impedance characteristics.
- More research is also required into novel liner designs and novel materials for acoustic liners.
- In order to ensure aero-engine liners are optimised, improved duct propagation prediction models are required, in particular for 3D intakes (including non-linear propagation effects) and for 3D bypass ducts (including propagation through the jet shear layer)