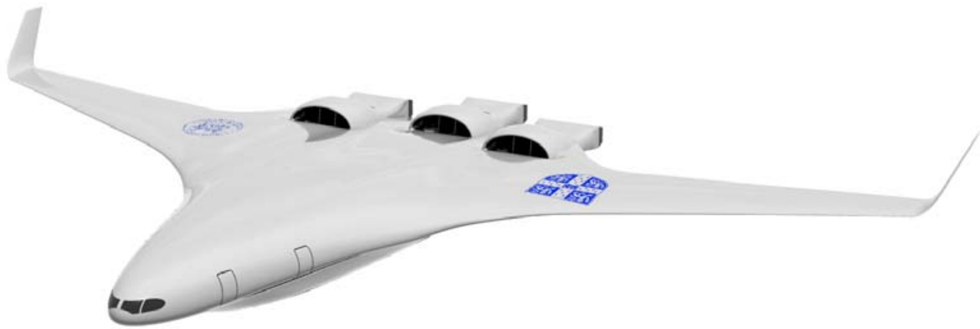
The Cambridge-MIT Institute

Silent Aircraft Initiative

The Silent Aircraft Initiative – Overview

Ann Dowling and Ed Greitzer

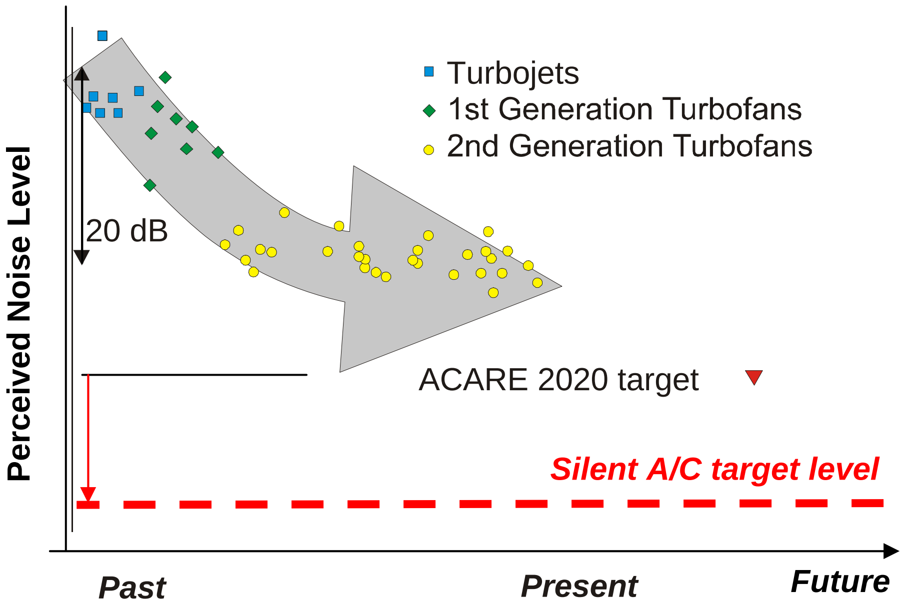


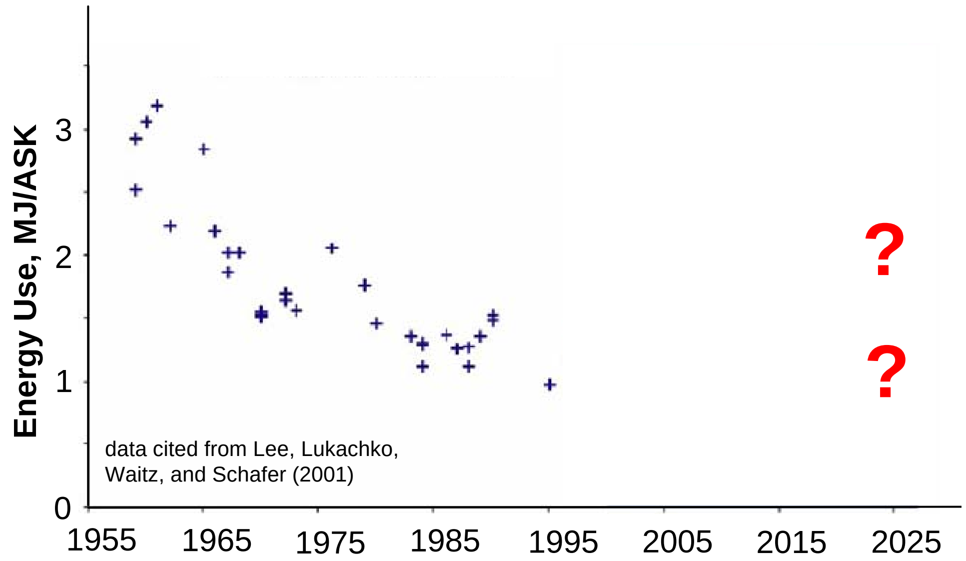
Presented at the 45th AIAA Aerospace Sciences Meeting, Reno, 9th January 2007

Background to the Silent Aircraft Initiative (SAI)

- A collaborative, multi-disciplinary project between MIT, Cambridge University, and a diverse Community of Partners
- Funded by CMI (Cambridge-MIT-Institute) and partners
- CMI's aim is
  - to fund bold experiments designed to understand and improve knowledge exchange
  - to set these experiments in the context of research programmes aimed at creating important new ideas, developed with a consideration for use
- SAI is one such research programme and is centered around a Knowledge Integration Community (KIC) addressing a 'grand' challenge

The Challenge





- **Starting with a blank piece of paper, can one design a mid-range passenger aircraft that is inaudible outside a typical airport?**

- **If so, how does this 'silent' aircraft compare to existing and next generation aircraft in terms of fuel burn and emissions?**

The Knowledge Integration Community (KIC)

is a community of over 30 aerospace partners, industry, airline and airport operators, policy makers and academics

There has been continuous involvement of the KIC from first day of project at strategic and working levels helping to:

- prioritise research items and focus on key issues
- make decisions as a multi-disciplinary team
- provide continuous support with knowledge and access to some industry software tools
- review and provide feedback on the emerging designs

Some of the members of the Knowledge Integration Community

Cambridge/MIT Silent Aircraft Team ~ 40 Researchers

Faculty: A. Dowling, E. Greitzer, H Babinsky, P. Belobaba, J.-P. Clarke, M. Drela, C. Hall, W. Graham , T. Hynes, K. Polenske, Z. Spakovszky, I. Waitz, K. Willcox, L. Xu

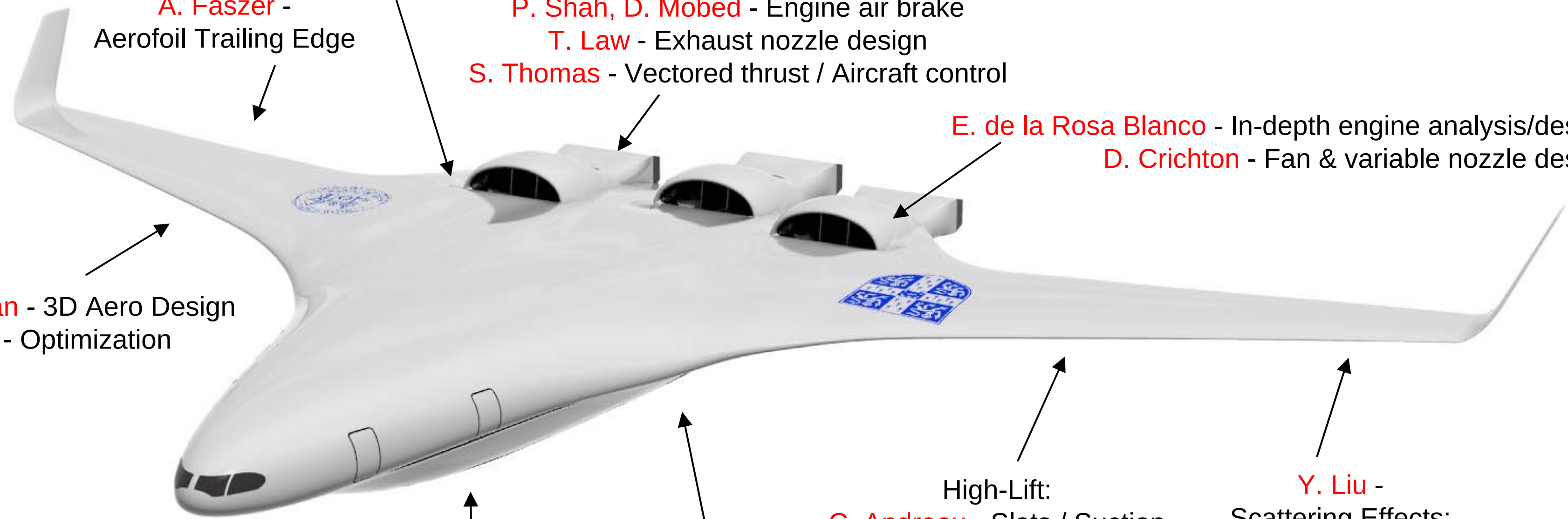
V. Madani - Inlet design
A. Plas - Effect of boundary layer ingestion on fuel burn
M. Sargeant - Inlet/airframe integration / 3D Airframe CFD

R. Tam - Economics
T. Reynolds - Operations

A. Faszer - Aerofoil Trailing Edge

P. Shah, D. Mobed - Engine air brake
T. Law - Exhaust nozzle design
S. Thomas - Vectored thrust / Aircraft control

E. de la Rosa Blanco - In-depth engine analysis/design
D. Crichton - Fan & variable nozzle design



J. Hileman - 3D Aero Design
A. Jones - Optimization

High-Lift:
C. Andreou - Slats / Suction
A. Townsend - L.E. Rot Cylinder

Y. Liu - Scattering Effects: Surface finish

A. Quayle - Undercarriage

A. Agarwal – Acoustic Shielding

H.-C. Shin - Acoustic Measurements & Phased Array Design

Former Members:
A. Diedrich - SAX10 planform
P. Freuler - Inlet Design
D. Tan - Noise propagation modeling
G. Theis – Economics
N. Sizov – Operations
R. Morimoto - Economics
C. Hope – Economics
K. Sakaliyski – Drag Rudders / Spoilers
P. Collins - KIC Manager

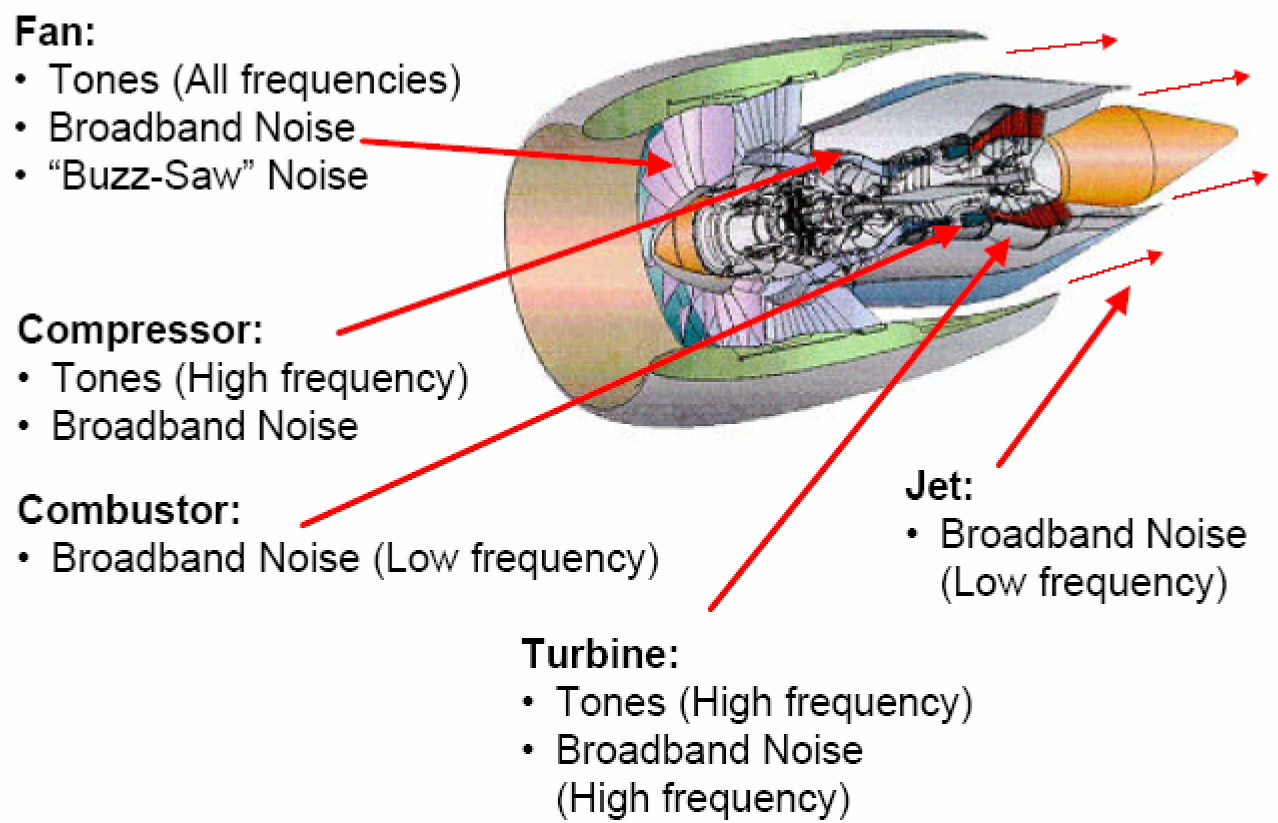
Chief Engineers: J. Hileman and Z. Spakovszky

Process

- Spent over half a person-century of work on conceptual aircraft design (3 year project, a team of ~40 researchers)
- Used industry design codes where possible
- As we moved outside the usual design space, we needed to develop new models
- Noise estimates were validated where possible through noise measurements of components in wind-tunnels/open jets with phased microphone arrays
- Technologies and modelling integrated around a strong product focus of the 'Silent' Aircraft
- Researchers operated as an integrated team

Noise sources on conventional aircraft

Main engine noise sources



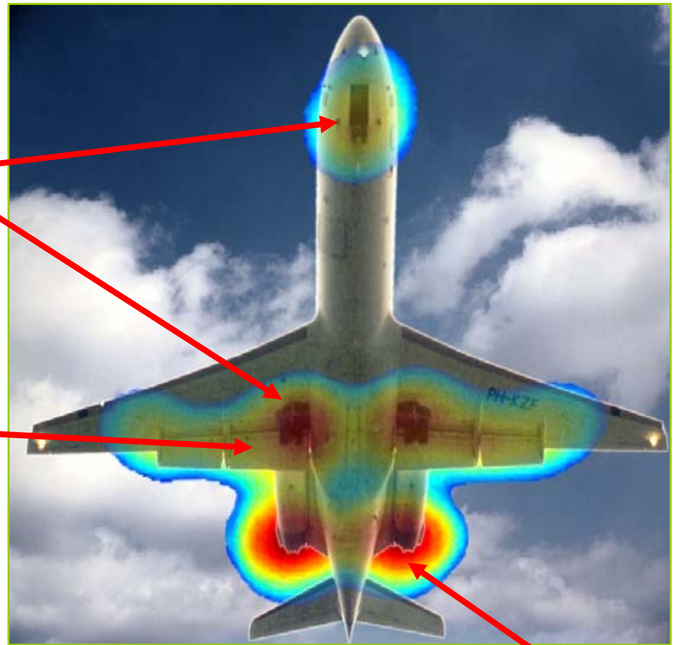
Noise sources on conventional aircraft

Main airframe noise sources

undercarriage

flaps

slats

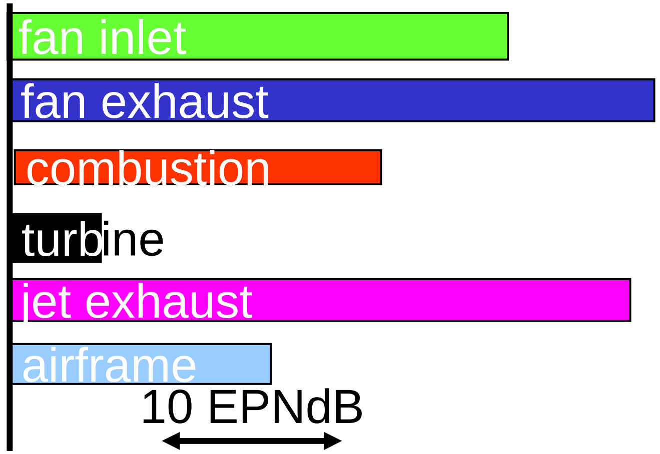


courtesy of NLR

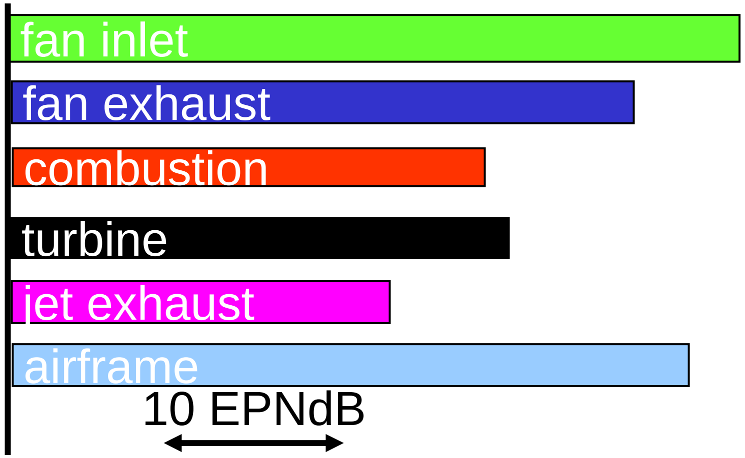
jet noise contribution

Noise sources on conventional aircraft

- Take-off



- Approach



What can we do about them?

- Take-off

- Approach

•Low-noise operations informing the design

• Greater integration of airframe and engine

• Use airframe to
    • shield engine noise
    • provide room for extensive acoustic liners

• Need quiet high-lift and drag

• Lower jet noise

Evolution of the Design

***SAX-10**: First Generation Design*

- Based on Boeing PW planform design tool
- Optimized on maximum take-off weight
- 4 Granta-252 engines
- First industry non-advocate reviews

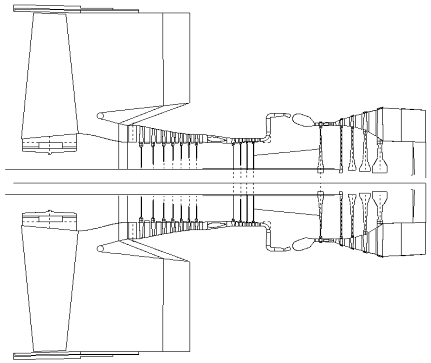
***SAX-20**: Second Generation Design*

- 3D airframe design methodology
- Design for low stall speed to reduce approach noise
- 3 Granta-3201 clusters
- Boeing Phantom Works design review and 3D viscous analysis

***SAX-40**: Third Generation Design*

- Optimized outer wing using 3D design methodology
- Elliptical lift distribution
- Distributed propulsion: 3 Granta-3401 clusters
- Second industry non-advocate reviews

Granta-252 (4 Engines)



Geared Low Pressure Turbine
No Boundary Layer Ingestion

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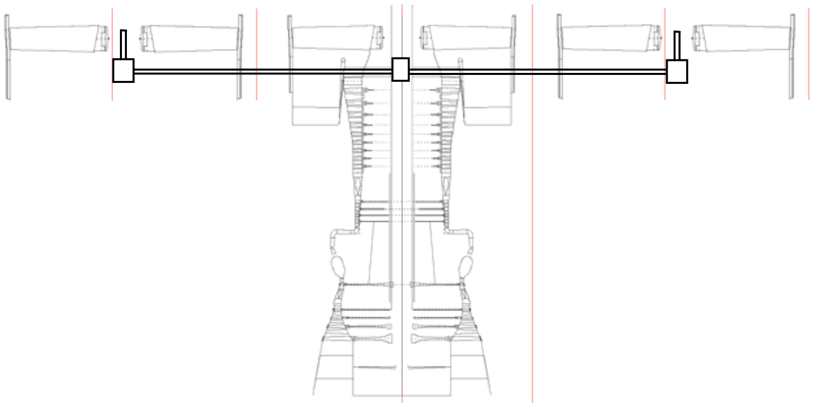
SAX-20

Granta-3201 (3 Engines)



Boundary Layer Ingestion
Gear and Transmission Concepts

Evolution of the Design

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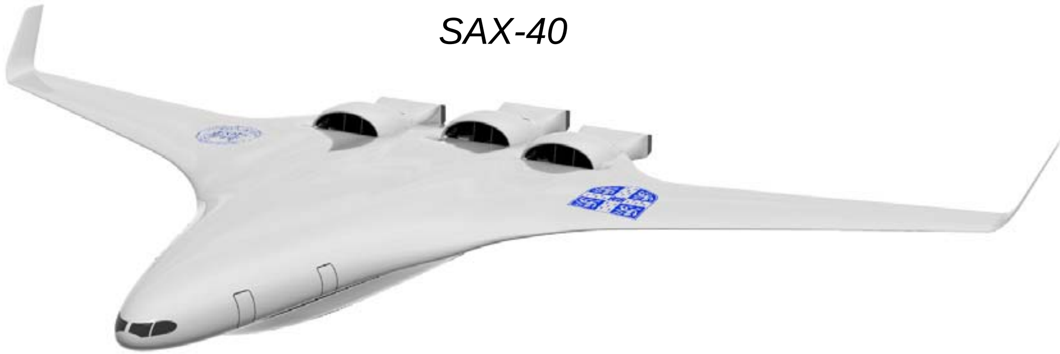
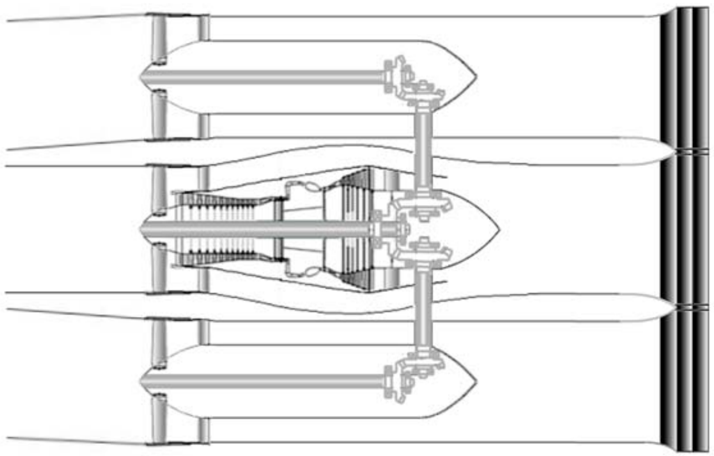
SAX-40



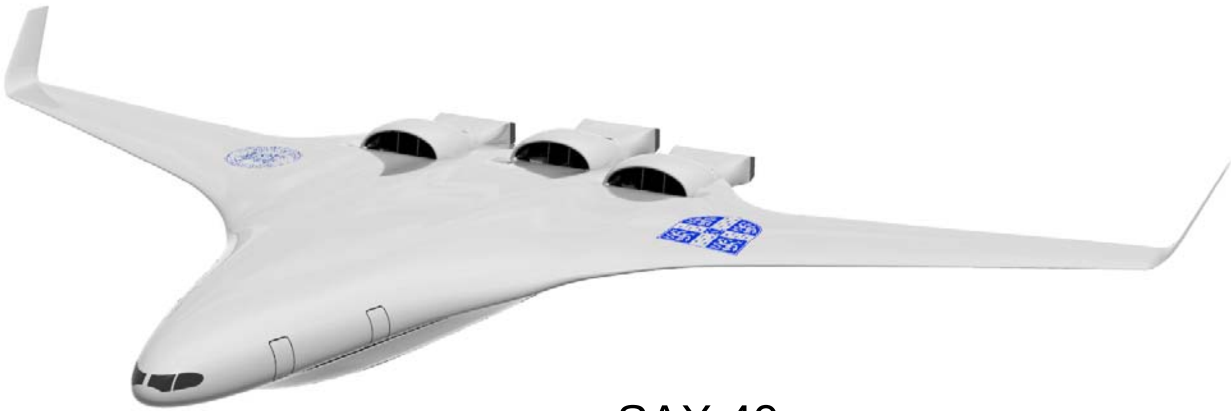
Granta-3401 (3 Engines)



Boundary Layer Ingestion
Detailed Transmission Design

Summary of Main Outputs from the Silent Aircraft Initiative

- Conceptual design of a 215 PAX 5000nm ‘silent’ aircraft



SAX 40

- Noise level predicted to be less than 62 dBA beyond airport perimeter
- Fuel Burn of 124 PAX-miles per US gallon (cf 101 for B777)

SAX-40 EPNL

SAX-40 is predicted to achieve a step-change in noise from existing fleet.

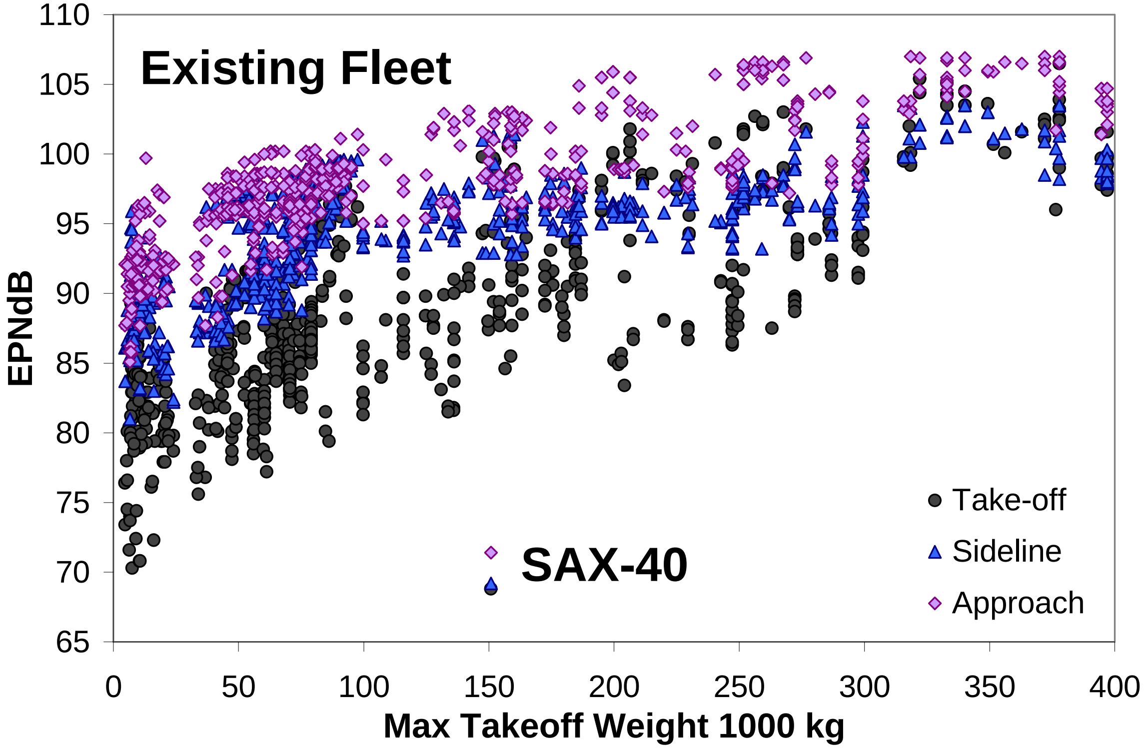
SAX-40 EPNL estimates:

- Sideline: 68.8 EPNdB
- Takeoff: 69.2 EPNdB
- Approach: 71.9 EPNdB

Used ICAO certification points.

Take-off, climb and approach analysed in companion papers:

- AIAA 2007-0451
- AIAA 2007-0456



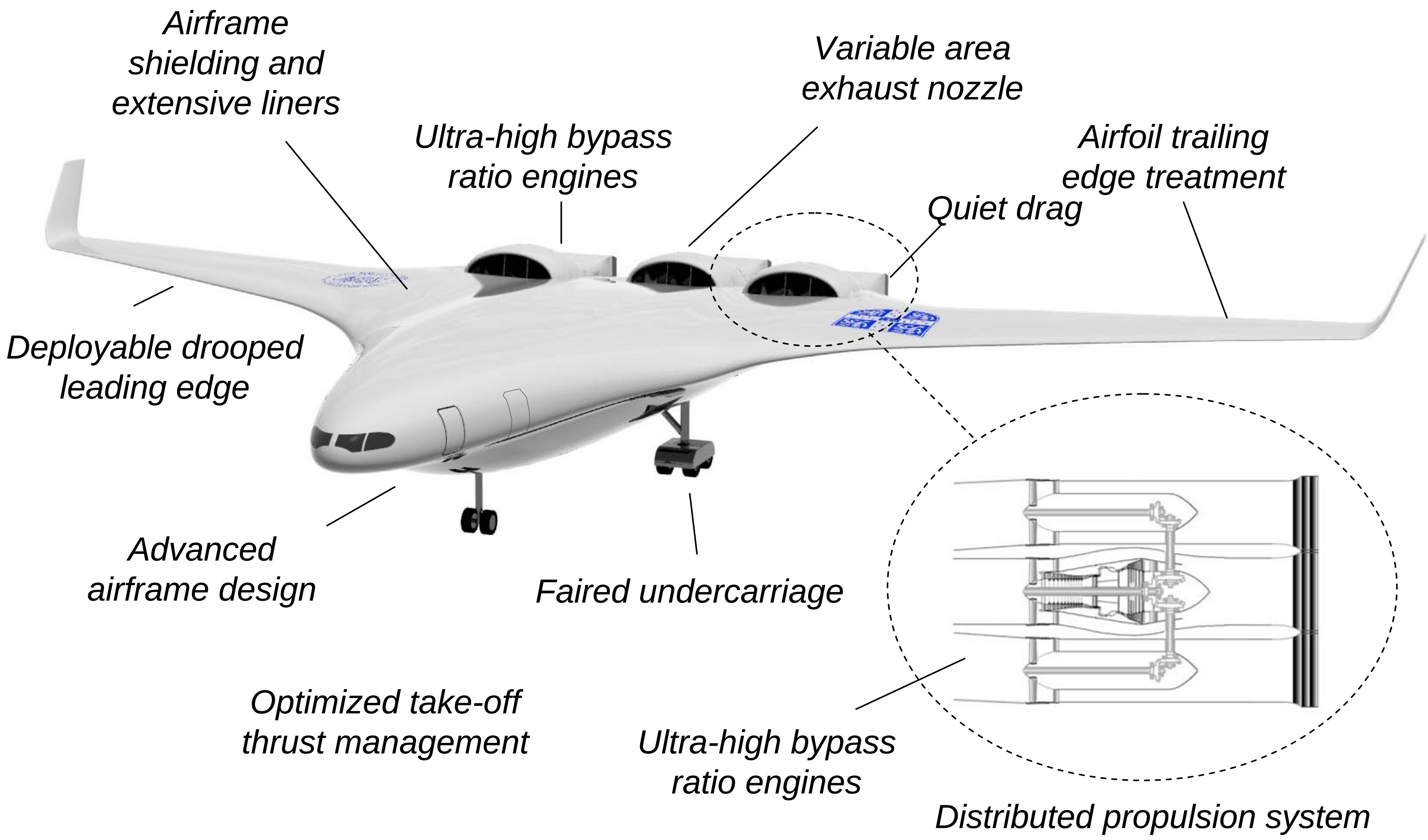
Cumulative noise is **75 cumulative EPNdB** below ICAO Chapter 4 requirement of 284.5 cumulative EPNdB.

Summary of Main Outputs from the Silent Aircraft Initiative

- **Low noise is achieved by**
  - Using the airframe to shield fan noise from listeners on the ground
  - extensive sound absorption
  - novel ultra-high bypass engines with a variable-area exit nozzle can be configured for low noise at take off and for minimum fuel burn in cruise
  - after take-off, choosing the power settings and climb rate to minimise noise
  - low airframe noise on approach which is due to
    - an efficient airframe enabling approach at lower speed and landing further down the runway
    - engine with low flight-idle speed and quick spool up time
    - a design with no flaps or slats
    - a deployable drooped leading edge on the wings to enable low-speed flight without more noise
    - low-noise fairings on the undercarriage
    - low-noise drag
    - advanced airfoil trailing edge treatment

- Low noise is thus not due to a single design feature but rather integration of many disciplines into the design and operation of a noise-minimizing aircraft

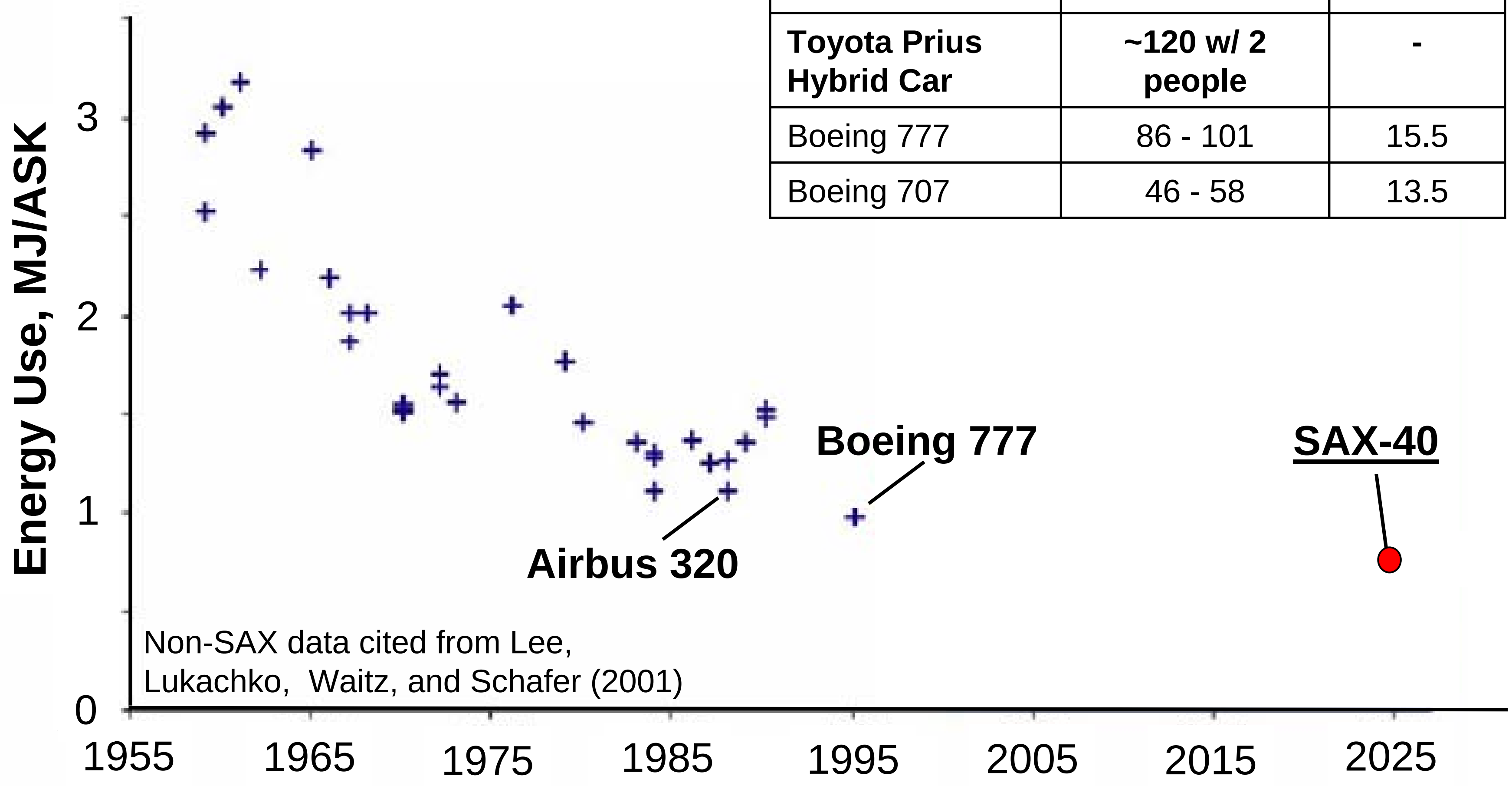
Enabling Technologies for Low Noise



SAX-40 Fuel Efficiency

In addition to quiet, analysis suggests high fuel efficiency.

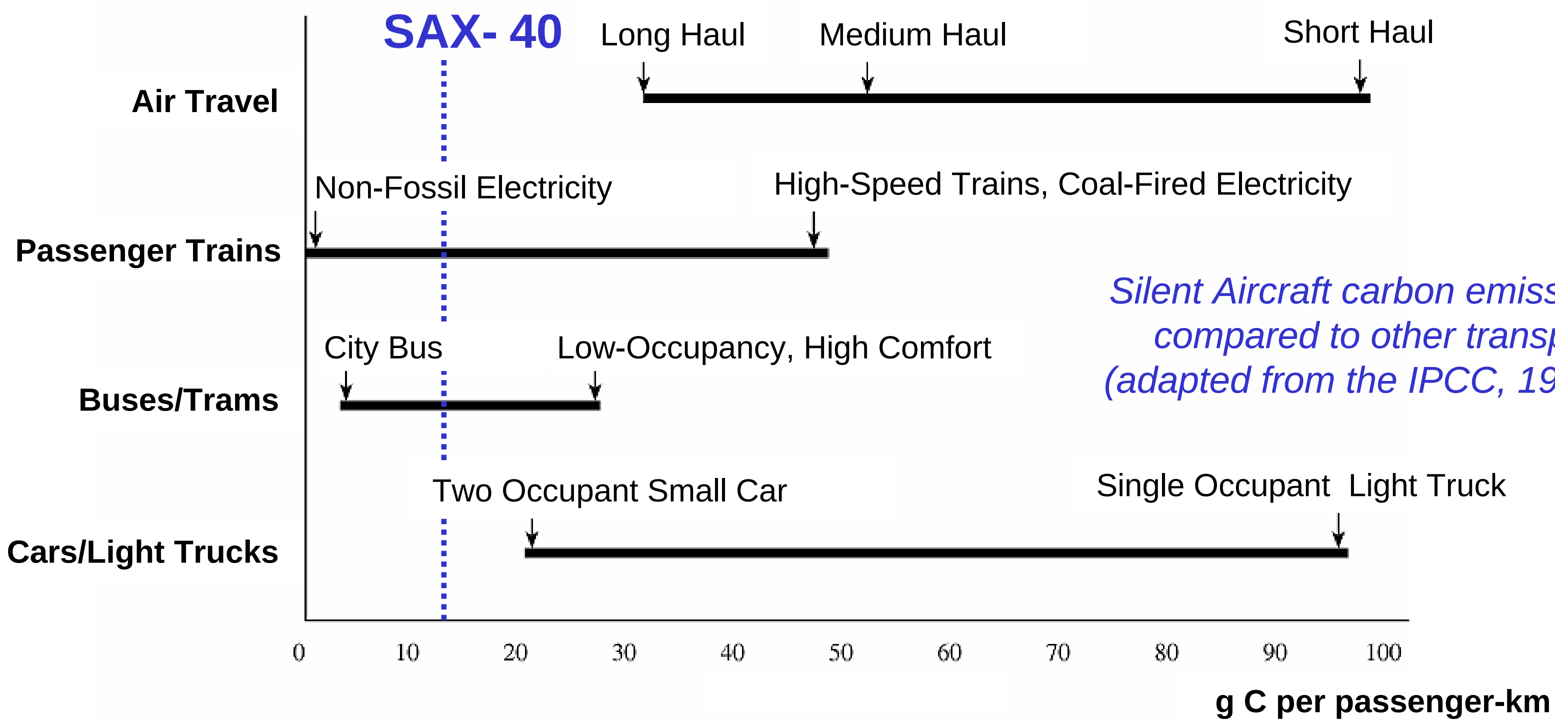
	passenger miles per gallon	Mach * Lift/Drag
SAX-40	**~124**	**20.1**
Toyota Prius Hybrid Car	**~120 w/ 2 people**	**-**
Boeing 777	86 - 101	15.5
Boeing 707	46 - 58	13.5



Comparison with other forms of transport

Low noise solution expected to have low pollutant emission.

Low pollutant emission primarily a result of low aircraft fuel burn.



Silent Aircraft carbon emission compared to other transport (adapted from the IPCC, 1999)

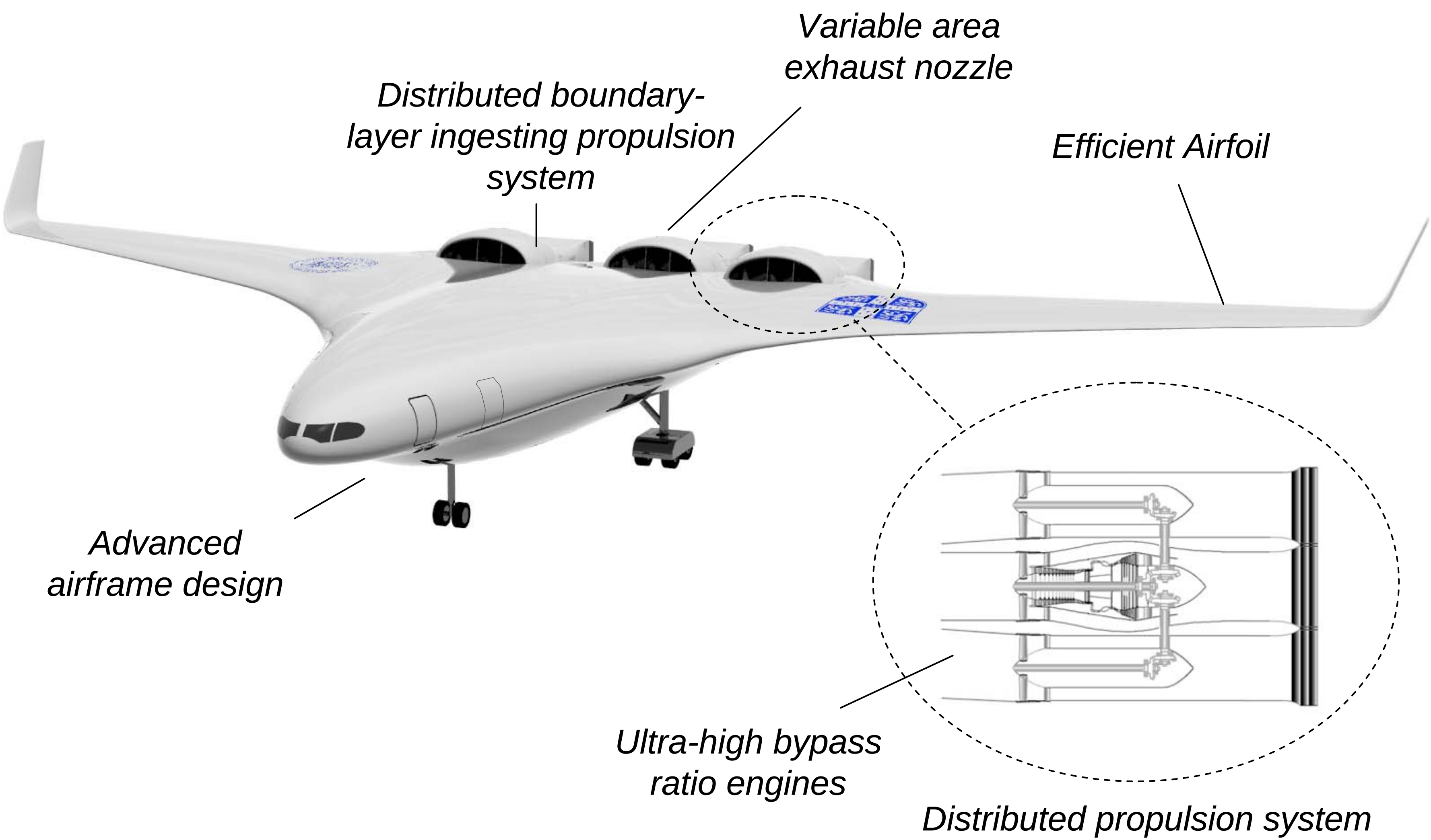
Total CO_2 emission is 89.5 g per pass-nm

Total NO_X emission is 0.22 g per pass-nm

Summary of Main Outputs from the Silent Aircraft Initiative

- **Low fuel burn is achieved by**
- a very efficient aircraft based on the 'flying wing' or Blended-Wing-Body, with a lift to drag ratio of 25 to 1 (some 10% higher than other designs)
- the aircraft wake is further reduced by ingesting the air near the aircraft into the engines
- the engine exit nozzle is adjusted for optimum efficiency throughout cruise

Enabling Technologies for Low-Fuel burn



Summary of Main Outputs from the Silent Aircraft Initiative

- **The conceptual design has relied on advances in**
  - design methodology, integrating low-noise and low-fuel burn technologies with optimised operations
  - methods to predict and measure noise

- **In addition to the conceptual design, the research has included**
  - Identification of specific major technology challenges that must be addressed to enable a silent aircraft
  - Study of the business case for a ‘silent’ aircraft
  - Economic study of a the impact of a ‘silent’ aircraft on regional economy in UK
  - Noise / fuel decrease through new operational strategies (enhanced CDAs) for existing aircraft

SAI Operations Activities

- Develop noise abatement approach procedures
  - Silent Aircraft (long term)
    - Slow, displaced threshold, Continuous Descent Approaches
  - Existing aircraft (short term)
    - CDAs at Nottingham East Midlands Airport (NEMA)

- Simulation and analysis tool development
  - Flyability, Noise, Fuel burn, Emissions

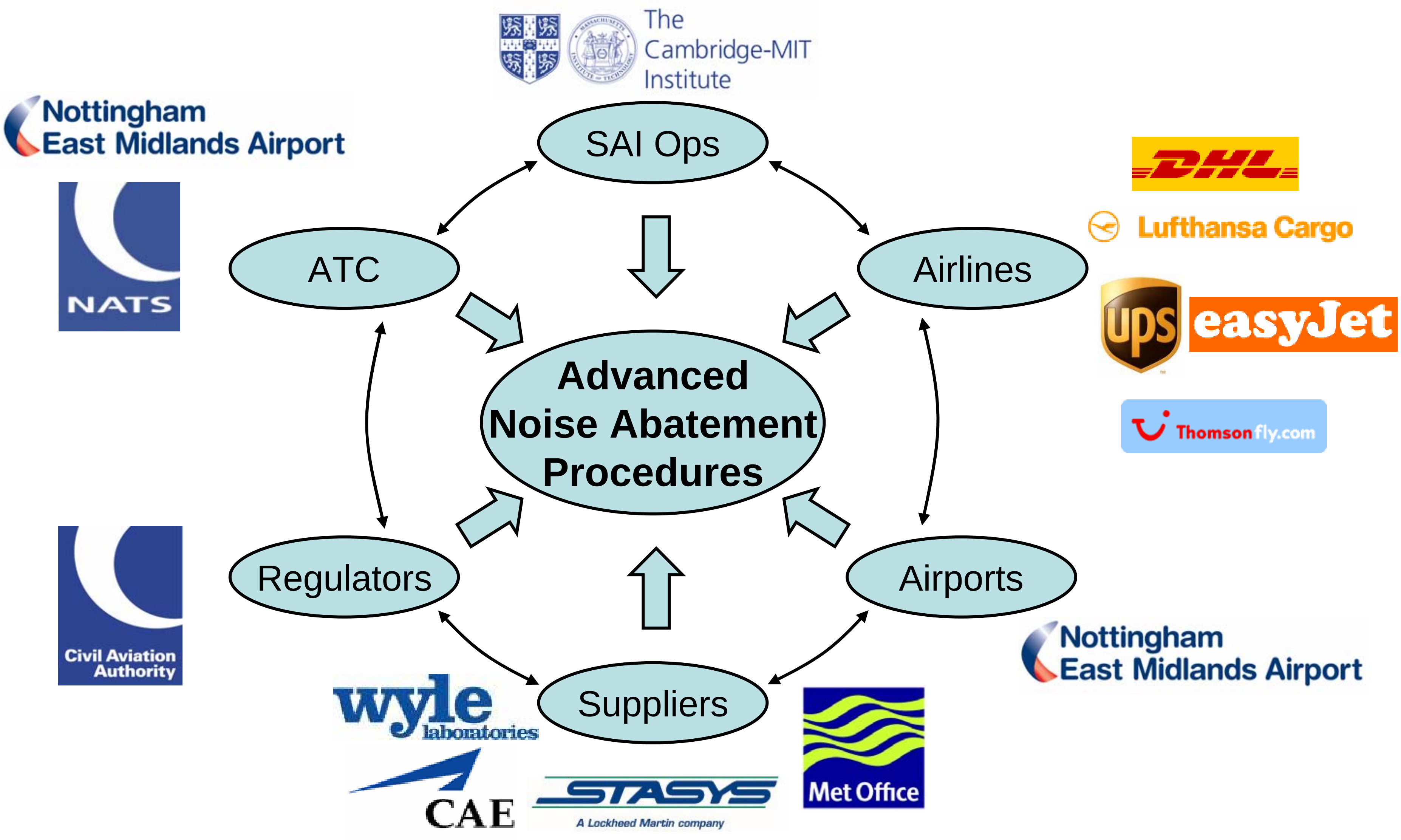
Ops team in airline simulator

A320 (easyJet) & 767 (UPS) tested procedures in simulator under variety of wind and pressure environments lead to minor changes before the flight trials (ongoing)

Knowledge Exchange

- Knowledge Integration Community as a model for the aviation industry, government and universities working together
  - University researchers using industry design codes
  - Industry participation at both a strategic and a working level
    - Frequent interaction
    - Two-way flow of information
  - Collaborative development and implementation of enhanced CDAs
  - Industry and government laboratory reviewing and providing feedback on the emerging design and supporting technologies
    - Boeing, Rolls-Royce, ITP, NASA
    - Tangible SAI action in response to industry comments
- KIC composed of diverse constituency, with wide range of views
- Engagement with public through lectures, interviews, and the press as well as through schools outreach activities

Strong Collaboration is Critical



Processes

- Integrated product team approach to project
  - Regular (2 weekly) videoconferences
  - Product ('Silent' aircraft) focus
  - Peer review of students' work
- Ad hoc "task force" formation for specific aspects
- Creation and transfer of knowledge through frequent exchange of people
- Joint (across universities) publications and presentations
- Collaboration with KIC
  - academia – industry – government, throughout project

People & Education

- 12 Masters students
- 13 PhD students
- 23 Undergraduates as Final Year Project students or UROPs (Undergrad Researchers)
- 2 RR trainees based in Cambridge working with SAI team
- New CU undergraduate course involving many Silent Aircraft team members
- New MIT aeroacoustics graduate course
- Outreach to school children via
  - Brunel Lecture, Farnborough Air Show Youth Day
  - school design projects on undercarriage noise mitigation tested in Markham tunnel
- Bottom line: Trained people with the appropriate skills for effective integration of complex systems (e. g., an aircraft)

SAI Papers

- *This session*
- AIAA-2007-0453 Airframe design
- AIAA-2007-0454 Engine design
- AIAA-2007-0450 Boundary-layer ingestion
- AIAA-2007-0456 Take-off
- AIAA-2007-0451 Approach
- AIAA-2007-0455 Economics

- *Yesterday*
- AIAA-2007-0230 Drooped leading edge for high lift
- AIAA-2007-0231 Landing gear

- *Wednesday morning*
- AIAA-2007-0866 Dynamics and control

- *Wednesday afternoon*
- AIAA-2007-1032 and AIAA-1007-1033 Quiet drag

SAX 40 – Silent Aircraft Conceptual Design