# Aircraft Design and Engine-Airframe Integration for Reduced Environmental Impact

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**Bristol University – 6th November 2014**

# ACARE* targets for 2020

Reduce perceived external noise by 50%



Reduce fuel consumption and $CO_2$ emissions by 50%

Reduce $NO_X$ emissions by 80%

Targets for new aircraft and whole industry relative to 2000

**AeIGT**

* <u>A</u>dvisory <u>C</u>ouncil for <u>A</u>eronautical <u>R</u>esearch in <u>E</u>urope

# New ACARE Vision – "FLIGHTPATH 2050"

**In 2050:-**

• Technologies and Procedures available to give 75% reduction in $CO_2$ emissions , 90% reduction in NOx emissions and 65% reduction in perceived noise (relative to new aircraft delivered in 2000)

• Aircraft are emission free when taxiing

• Air vehicles designed and manufactured to be recyclable

• Europe established as a centre of excellence on sustainable alternative fuels including for Aviation

• Europe leading on atmospheric research and establishment of global environmental standards

# Contrails and Contrail induced Cirrus

# Persistent contrail induced cirrus cloud

# Aviation chief contributors to Climate Change (after TRADEOFF, 2003)

- **$CO_2$**                                            **100%**

- **$NO_X$ (net effect of $O_3$ – $CH_4$)**        **45%**

- **Contrails plus Contrail Cirrus**      **79 – 355%**

**Total compared with $CO_2$ alone:-**    **224% to 500%**

**To reduce the impact, the most significant improvement will be to reduce fuel burn**

# Reducing NOx –
# the lean-burn premixed combustor



Premixed flame does not
pass through
stochiometric mixture,
avoiding peak NOx
production.
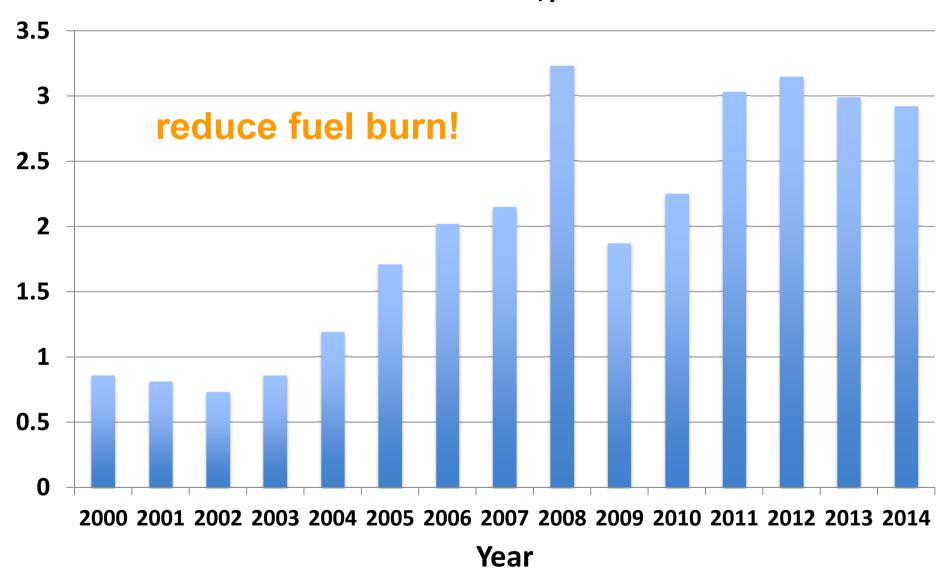
Direct injection, lean-burn
single annular combustor

Staged injector

40% CAEP/2 NOx

Source  Rolls-Royce
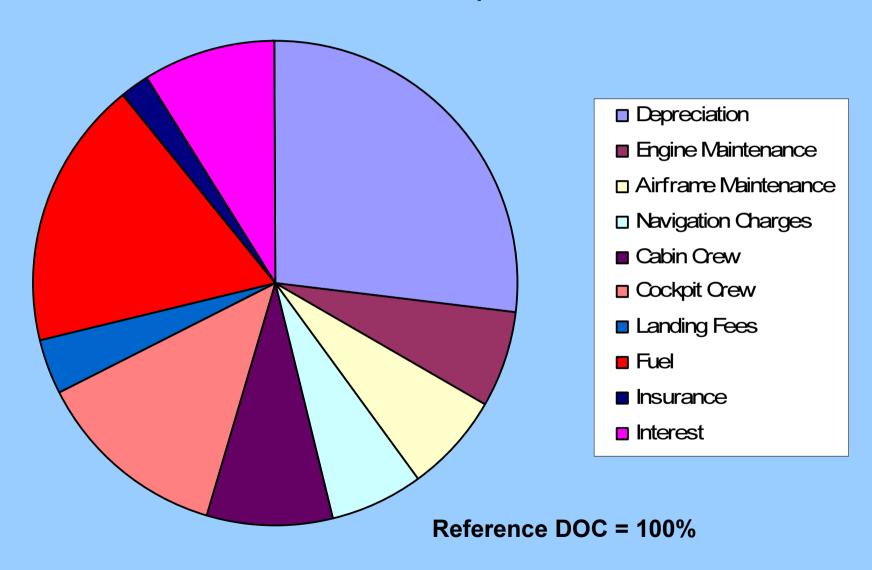
# Aviation Fuel Price - $/US Gallon
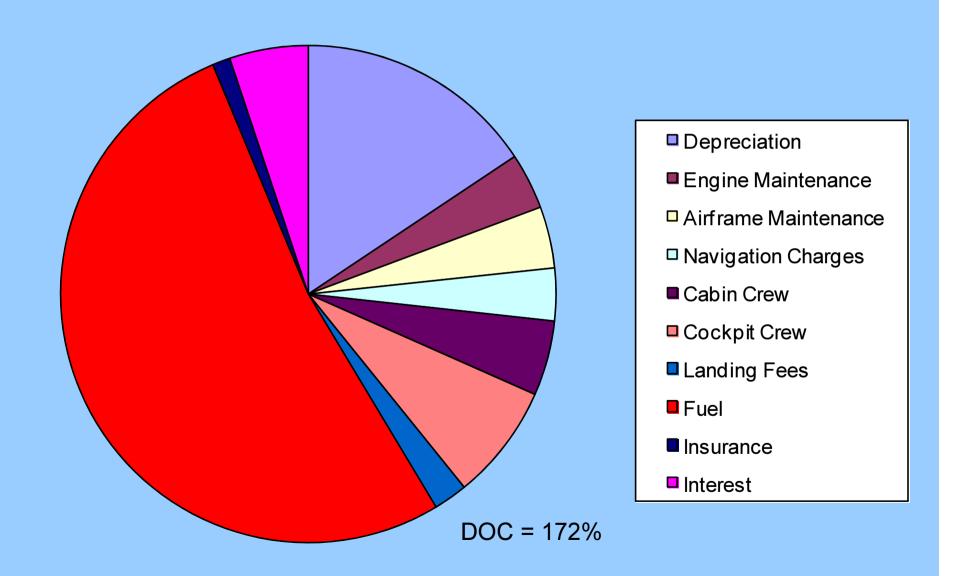
reduce fuel burn!

# What about Bio-fuels?

- It is fundamental that production must be sustainable, without prejudice to land and water resources for food production

- There are good possibilities - for example Halophytes (salt water tolerant plants eg Salicornia) and Algae

- But all predictions are that the cost will be high (at least the equivalent of 4$/USG) and therefore the demand for reduced fuel burn will remain.

**reduce fuel burn!**

**Typical Direct Operating Cost Breakdown -
Fuel Price $0.8**
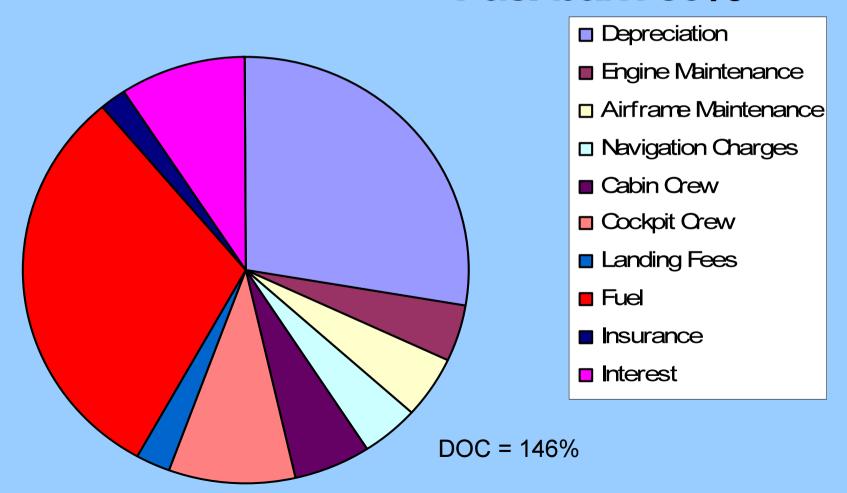
Legend:
- Depreciation
- Engine Maintenance
- Airframe Maintenance
- Navigation Charges
- Cabin Crew
- Cockpit Crew
- Landing Fees
- Fuel
- Insurance
- Interest

Reference DOC = 100%

# Direct Operating Cost Breakdown - Fuel Price $4



**Legend:**
- Depreciation
- Engine Maintenance
- Airframe Maintenance
- Navigation Charges
- Cabin Crew
- Cockpit Crew
- Landing Fees
- Fuel
- Insurance
- Interest

DOC = 172%

Direct Operating Cost Breakdown
- Fuel Price $4
- First cost 150%
- Fuel burn 50%

DOC = 146%

Legend:
- Depreciation
- Engine Maintenance
- Airframe Maintenance
- Navigation Charges
- Cabin Crew
- Cockpit Crew
- Landing Fees
- Fuel
- Insurance
- Interest

# Options for reducing fuel burn per passenger-km

## The Bréguet range equation

Fuel burn per tonne-kilometre
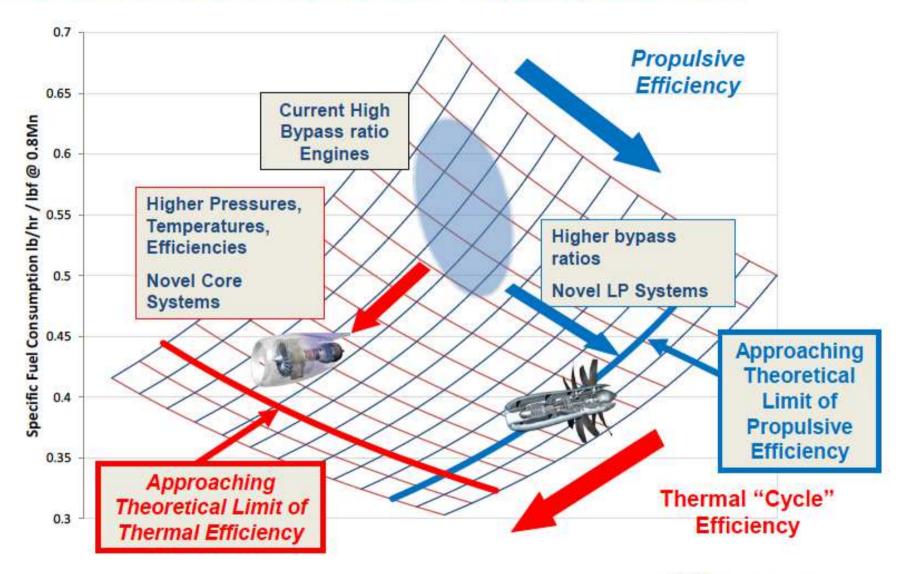
$$\frac{W_F}{W_P R} = \frac{1}{X}\left(1 + \frac{W_E}{W_P}\right)\left(\frac{1.022\exp\left(\frac{R}{X}\right) - 1}{\left(\frac{R}{X}\right)}\right)$$

$W_F$ = Fuel Weight

$W_P$ = Payload

$W_E$ = Aircraft Weight-Empty

$R$ = Range

$X$ = $H\eta L/D$

$H$ = calorific value of fuel

$\eta$ = overall propulsive efficiency

$L/D$ = lift/drag ratio

# Reducing fuel burn by reducing weight – A350 CFRP Fuselage Test Specimen



Copyright Airbus/M.Lindner

# Efficiency improvements - cycle potential



Specific Fuel Consumption lb/hr / lbf @ 0.8Mn

**Propulsive Efficiency**

**Current High Bypass ratio Engines**

**Higher Pressures, Temperatures, Efficiencies**

**Novel Core Systems**

**Higher bypass ratios**

**Novel LP Systems**

**Approaching Theoretical Limit of Propulsive Efficiency**

*Approaching Theoretical Limit of Thermal Efficiency*

**Thermal "Cycle" Efficiency**

**Rolls-Royce**

# Evolutionary development of current powerplants – Higher bypass ratio etc.
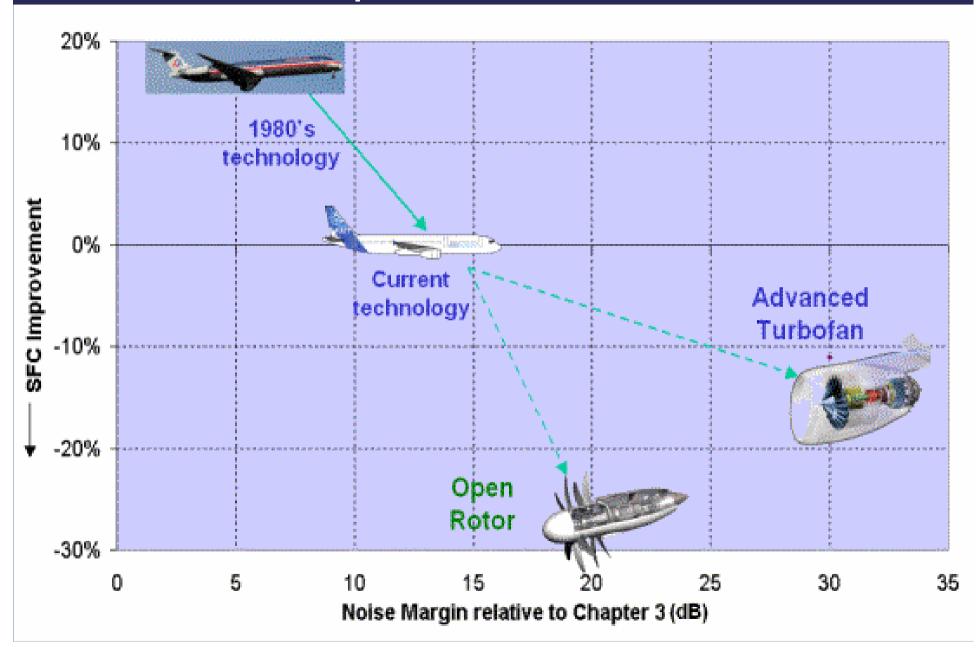
# Open Rotor Configurations

**1952- Bristol Britannia**

# Tupolev TU-114



Ту-114

# A400M

Specific fuel consumption versus noise for open-rotor vs Turbo-fan

# Next generation product evolution



| | Trent XWB | Advance | UltraFan™ / Open Rotor |
|---|---|---|---|
| | World's most efficient engine | | |
| Technology EIS Readiness | | 2020+ | 2025+ |
| Bypass Ratio | | 11+ | 15+ |
| Overall Pressure Ratio | | 60+ | 70+ |
| Efficiency relative to Trent 700 | | 20%+ | 25%+ |

**Rolls-Royce**

007638

# Maximising lift-to-drag ratio in cruise

$$\text{Drag} = qS_{DO} + \frac{\kappa}{\pi q}\left(\frac{W}{b}\right)^2 \qquad (C_D = C_{D0} + \kappa C_L^2/\pi A)$$

L/D is a maximum when the two components of drag are equal, giving

$$\left(\frac{L}{D}\right)_{MAX} = b\sqrt{\frac{\pi}{4\kappa S_{DO}}}$$

when $q = W\sqrt{\dfrac{\kappa}{\pi b^2 S_{DO}}}$

$S_{D0}$ = $\sum SC_{D0}$
W = Weight
b = Span
q = dynamic pressure
$\kappa$ = Induced Drag Factor
L/D = Lift/Drag Ratio

# Minimising Surface Area

# Boeing X48-B  1/6 scale test vehicle – made by Cranfield Aerospace Ltd.

# Reducing $C_{D0}$ - Hybrid Laminar Flow



**Modified Fin**

**Suction System**

**A320 - Hybrid Laminar Flow Fin**

- Flight trials successfully completed

- Up to 50% chord laminarised

- Better than anticipated tolerance to external environment

# Reducing $C_{D0}$ – Natural Laminar Flow
# Reducing Vortex Drag – High Span

1903

1947

2005

# Future Aircraft Configurations? Unlikely?

**Transonic      M = 0.9 – 1.2**

**Supersonic M = 2.2 – 2.4**

# A350 – First Flight 14th June 2013

# Short range configuration concepts
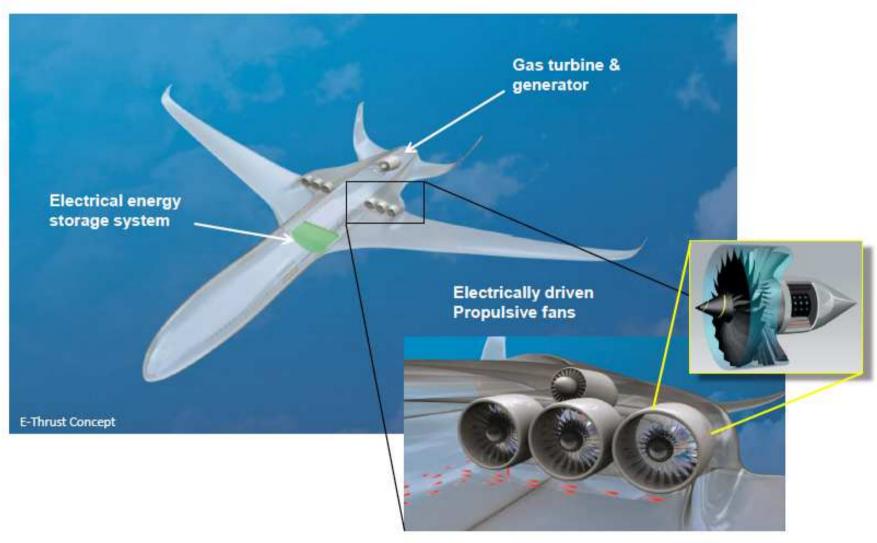
# A320neo First Flight – 25th September 2014

# Concept studied in EU NACRE project

# Boeing "SUGAR" Braced Wing Concept

# Hybrid turbo-electric propulsion



Gas turbine & generator

Electrical energy storage system

Electrically driven Propulsive fans

E-Thrust Concept

Rolls-Royce

# Effect of design range on fuel burn for long-distance travel

| Design range km | Payload tonne | Mission fuel tonne | Reserve fuel tonne | Max TOW tonne | OEW tonne | Fuel for 15,000km tonne |
|---|---|---|---|---|---|---|
| 15,000 | 25.9 | 120.3 | 13.5 | 300.0 | 140.3 | 120.3 |
| 5,000 | 25.9 | 20.4 | 5.4 | 120.0 | 68.4 | 61.1 |

**Travelling 15,000km in one hop or three**

**Revision of earlier GBD estimates:**

**Correction published in August 2006 issue of the Aeronautical Journal**

**2040 - The Ultra Green
Intermediate Range 300 Seater?**

With thanks to NASA