Aircraft Design
and Engine-Airframe Integration
for Reduced Environmental Impact

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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

* Advisory Council for Aeronautical Research in Europe

New ACARE Vision – “FLIGHTPATH 2050”

In 2050:-

- Technologies and Procedures available to give 75% reduction in CO_2 emissions , 90% reduction in NO_x 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

A380 –Balance between Airport noise and Fuel burn

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.

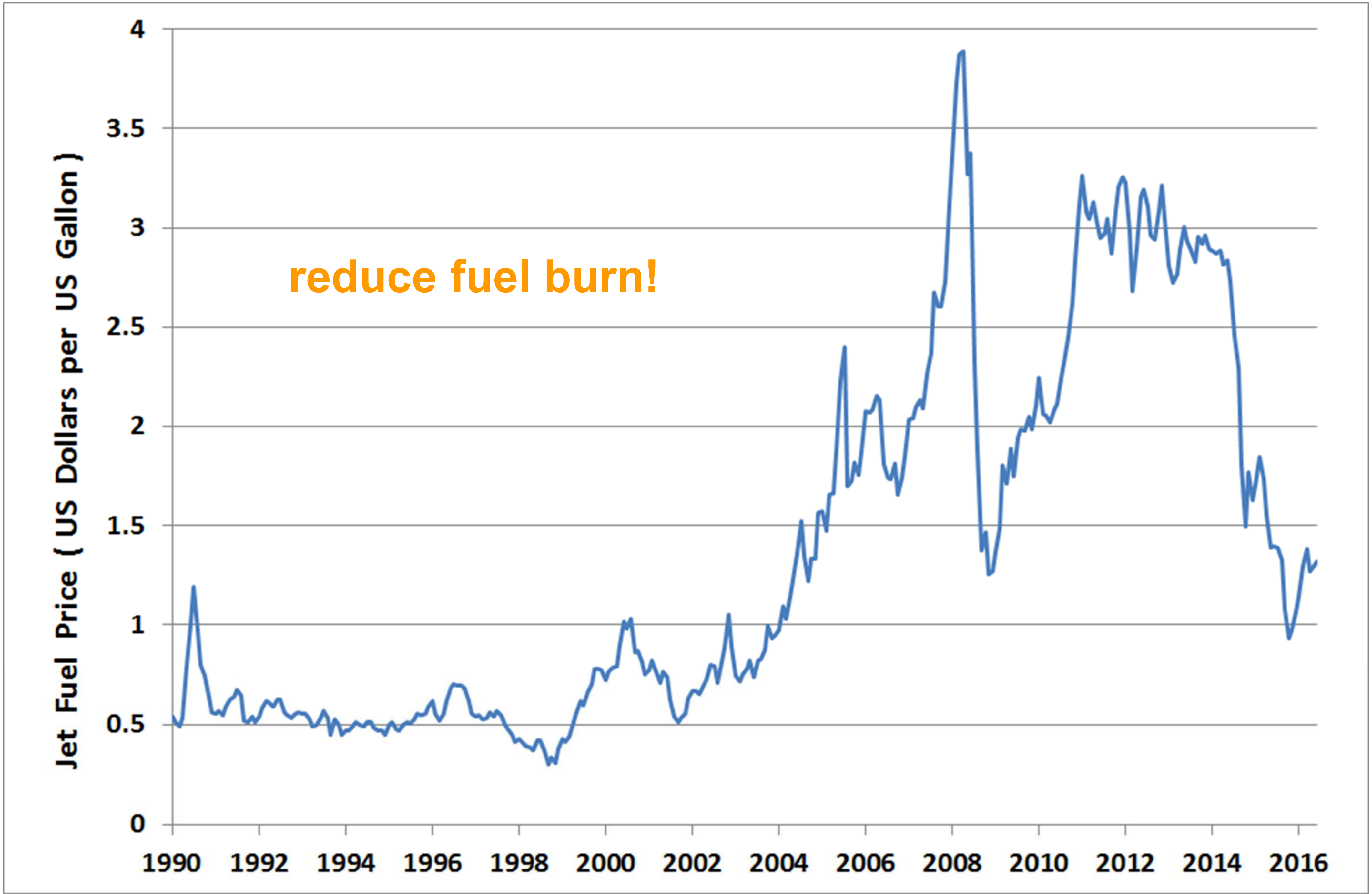
Direct injection, lean-burn single annular combustor

Staged injector

40% CAEP/2 NOx

Source Rolls-Royce

Jet Fuel Price – US Dollars per US Gallon



What about Bio-fuels?

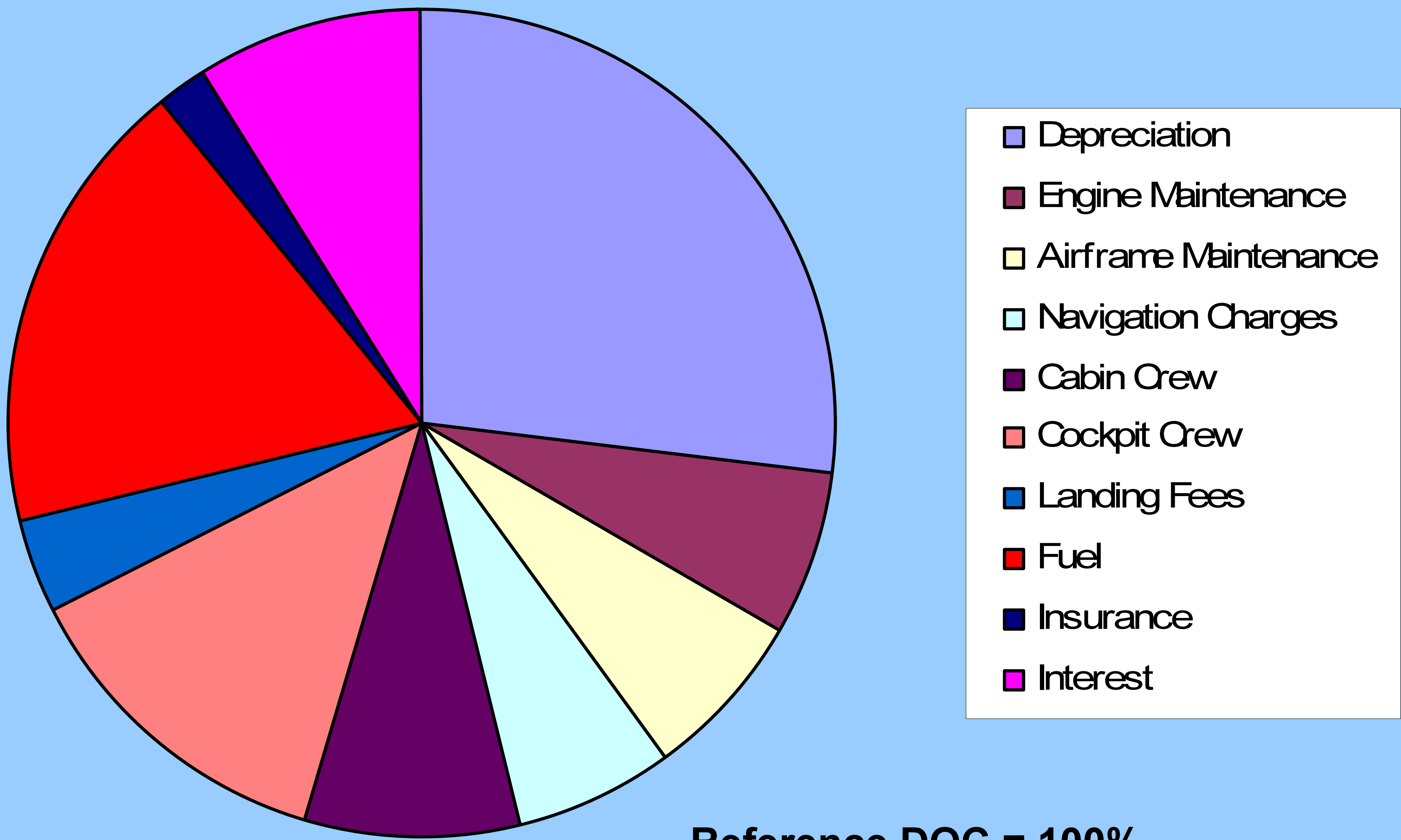
•It is fundamental that production must be sustainable, without prejudice to land and water resources for food production

•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.

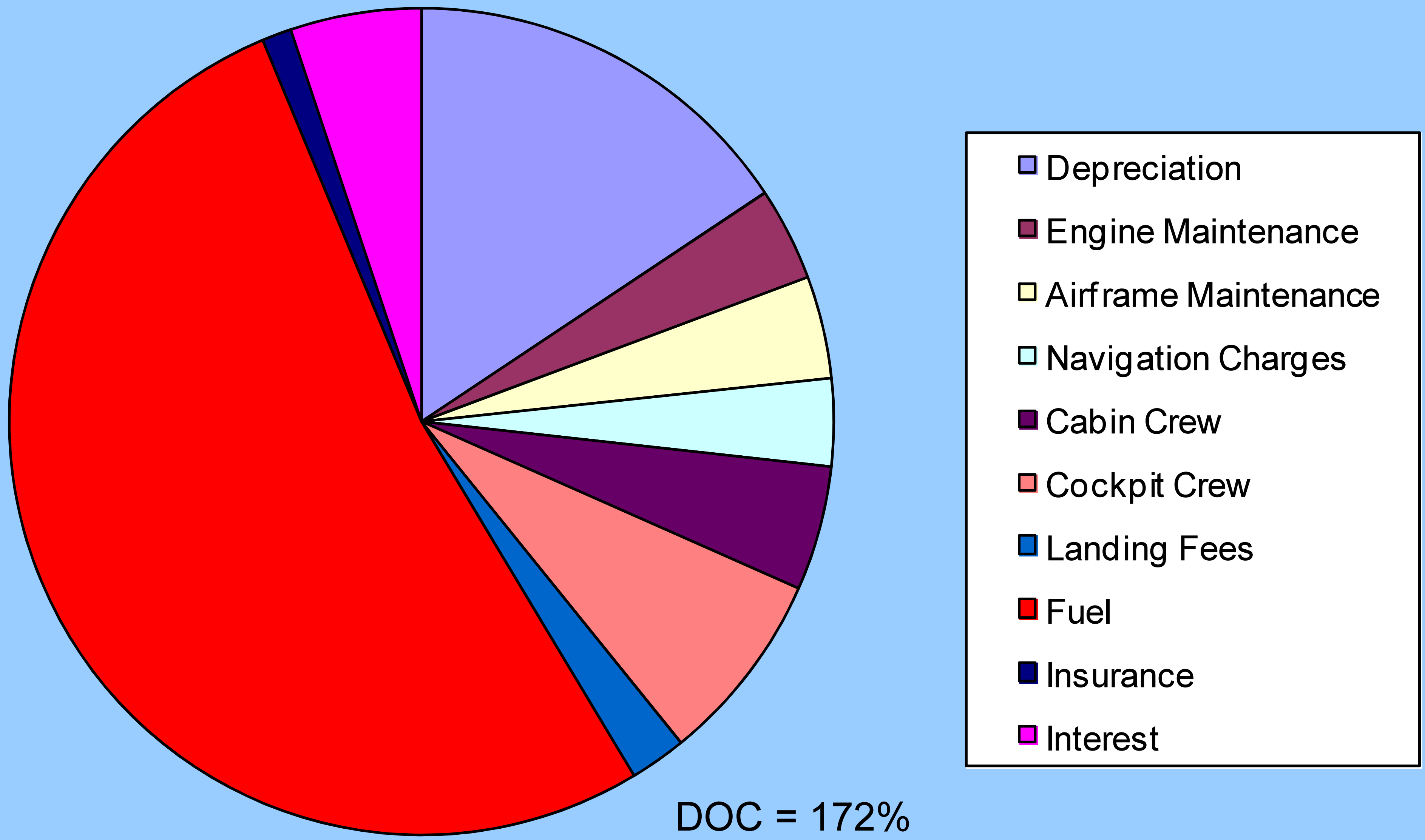
reduce fuel burn!

Typical Direct Operating Cost Breakdown - Fuel Price $0.8



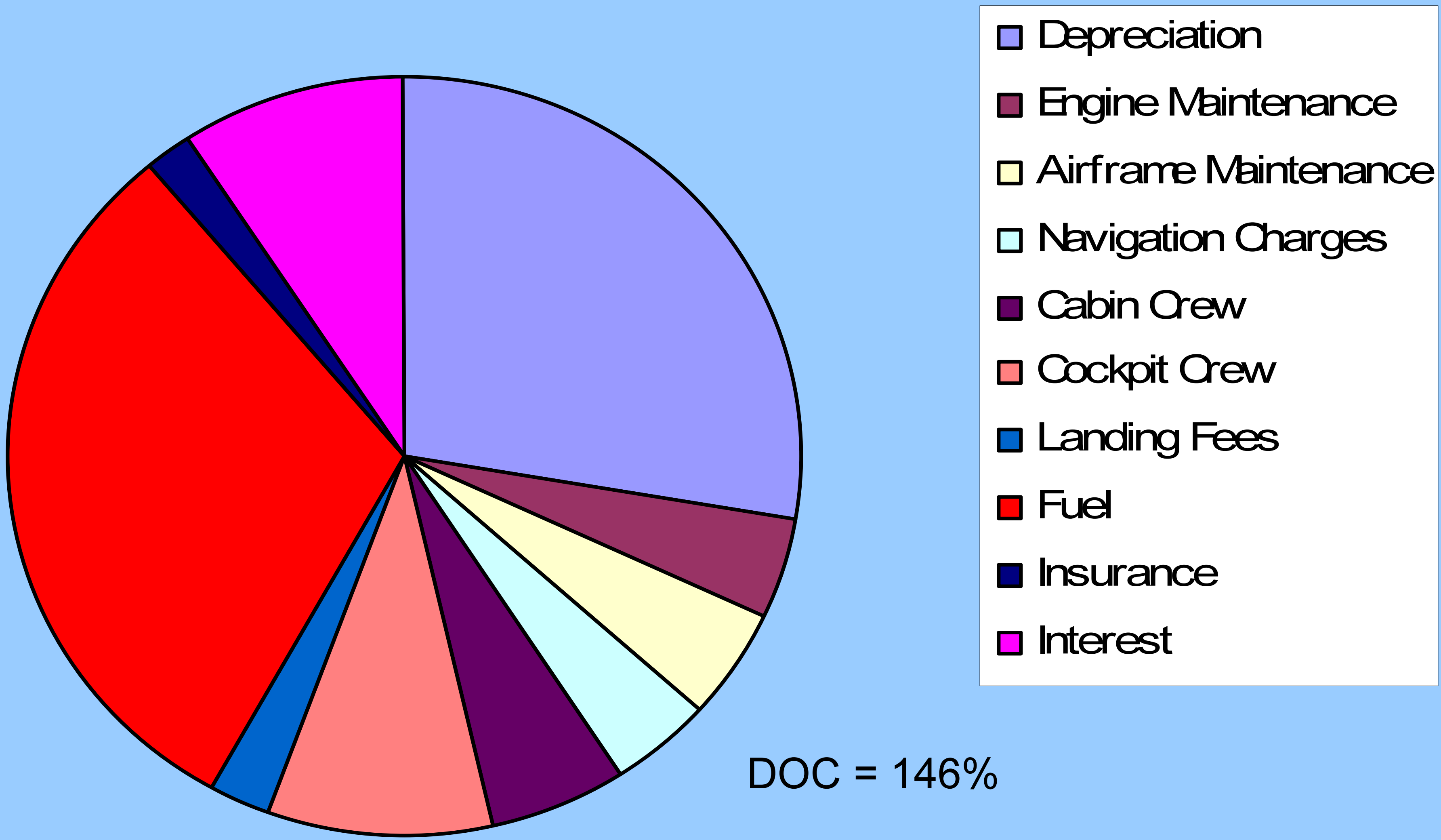
Reference DOC = 100%

Direct Operating Cost Breakdown - Fuel Price $4



Direct Operating Cost Breakdown

- Fuel Price $4
- First cost 150%
- Fuel burn 50%



DOC = 146%

Options for reducing fuel burn per passenger-km

The Bréguet range equation

Fuel burn per tonne-kilometre

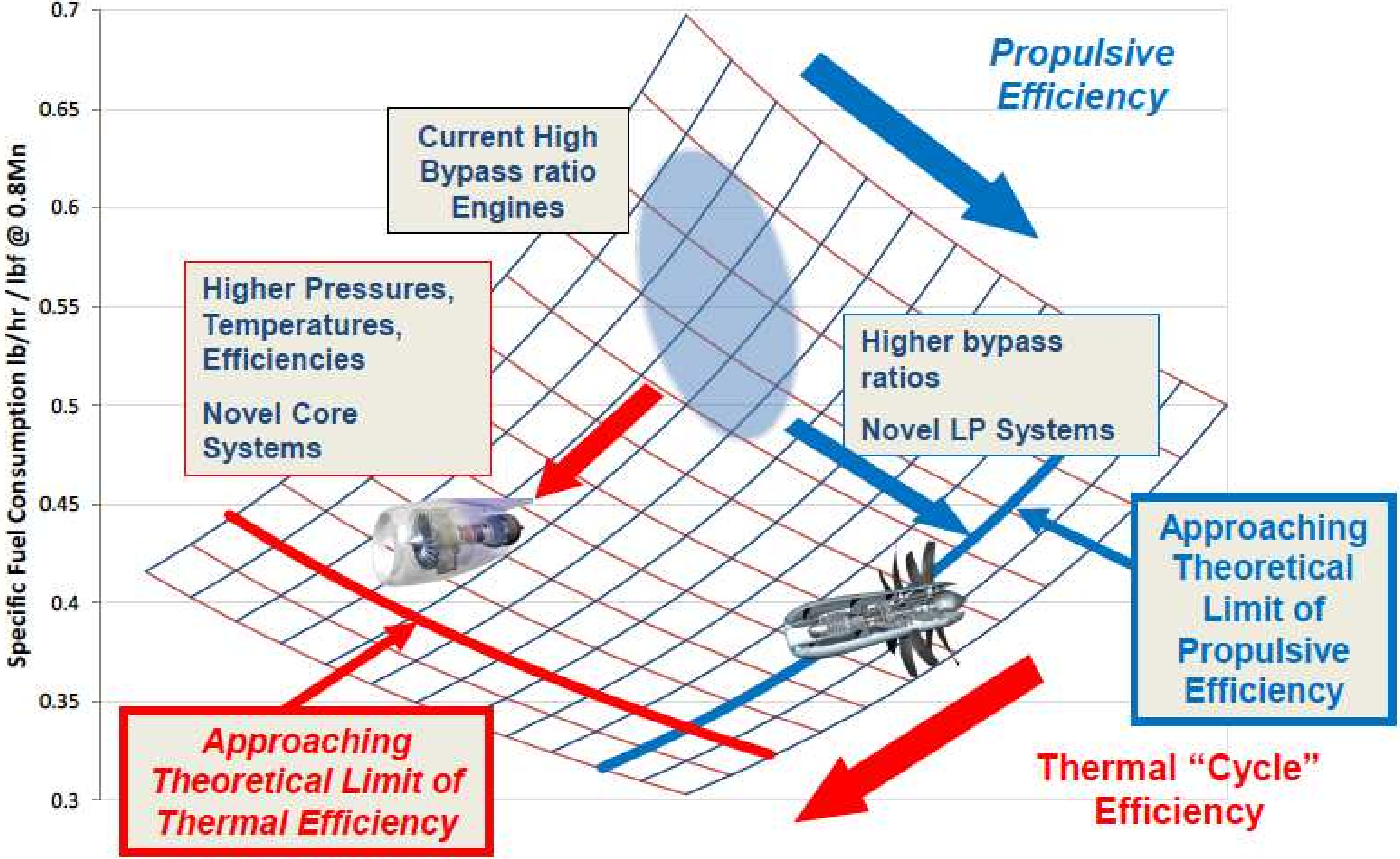
$$\frac{W_F}{W_P R} = \frac{1}{X}\left(1 + \frac{W_E}{W_P}\right)\left(\frac{1.022\exp\left(\frac{R}{X}\right) - 1}{\left(\frac{R}{X}\right)}\right)$$

W_F = Fuel Weight
W_P = Payload
W_E = Aircraft Weight-Empty
R = Range

X = $H\eta L/D$
H = calorific value of fuel
η = overall propulsive efficiency
L/D = lift/drag ratio

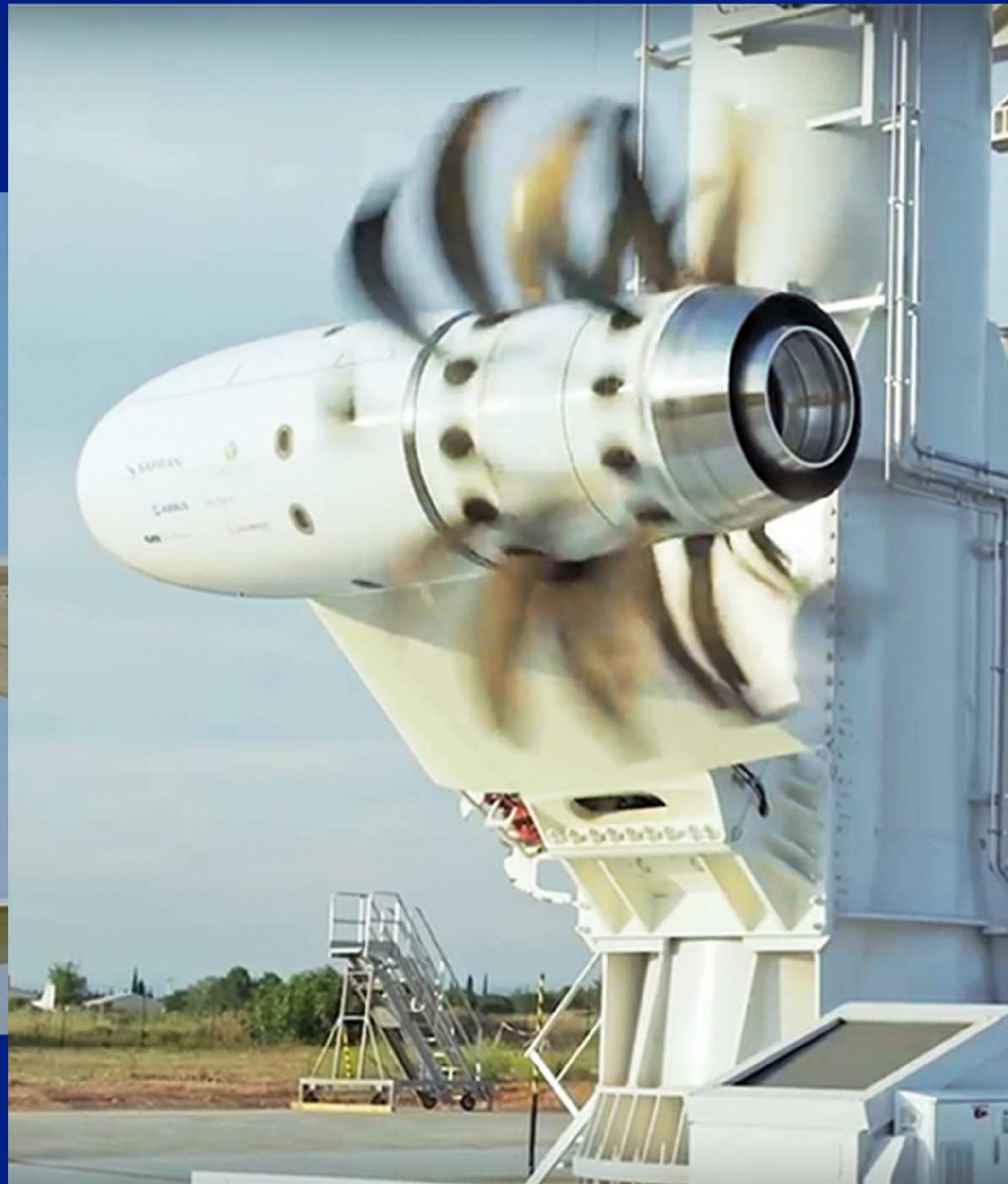
Reducing fuel burn by reducing weight – A350 CFRP Fuselage Test Specimen

Efficiency improvements - cycle potential



Evolutionary development of current powerplants – Higher bypass ratio etc.

Open Rotor Configurations

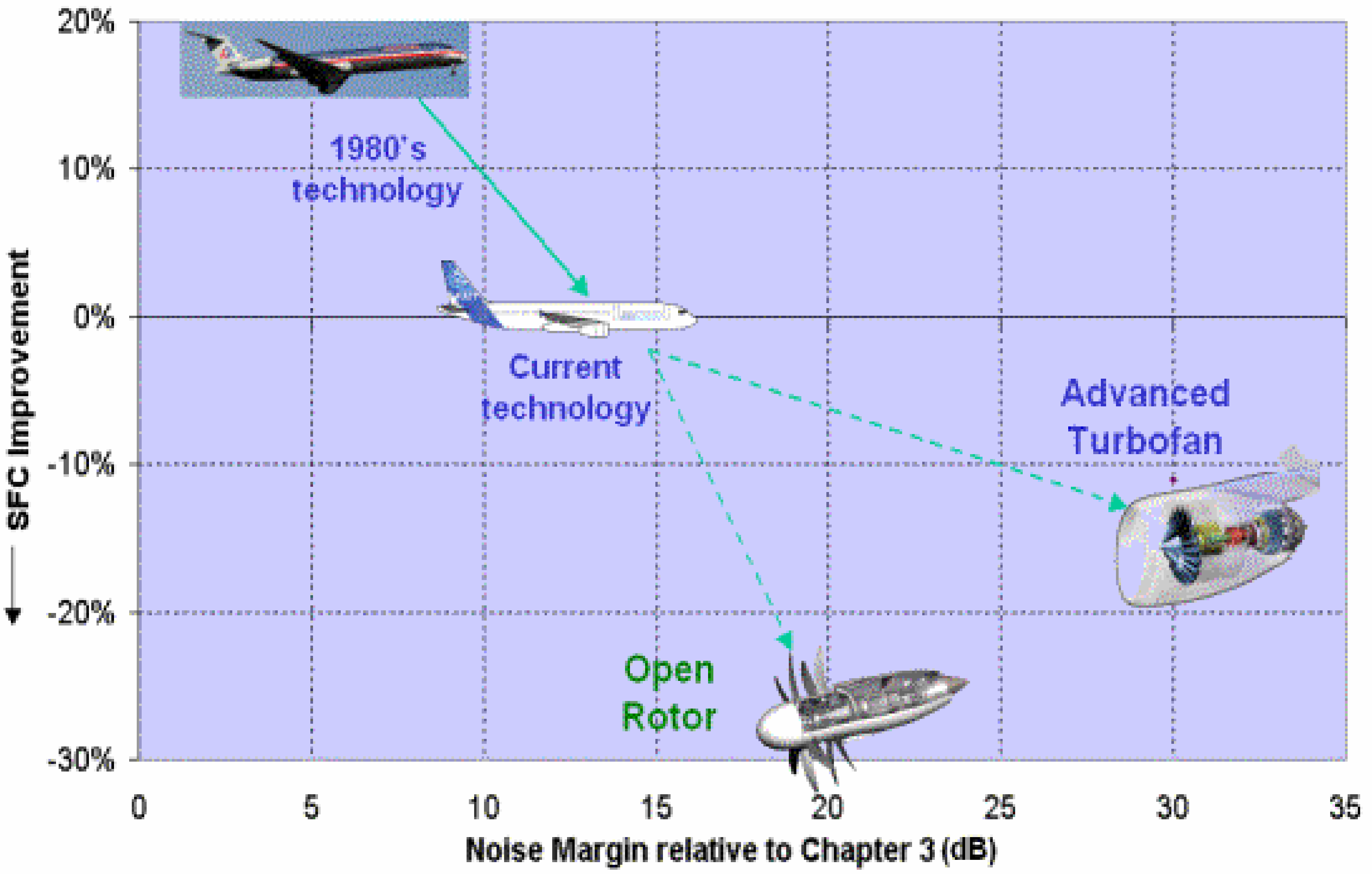


1952- Bristol Britannia

Tupolev TU-114

A400M

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



Next generation product evolution

Technology EIS Readiness	2020+	2025+
Bypass Ratio	11+	15+
Overall Pressure Ratio	60+	70+
Efficiency relative to Trent 700	20%+	25%+

Rolls-Royce

Maximising lift-to-drag ratio in cruise

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

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

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

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

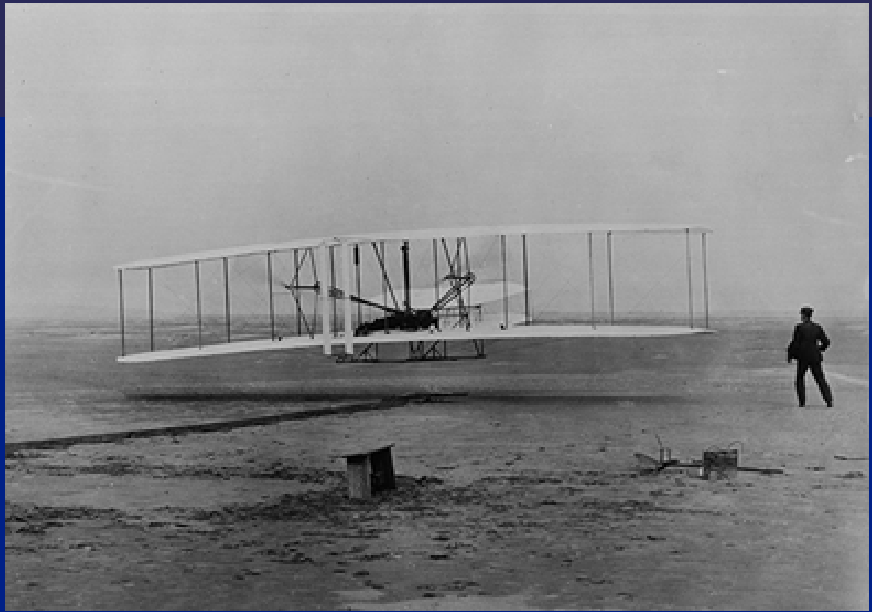
$S_{D0} = \sum SC_{D0}$
W = Weight
b = Span
q = dynamic pressure
κ = Induced Drag Factor
L/D = Lift/Drag Ratio

Minimising Surface Area

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

Reducing C_{D0} – Natural or Hybrid Laminar Flow
"BLADE" – European Clean Skies Research Programme

Reducing Vortex Drag – High Span



1903

1947

2005

Future Aircraft Configurations? Unlikely?

Transonic M = 0.9 – 1.2

Supersonic M = 2.2 – 2.4

NASA Supersonic X-Plane demonstrator

Airbus A350 - In Service January 2015

A320neo First Flight – 25th September 2014

AIRBUS

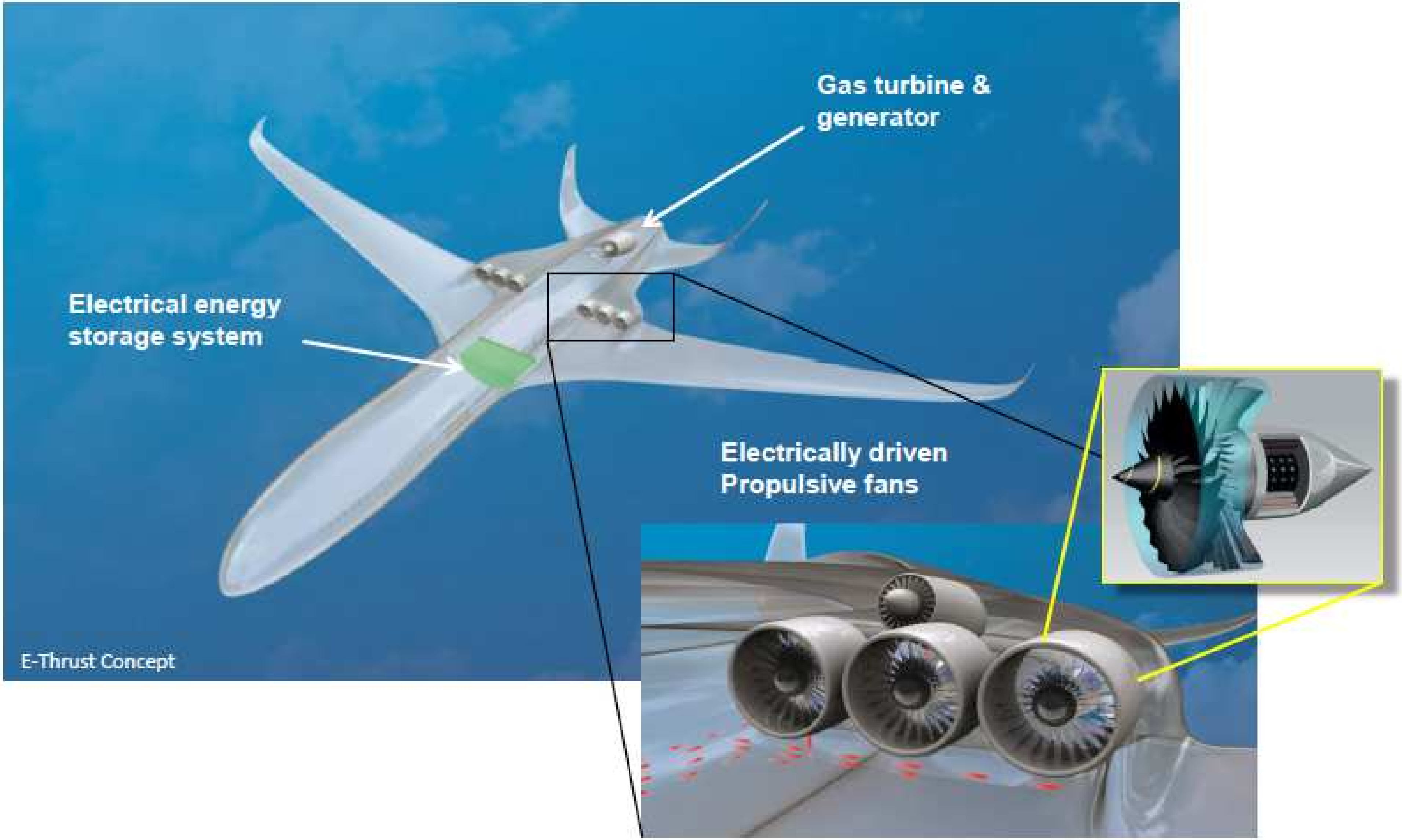
Coping with Very High Bypass Ratios (13 -15)

Concept studied in EU NACRE project

NASA Transonic Braced Wing Wind Tunnel Test

“Wake-Filling” rear fuselage propulsion concept

Hybrid turbo-electric propulsion



NASA X-Plane Demonstrator proposal
Hybrid turbo – electric feederliner

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