Greener by Design

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Aviation, Atmosphere and Climate

Graf-Zeppelin-Haus, Friedrichshafen

30 June – 3 July 2003

The Air Travel - Greener by Design Initiative (Launched March 2000)

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- **Sub-Groups:** Operations
  Technology
  Market-Based Options

Technology Sub-Group

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Scope

In:	**Noise** **Local Air Quality (LAQ)** **Climate Change**

Technology Sub-Group

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Technology Sub-Group

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New paper:	Aeronautical Journal June 2003

Technology perspective 2 years on

- regulation and economic instruments
- conflicts and trade-offs
- focus on climate change
    - main contributors
    - challenges to technology
        - reducing contrails
        - reducing NO_X
        - reducing CO_2
- design questions
- conclusions and recommendations

Emergence of the dominant configuration

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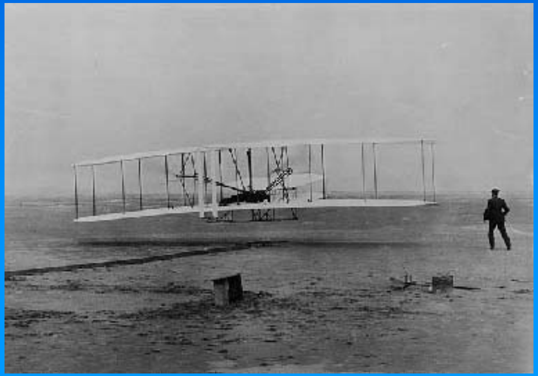

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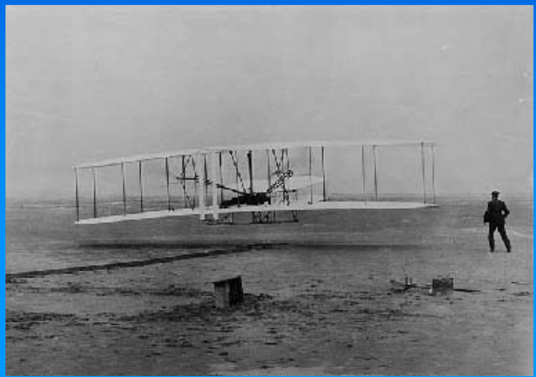  

- **Highly evolved**
- **Strictly limited scope for improvement**
- **Commercial forces alone unlikely to break the mould**

Regulation and economic instruments

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- climate proposals tend to be focussed on CO_2 emissions (with factor of 2.7 or 3 multiplier): this is likely to prove counter-productive

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“Aviation’s principal externality, which can be translated into monetary terms, arises from the effect of greenhouse gases and the impact they have on climate change”

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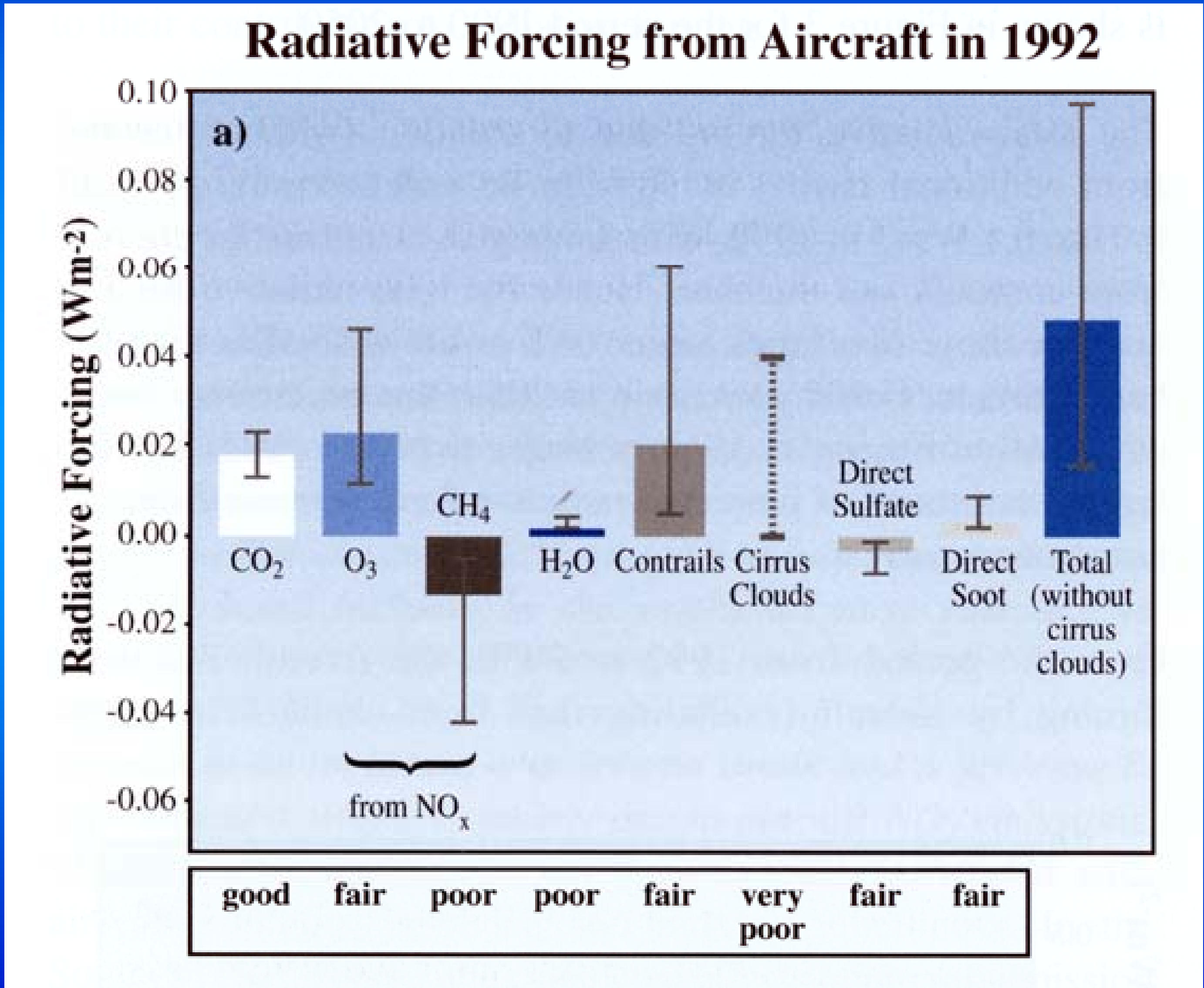
- operational measures to reduce contrails and cirrus cloud would increase fuel burn and CO_2 emissions

Contributions of aviation to climate change



Lifetimes of greenhouse gases and aircraft emissions

Carbon Dioxide	50 – 100 years
Methane	8 – 10 years
Water	days (sea level)
	weeks (tropopause)
Ozone	week (sea level)
	months (topopause)
NO_X	days (sea level)
	weeks (tropopause)

Challenges to technology

- Reducing persistent contrails and cirrus cloud
- Reducing impact of NO_X
- Reducing CO_2

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- Increasing propulsive efficiency reduces the mean exhaust temperature and increases the altitude range over which contrails will form

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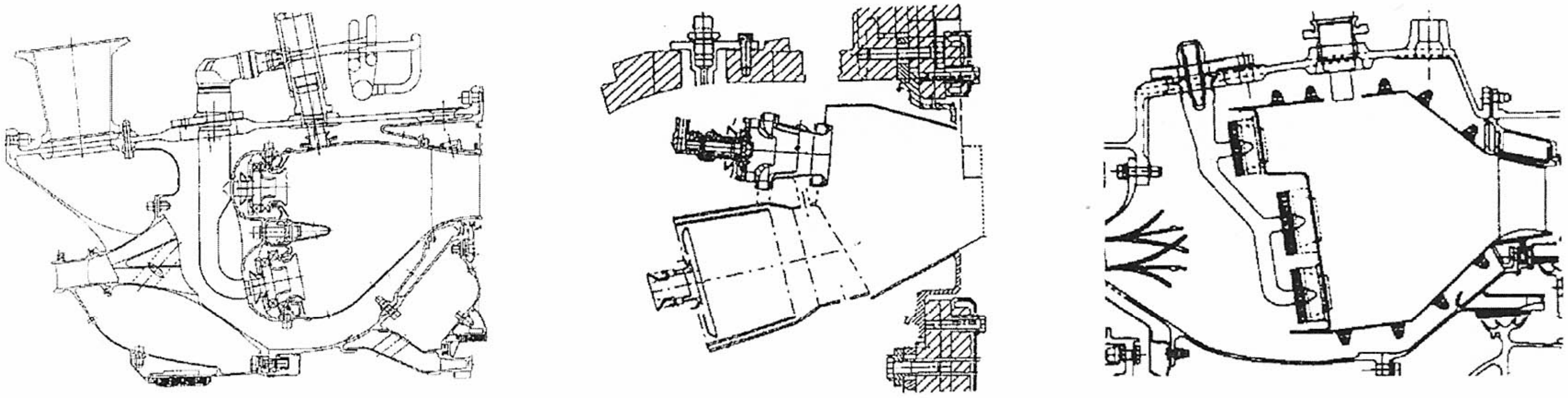
- **Persistent contrails can be avoided by flying above, below or around ice-saturated regions: this will increase fuel burn and CO_2 emissions**
- **To minimise the economic penalty of such a strategy, future aircraft design should aim for flexibility in economic cruise altitude**
- **Further advances in atmospheric science, air traffic management and meteorology are needed before such a strategy can be justified or adopted**
- **Nevertheless, reducing persistent contrails might prove to be the single most powerful means of reducing the impact of aviation on climate, even though it would increase CO_2 emissions**

Challenges to technology: reducing NOX

Challenges to technology: reducing NO_X

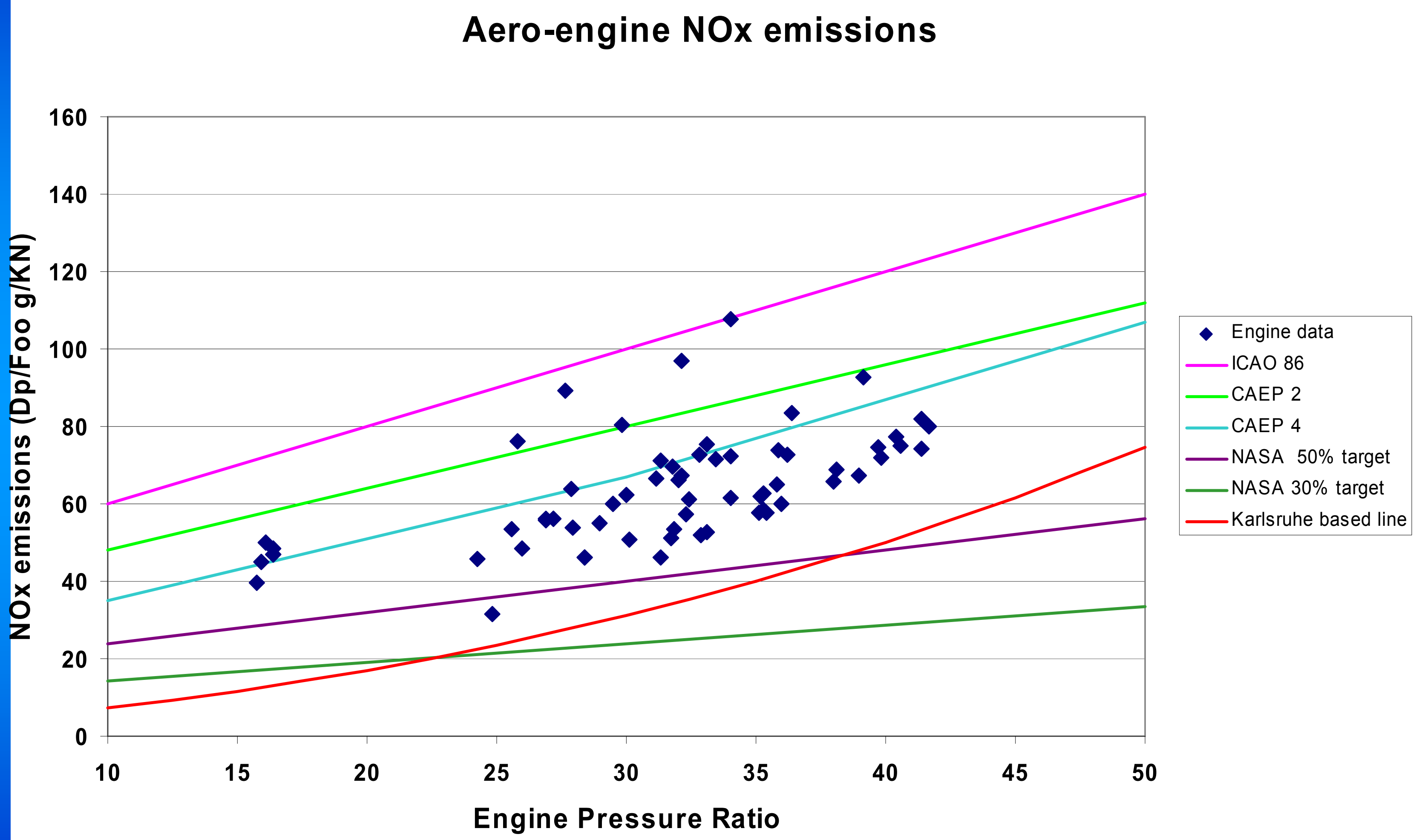


(a) (b) (c)

General Electric **Snecma** **Pratt and Whitney**

Staged Combustors

Challenges to technology: reducing NO_X



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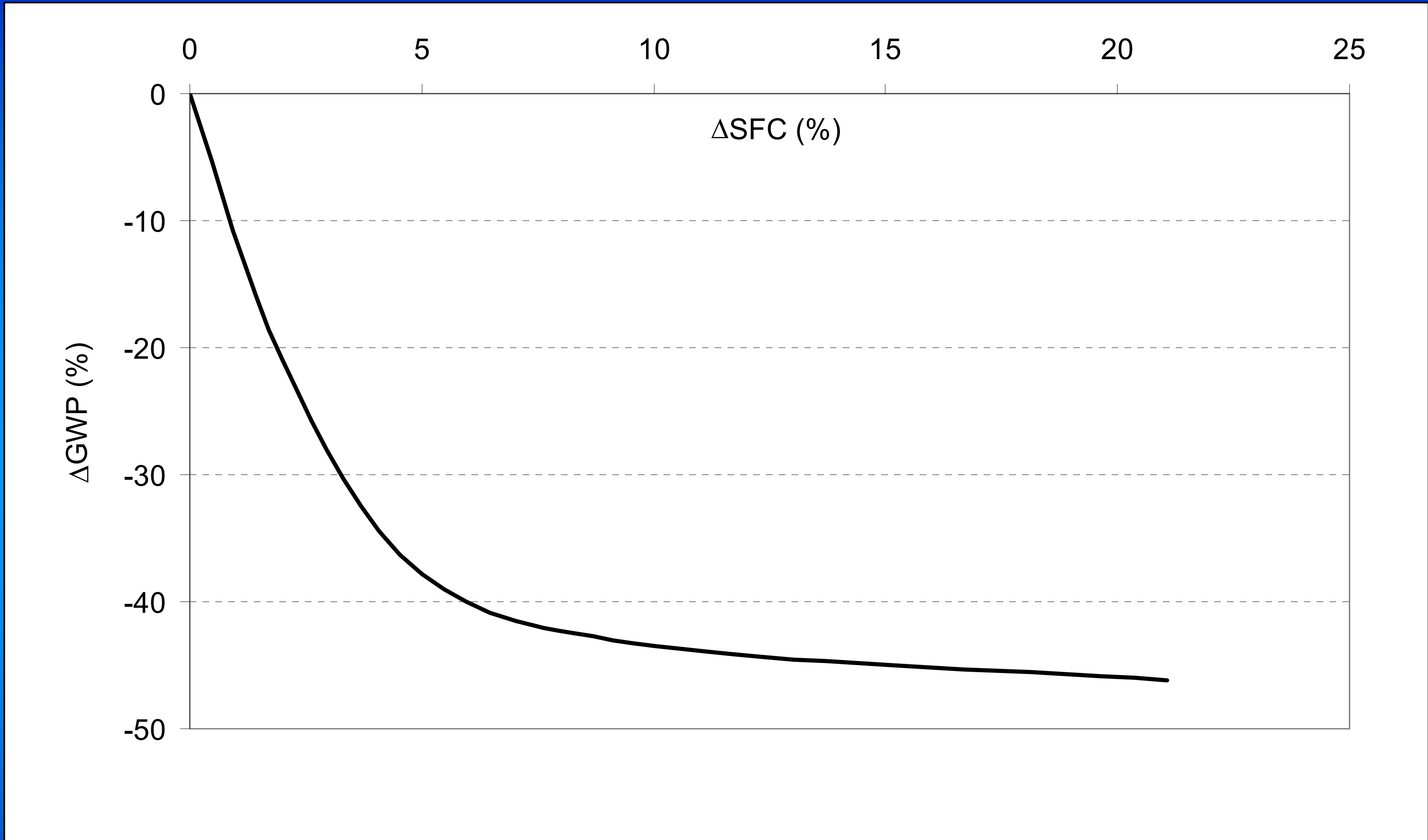

Trade off between reduced Global Warming Potential and increased SFC relative to minimum SFC datum (Whellens and Singh)

Challenges to technology: reducing CO_2 = reducing fuel burn per passenger km

Challenges to technology: reducing CO_2

Fuel burn per passenger kilometre: -

$$\frac{W_f}{RW_p} = \left(1 + \frac{W_E}{W_p}\right)\left(\frac{\exp\left(\frac{R}{X}\right) - 1}{R}\right)$$

Breguet range equation

where	X	=	HηL/D
	H	=	calorific value of fuel
	η	=	overall propulsive efficiency
	L/D	=	lift/drag ratio

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- Design parameters – design range, cruise Mach number

Challenges to technology: reducing CO_2 by increasing propulsive efficiency

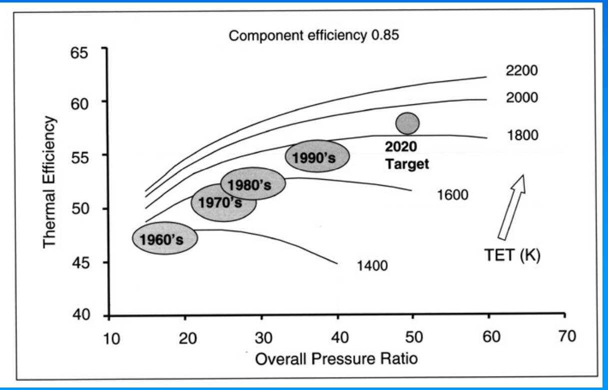
Overall propulsive efficiency

$$\eta = \eta_E \eta_P$$

where η_E = thermal efficiency

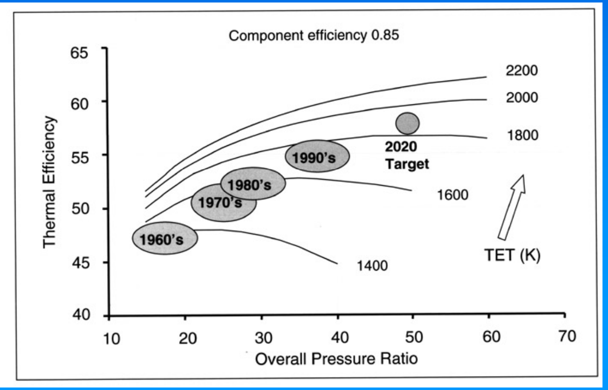
and η_P = jet propulsive efficiency

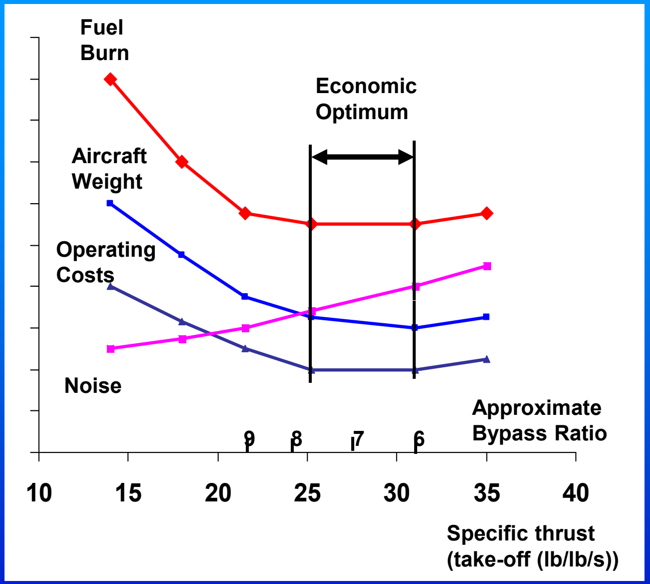
Challenges to technology: reducing fuel burn by increasing propulsive efficiency - Joule cycle turbofan



- Increasing thermal efficiency requires increases in both overall pressure ratio and turbine entry temperature: these increase NO_X production

Challenges to technology: reducing fuel burn by increasing propulsive efficiency - Joule cycle turbofan





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- **Most large turbofans have specific thrust around the optimum for fuel burn: reducing specific thrust below this optimum in order to meet noise targets increases fuel burn and CO2**

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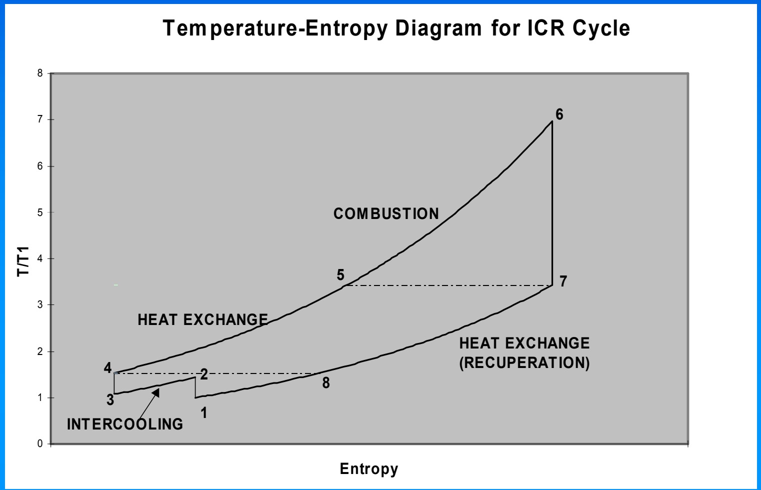

Intercooled recuperative engine cycle

- reduced fuel burn & CO_2
- reduced NO_X
- capable of podded installation
- increased weight and complexity

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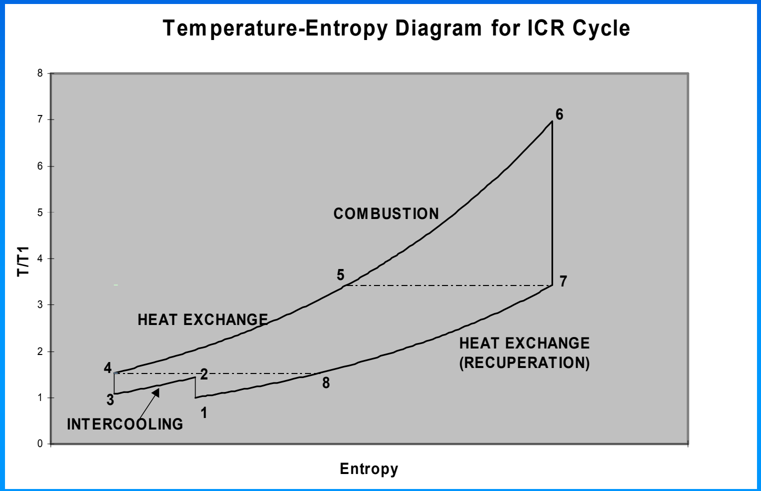

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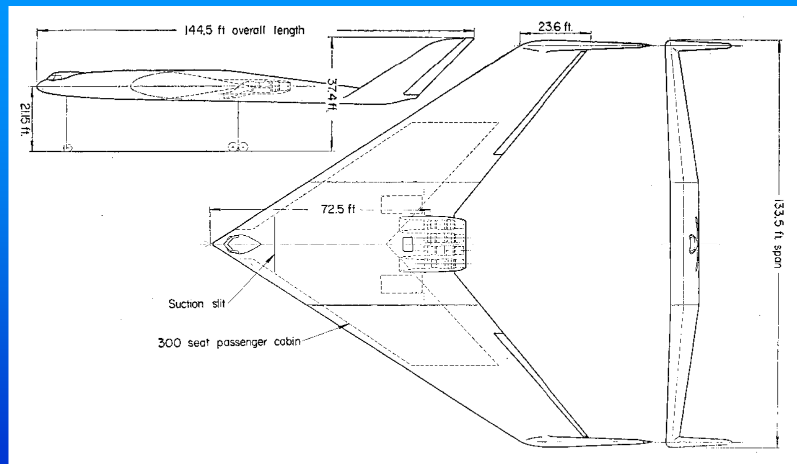
Unducted fan

- reduced fuel burn & CO_2
- reduced cruise Mach number
- complexity and flight safety issues

Challenges to technology: reducing CO_2 by reducing drag

- Dominant configuration with hybrid laminar flow control
- Blended wing body
- All laminar flying wing

Blended wing body model
NASA Langley Research Center 2/20/1998 Image # EL-1998-00245



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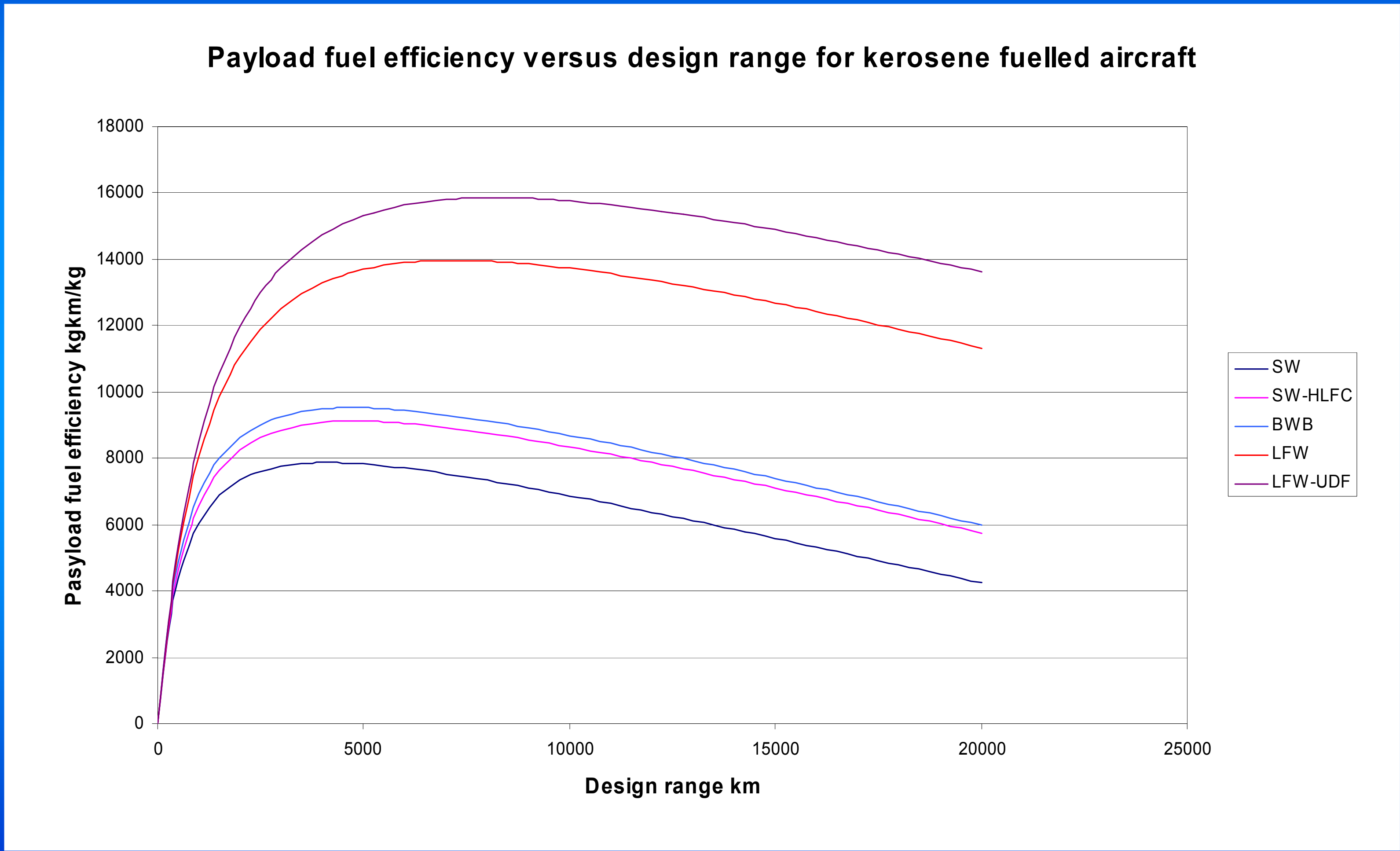
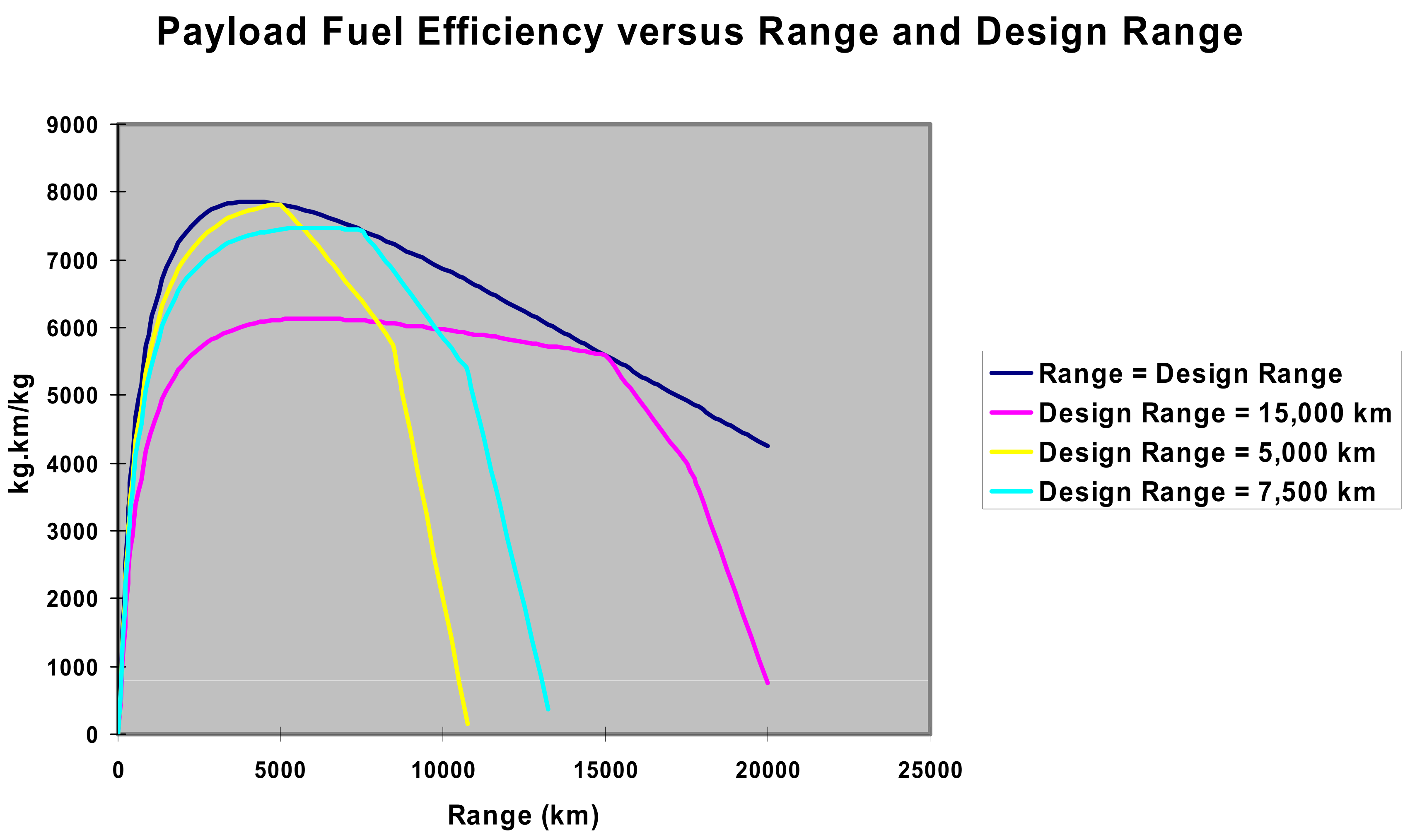


Challenges to technology: reducing fuel burn – effect of range



Reducing fuel burn: effect of design range

Design range km	Payload tonne	Fuel tonne	Max TOW tonne	Empty Weight tonne	Fuel for 15,000 km tonne
15,000	44.8	120.4	300.0	134.8	120.4
5,000	44.8	28.6	169.0	95.6	85.8

Multi-Sector Long Distance Travel ?

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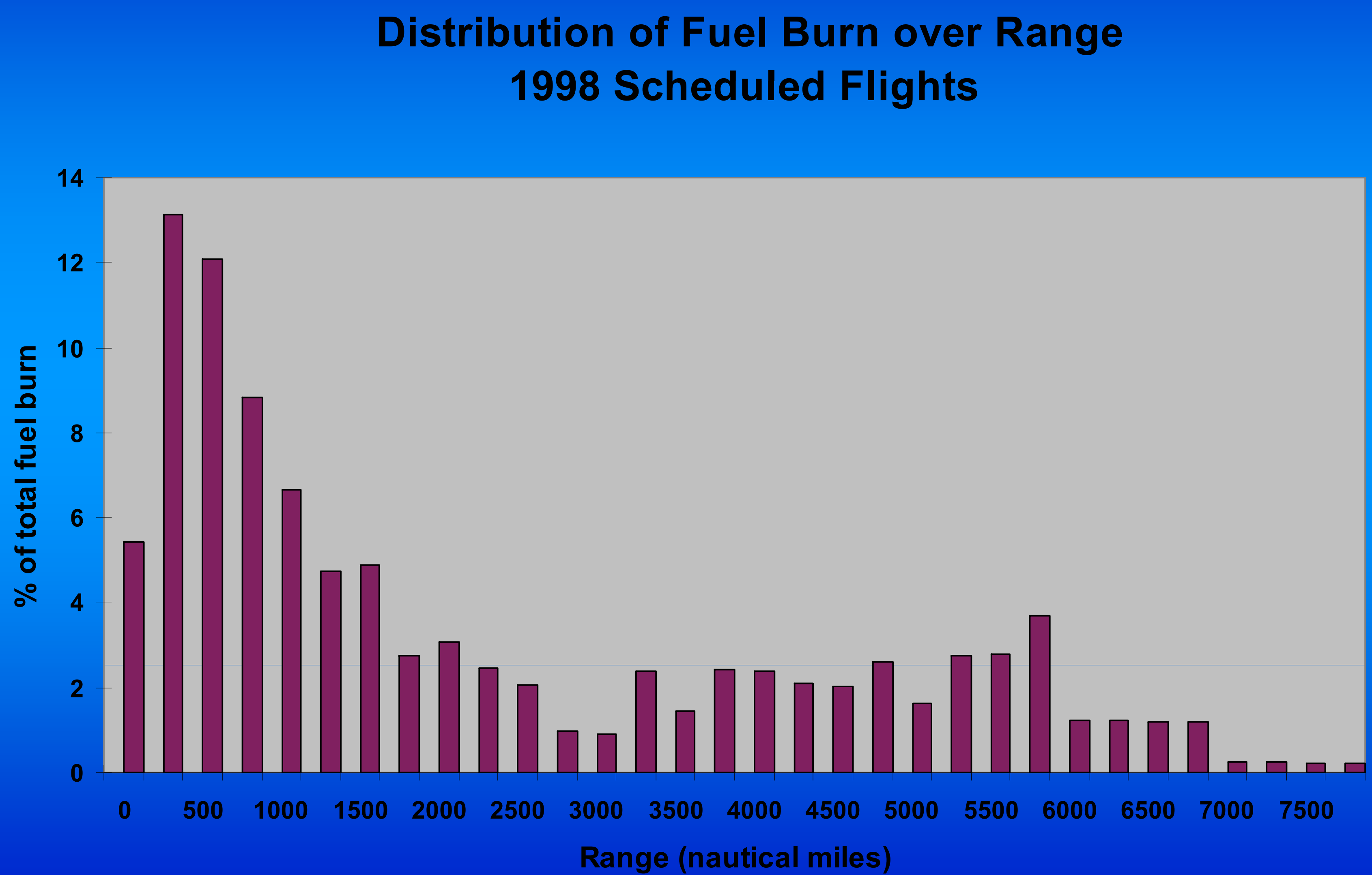
Significance of range



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  - **reduce fuel burn & CO_2, enable unducted fans ?**
- **Design for minimum impact on climate**
  - **trade off between operating and environmental costs ?**

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CONCLUSIONS I

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- Reducing NO_X and persistent contrails are probably the two most potent means of reducing this impact: in each case, the best environmental result is likely to entail some increase in CO_2 emissions.
- Because CO_2 is such a long lived greenhouse gas, reducing its emission is a key long-term goal: drag and weight reduction are the two most potent technologies. Aircraft design parameters – design range, cruise Mach number and altitude – are also significant factors.

CONCLUSIONS II

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CONCLUSIONS II

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- Regulatory and economic measures should be framed so as to promote the greatest possible reduction in impact on climate: measures based solely on CO_2 emission will probably do more harm than good.

- The challenge to technology is severe: the atmospheric science is not yet robust: the timescales for introducing new technology and new design concepts are long: the need for research and demonstration is urgent.

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- Low NO_X combustors
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Design studies

- Design to minimise impact on climate
- Design to increase cruise altitude flexibility
- Multi segment long-range travel