The Technology Challenge

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Sustainable Aviation: The Next Steps

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Fig 2 Technology Sub-Group

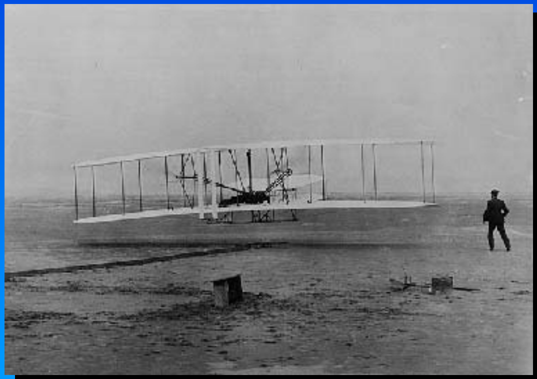
Scope

In:	Noise Local Air Quality (LAQ) Climate Change
Out:	Supersonic Transports ATC & NAV Ground Movements Manufacture and Disposal
Time Horizon:	2050 (fourfold traffic growth)
Full Report:	published in The Aeronautical Journal, February 2002

Fig 3 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

Fig 4 Emergence of the dominant configuration



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

Fig 5 Regulation and economic instruments

Noise	ICAO Annex 16 Chapters 3 & 4 (2006)
	Local (eg Heathrow, Washington)
LAQ	ICAO CAEP/2 & CAEP/4 (2004)
	Local (eg Zurich)
Climate Change	Kyoto (excludes international flights)
	ICAO)
	EU) considering options
	HMG)

- 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

Fig 6 Annual external costs of UK civil aviation (from recent HM Treasury/DfT discussion paper)

• Climate change	£1,400 M
• LAQ	£119 – 236 M
• Noise	£25 M

"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"

Fig 7 Conflicts and trade-offs

- on modern engines, reducing noise increases fuel burn, CO_2 emissions and costs
- reducing fuel burn and CO_2 emissions by increasing engine thermal efficiency increases NO_X
- operational measures to reduce contrails and cirrus cloud would increase fuel burn and CO_2 emissions

Fig 8 Contributions of aviation to climate change

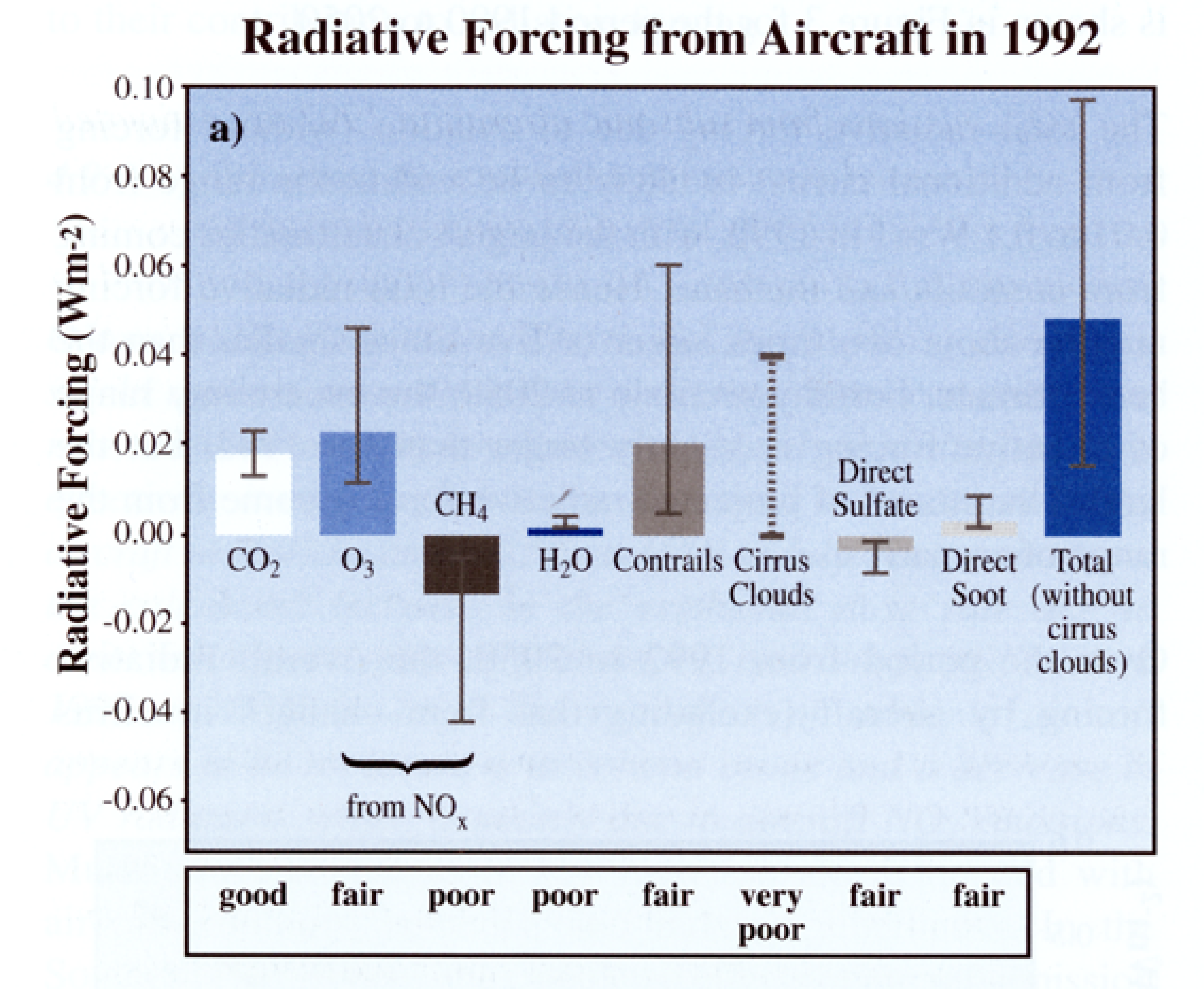


Fig 9 Lifetimes of greenhouse gases and aircraft emissions

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)

Fig 10 Challenges to technology

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

Fig 11 Challenges to technology: reducing persistent contrails and cirrus cloud

- Persistent contrails form only in air which is saturated with respect to ice: the conditions for formation and persistence are reasonably well understood

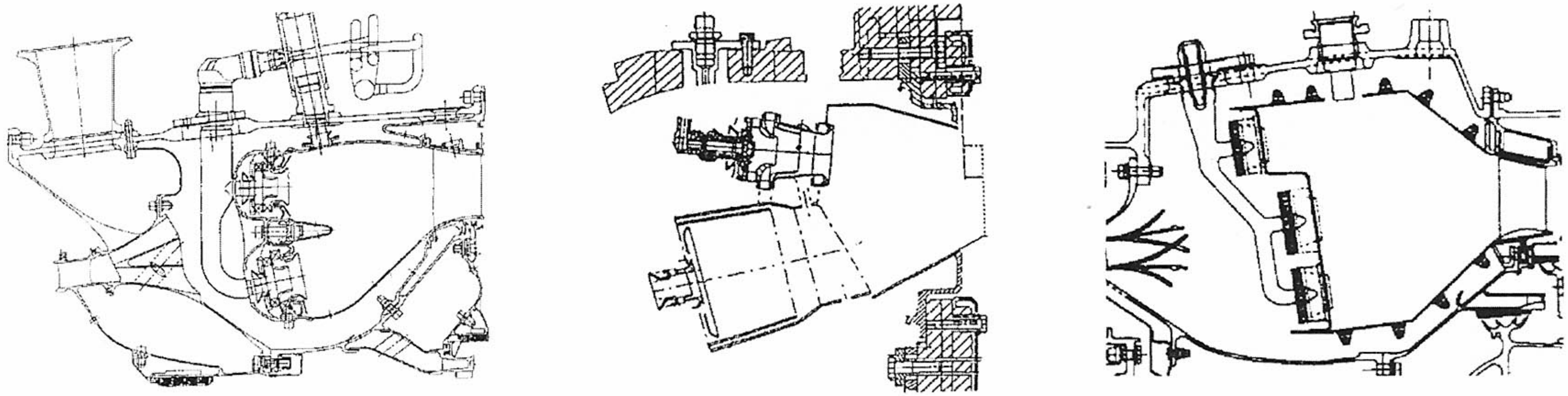
- There is no prospect of preventing contrail formation in an ice-saturated atmosphere by technological means

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

Fig 12 Challenges to technology: reducing persistent contrails and cirrus cloud

- 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

Fig 13 Challenges to technology: reducing NO_X



(a) (b) (c)

General Electric Snecma Pratt and Whitney

Staged Combustors

Fig 14 Challenges to technology: reducing NO_X

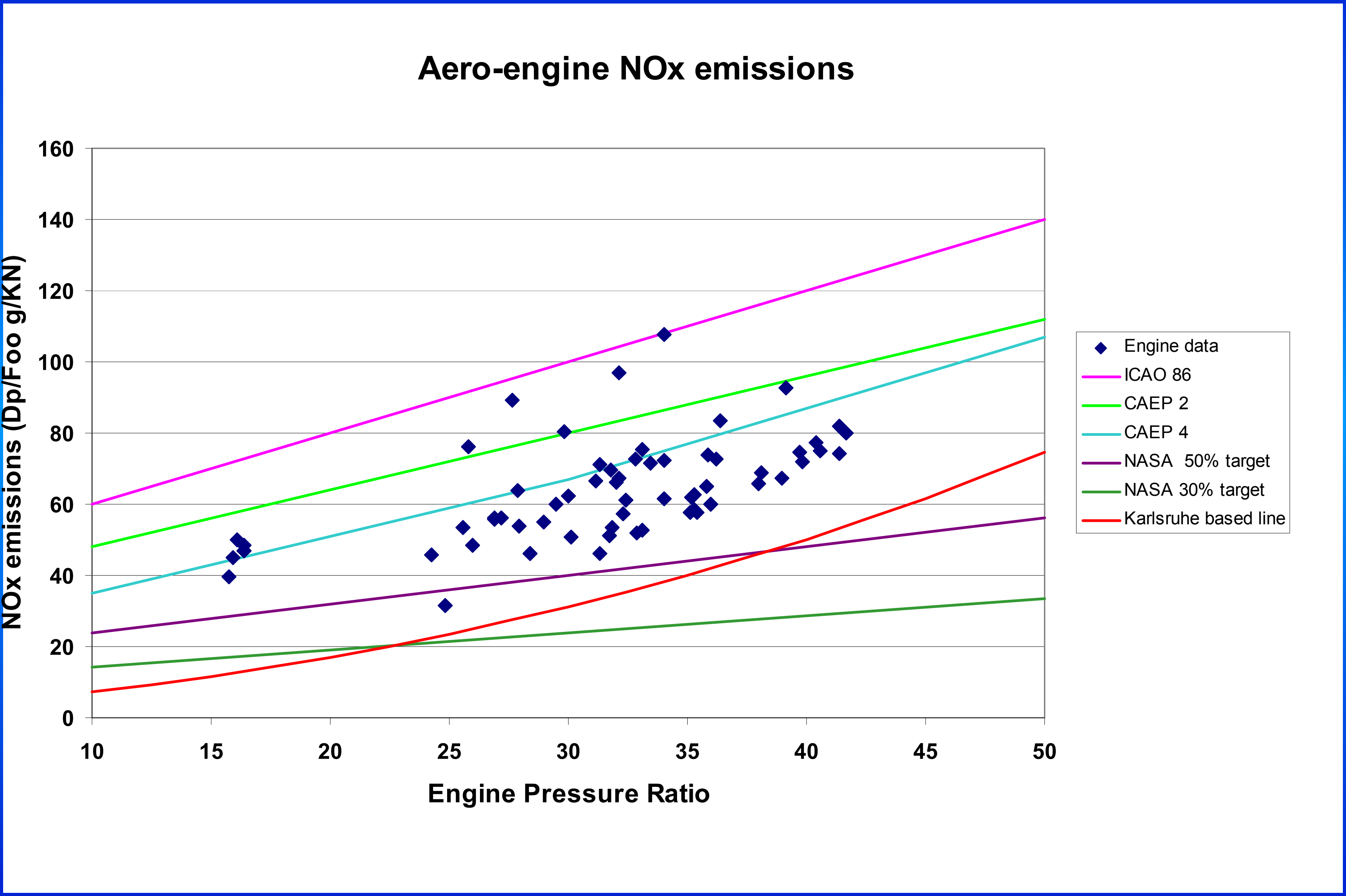
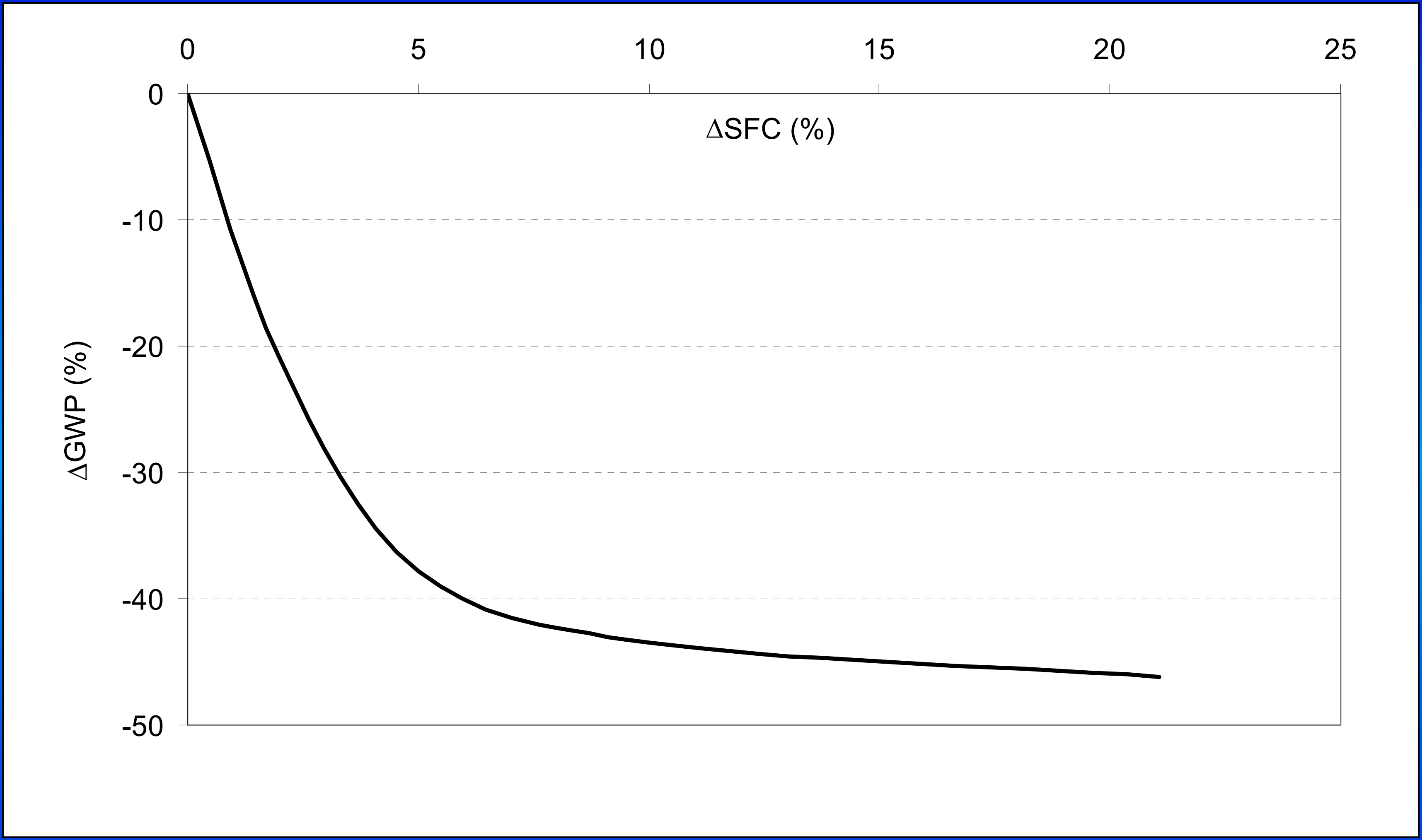


Fig 15 Challenges to technology: reducing NO_X



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

Fig 16 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	=	$H\eta L/D$
	H	=	calorific value of fuel
	η	=	overall propulsive efficiency
	L/D	=	lift/drag ratio

Fig 17 Challenges to technology: reducing CO_2 by reducing empty weight

- Increased use of CFRP and other light structural materials: cost is a significant inhibitor (1983 forecasts for use of composites by 1995 ranged from 25% to 65% by weight – actual composite weight in A330 and B777 is around 15%)
- More efficient structural design – flying wing for larger aircraft
- Reduced system weight – the More Electric Aircraft
- Design parameters – design range, cruise Mach number

Fig 18 Challenges to technology: reducing CO_2 by increasing propulsive efficiency

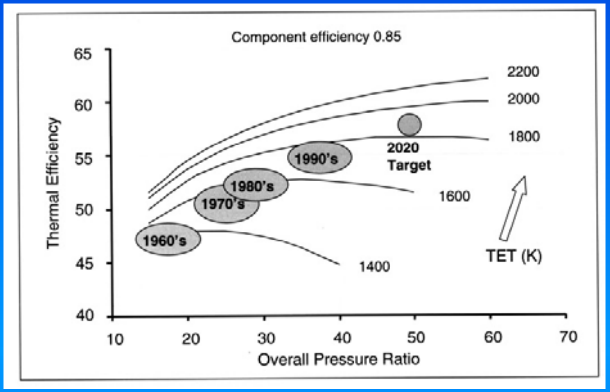
Overall propulsive efficiency

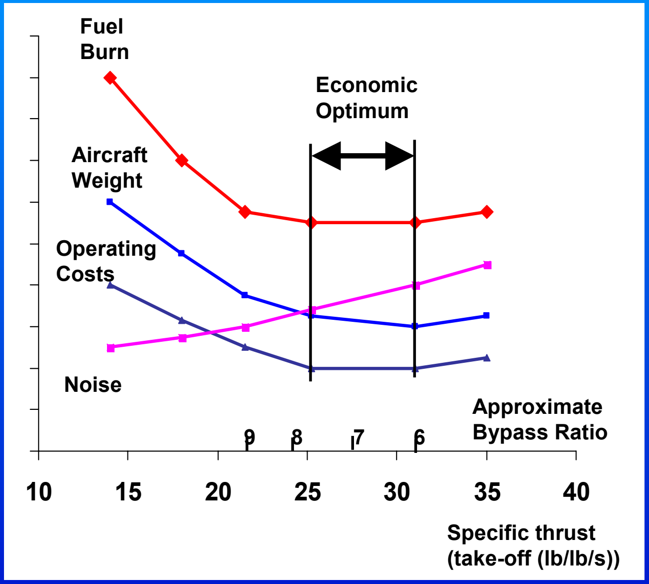
$$\eta = \eta_E \eta_P$$

where η_E = thermal efficiency

and η_P = jet propulsive efficiency

Fig 19 Challenges to technology: reducing CO_2 by increasing propulsive efficiency

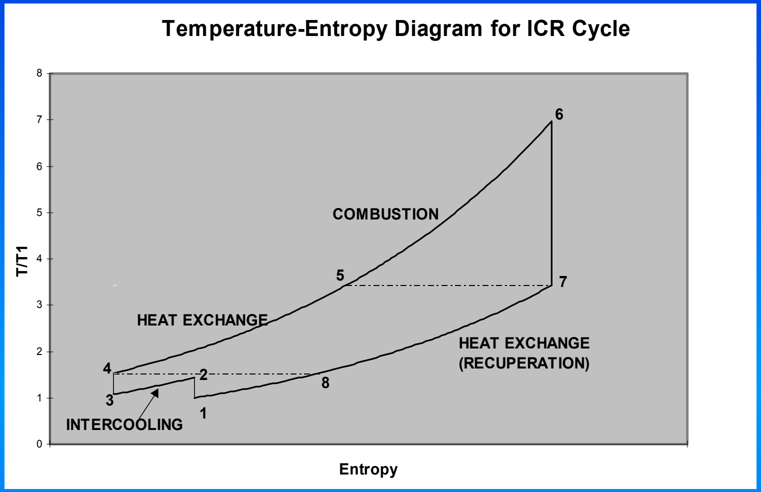




- Increasing thermal efficiency requires increases in both overall pressure ratio and turbine entry temperature: these increase NO_X production

- Most large turbofans have specific thrusts around the optimum for fuel burn: reducing specific thrust below this optimum in order to meet noise targets increases fuel burn and CO_2

Fig 20 Challenges to technology: reducing CO_2 by increasing propulsive efficiency



Intercooled recuperative engine cycle

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

Unducted fan

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

Fig 21 Challenges to technology: reducing CO_2 by reducing drag

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

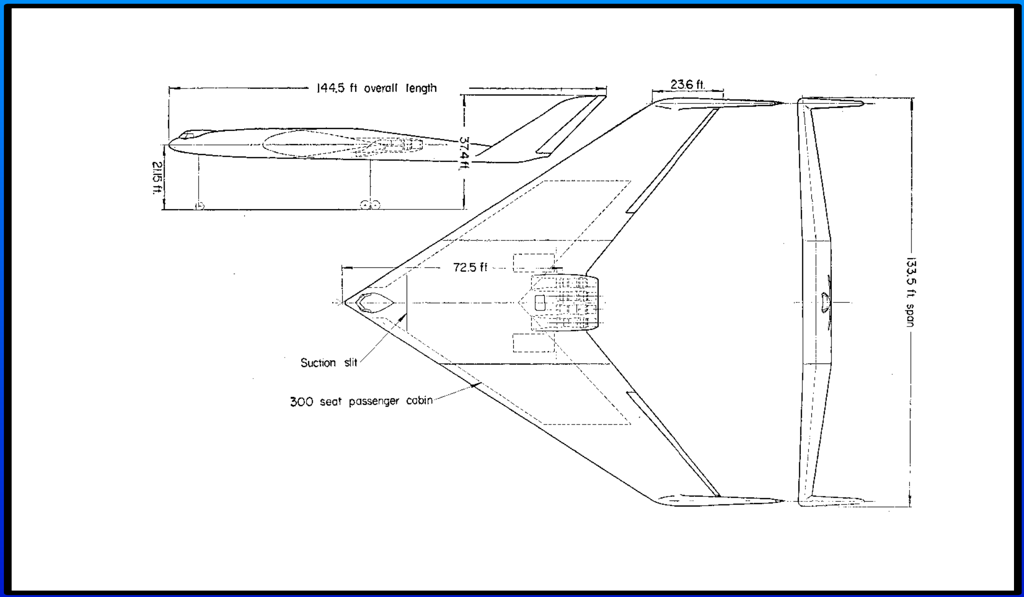


Fig 22 Challenges to technology: reducing CO_2 by reducing drag

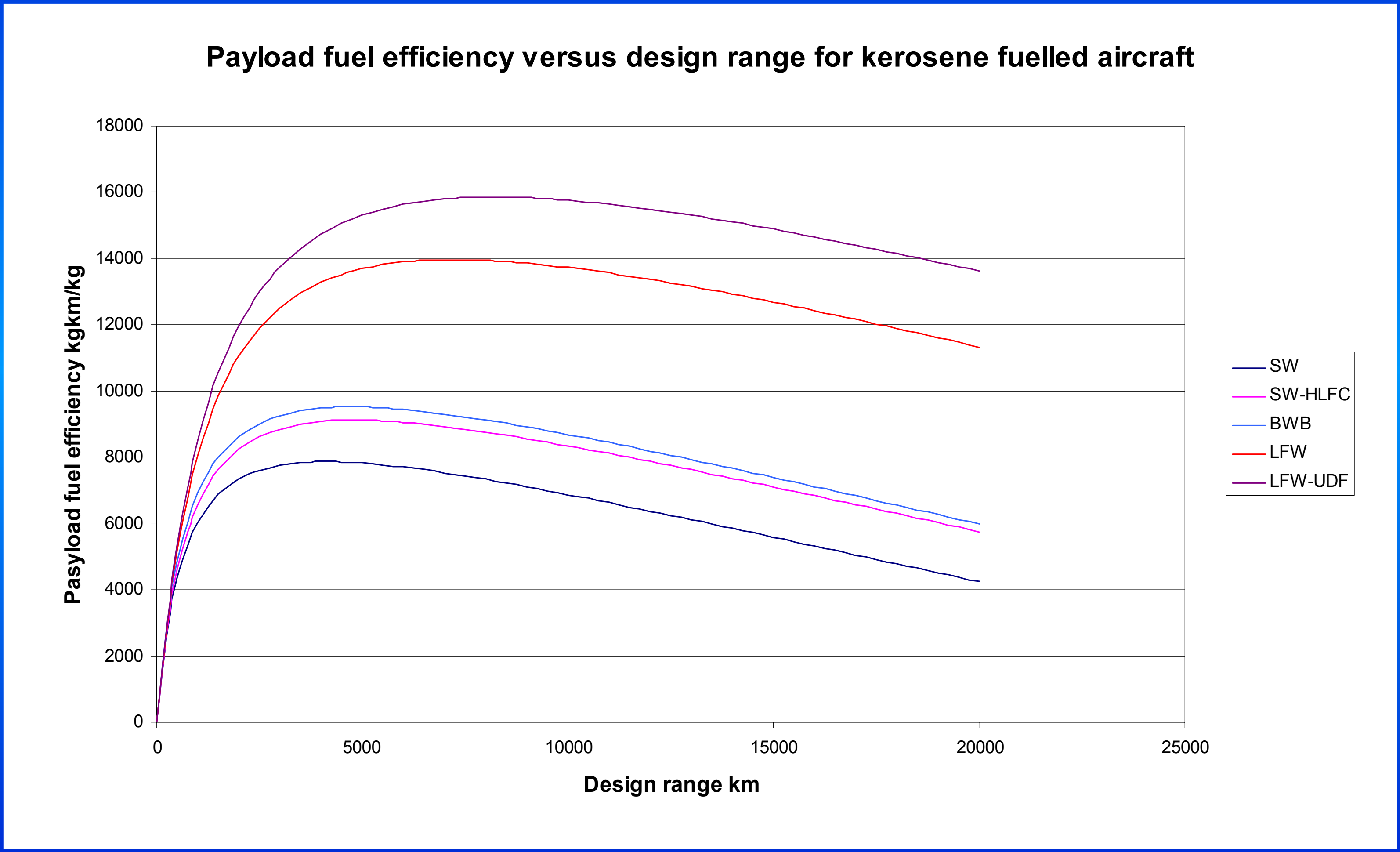


Fig 23 Design questions

- Design range
  - multi-segment long distance travel ?
- Cruise altitude
  - contrail avoidance, reducing NO_X impact ?
- Engine pressure ratio
  - trade-off increased CO_2 for reduced NO_X ?
- Cruise Mach number
  - reduce fuel burn & CO_2, enable unducted fans ?
- Design for minimum impact on climate
  - trade off between operating and environmental costs ?

Fig 24 CONCLUSIONS I

- In the long term, impact on climate change is the most important environmental effect of aviation.

- 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.

Fig 25 CONCLUSIONS II

- To achieve large reductions in CO_2 requires radical changes - a departure from the dominant configuration and the use of laminar flow control as a minimum.

- 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.

Fig 26 RECOMMENDATIONS – The Next Steps

Research priorities

- Atmospheric science
- Ultra low NO_X combustion

Technology demonstration

- Hybrid laminar flow control in airline service
- Low NO_X combustors
- Intercooled recuperative engine cycle
- Blended wing body concept

Design studies

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