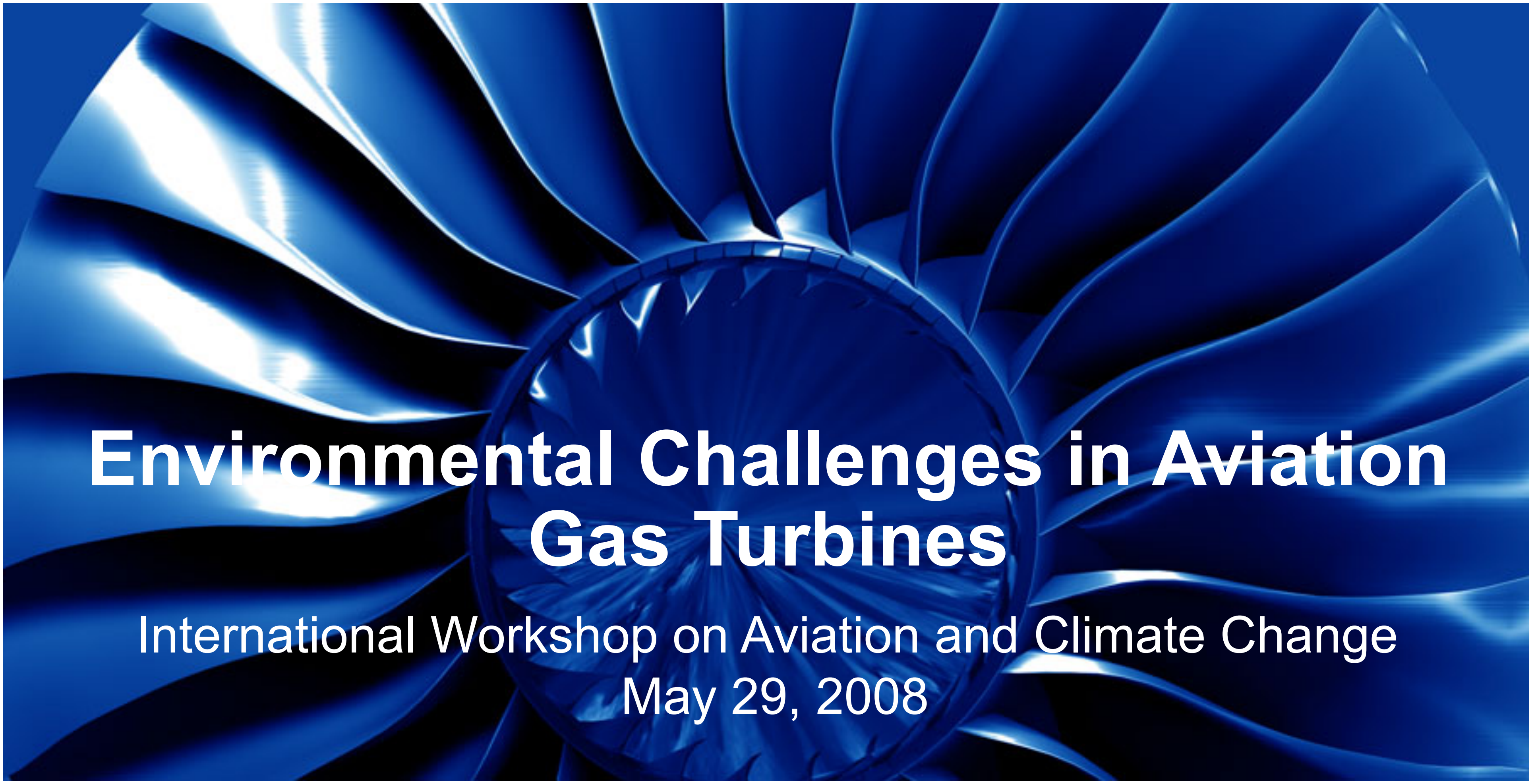


# Environmental Challenges in Aviation Gas Turbines

International Workshop on Aviation and Climate Change
May 29, 2008

Sam Sampath
Senior Fellow & Manager
Combustion and Emissions
Pratt & Whitney Canada

# OUTLINE

Challenges for Aviation

Environmental Impact from Aviation

Engine Emissions – Regulatory Requirements

Emissions of P&WC Engines

GHG Emissions & Carbon Trading

Aviation Fuel Challenges

Conclusions

PRATT & WHITNEY CANADA

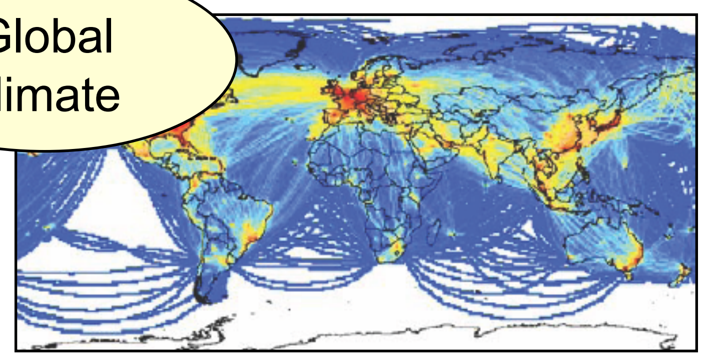
# ENVIRONMENTAL CHALLENGES FOR AVIATION

Local air quality

Communit y noise

Hazardous materials

Water quality

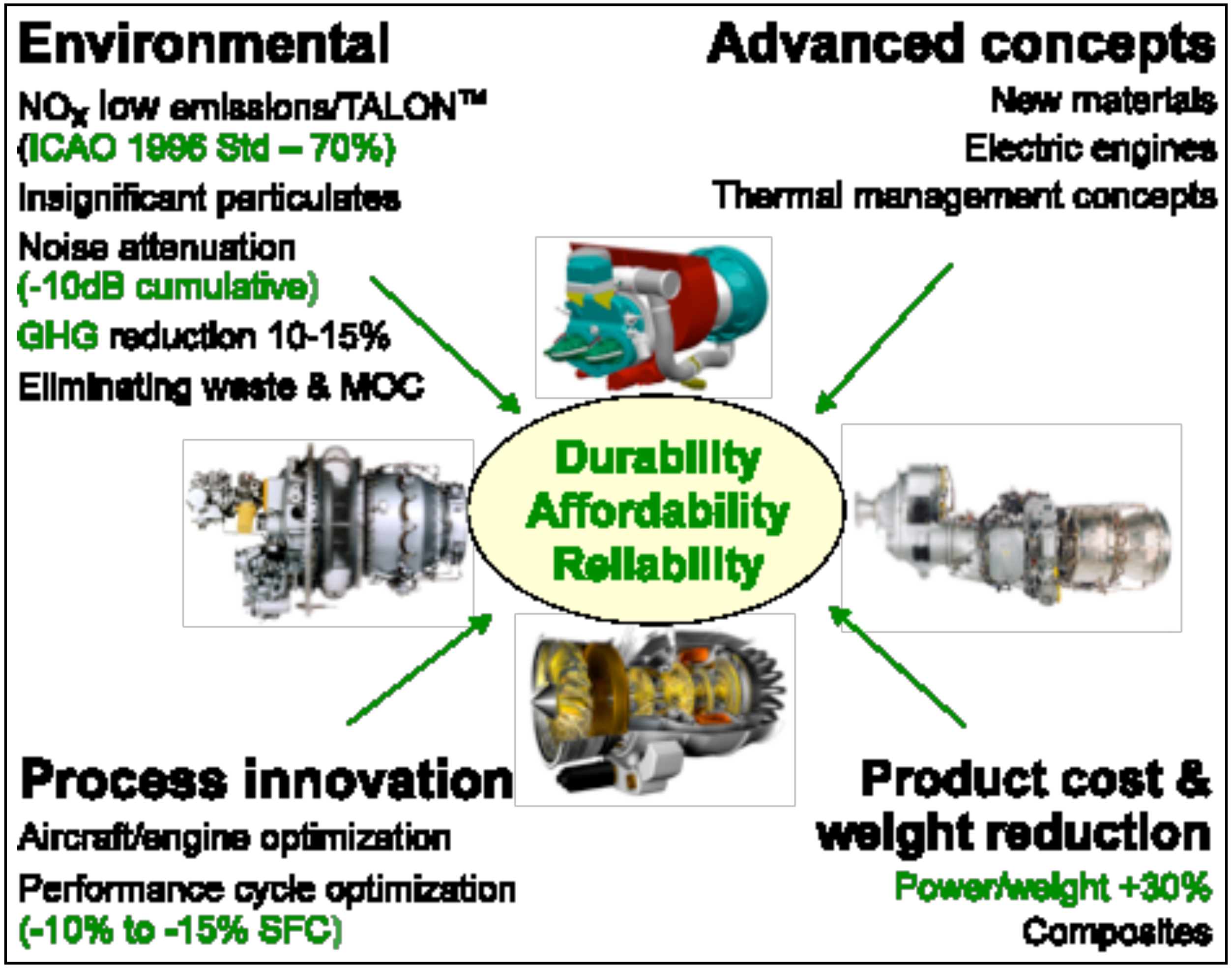


Fuel availability

Global climate

# GREEN ENGINE TECHNOLOGIES 2015 VISION

PRATT & WHITNEY CANADA




GOALS:

- Lowest possible emission impact
- Lowest possible noise impact
- Green materials & green processes
- Involve green suppliers and partners
- Material efficient Operations
- Address human factors
- Design for serviceability, reusability, recyclability

New technologies partnered with Canadian industries and universities

# EMISSION REGULATION STATUS (ICAO)

PRATT & WHITNEY CANADA

## Current Regulations

- NOx, CO, HC for a simulated landing take-off cycle below 3000 ft.
- NOx stringency progressively increasing since 1981 (4 steps)
- Exhaust smoke
- Fuel venting not allowed

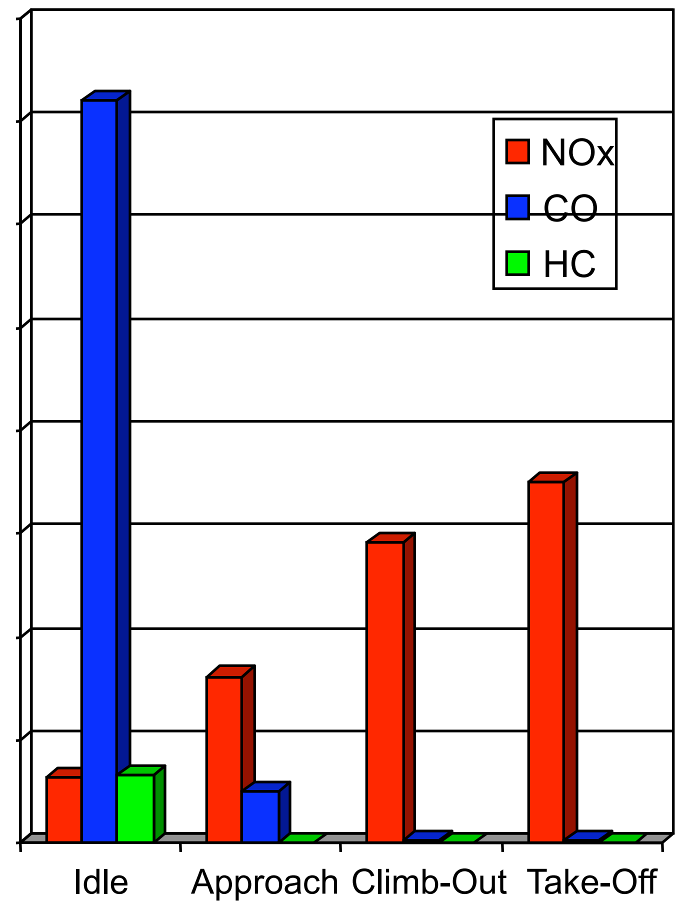
## Expected future regulations

- More stringency on NOx, including cruise
- Particulate matter ( and measurement methods)
- $CO_2$ through emissions trading schemes

## Other Concerns

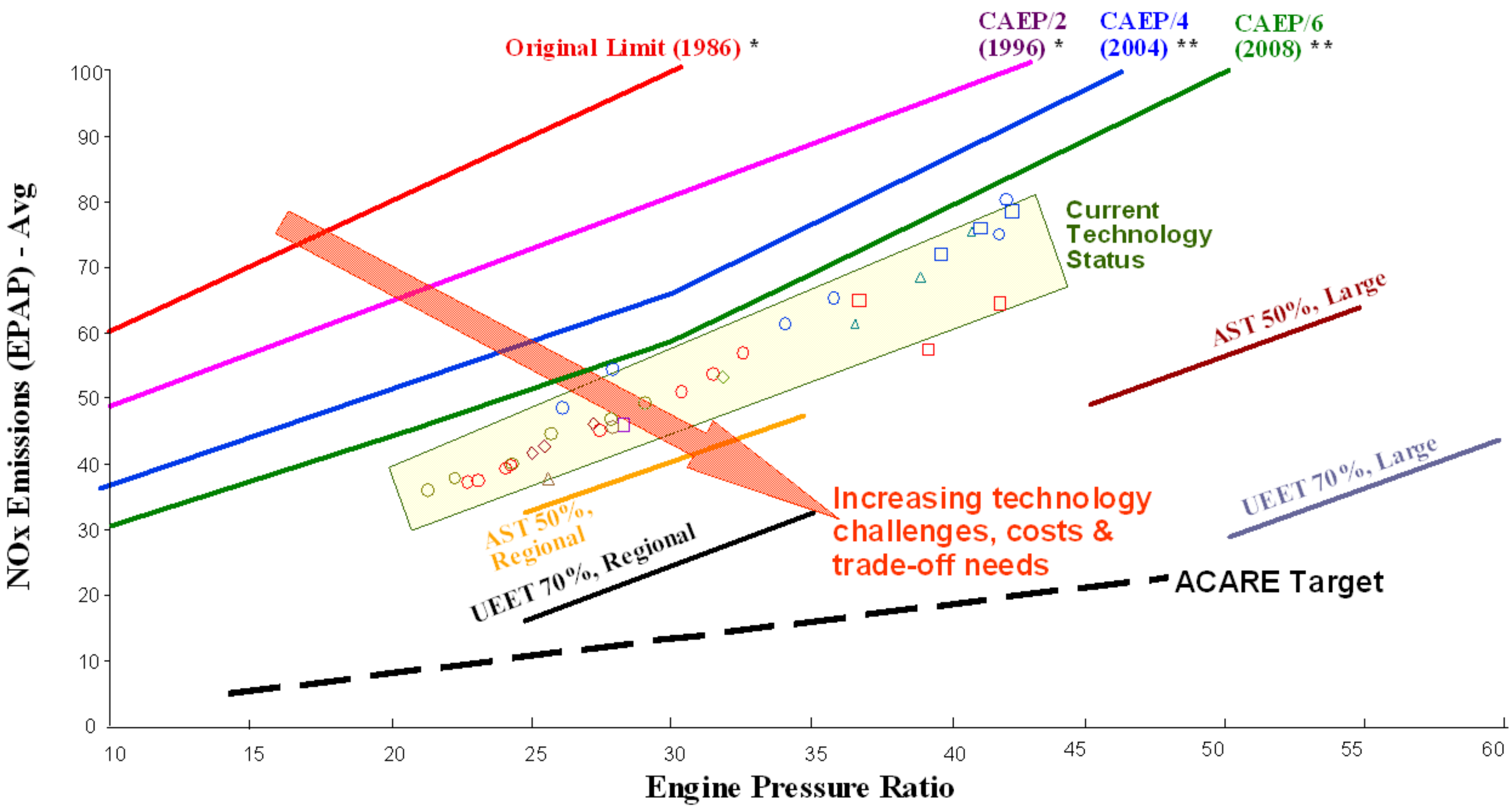
- Cirrus clouds / contrail cirrus (water and particulate matter)

**Typical Emissions Profile**



# NOx TECHNOLOGY STANDINGS vs REGULATIONS

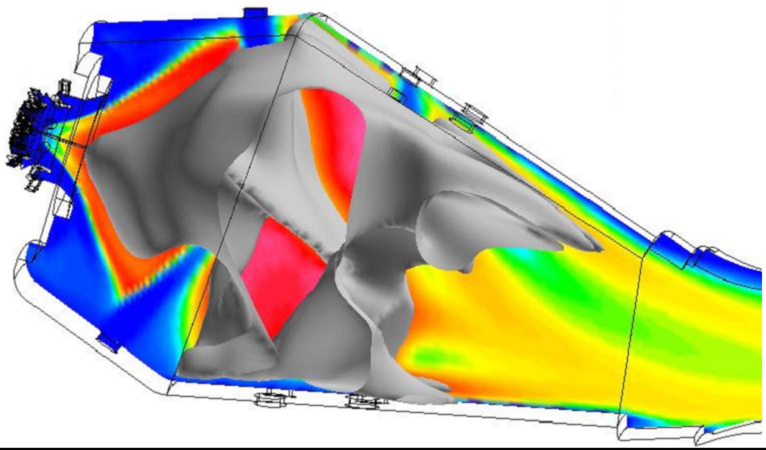
PRATT & WHITNEY CANADA



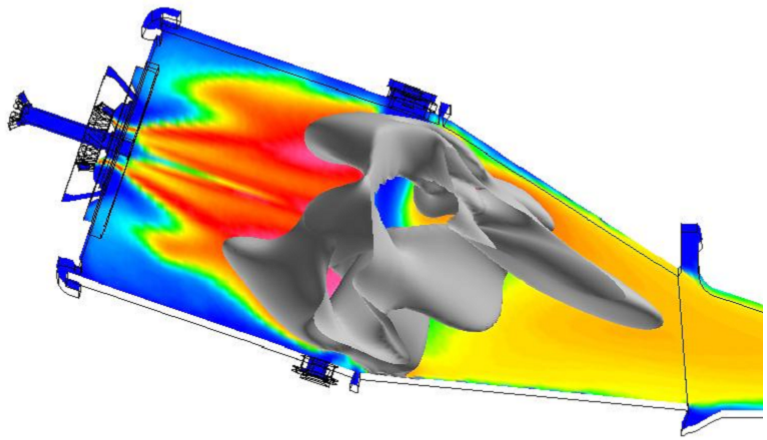

* For turbofan engines exceeding 6000 lb thrust only
** Correction for thrust down to 6000 lb with no additional stringency

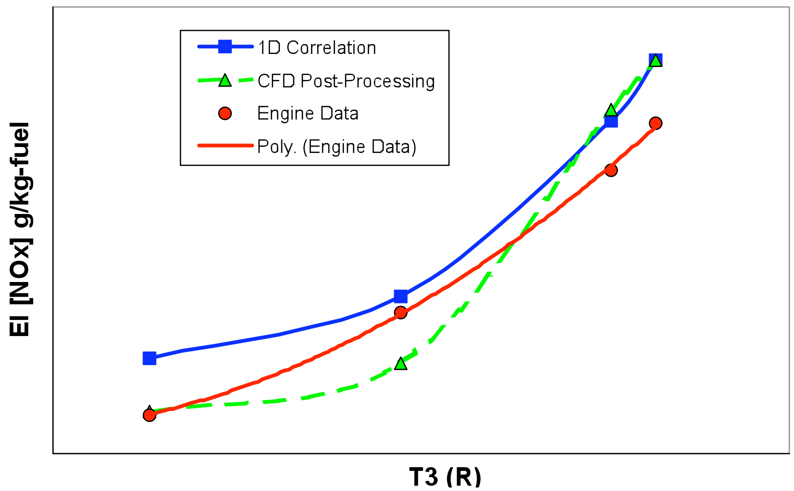
# CFD MODELLING ON NOx

NOx Generation Region In A Conventional Combustor



NOx Generation Region In A Low Emissions Combustor






- NOx post processing from CFD
- Extended Zeldovich mechanisms
- Predicted prompt NOx is small
- NOx is sensitive to spray quality

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# PARTICULATE MATTER

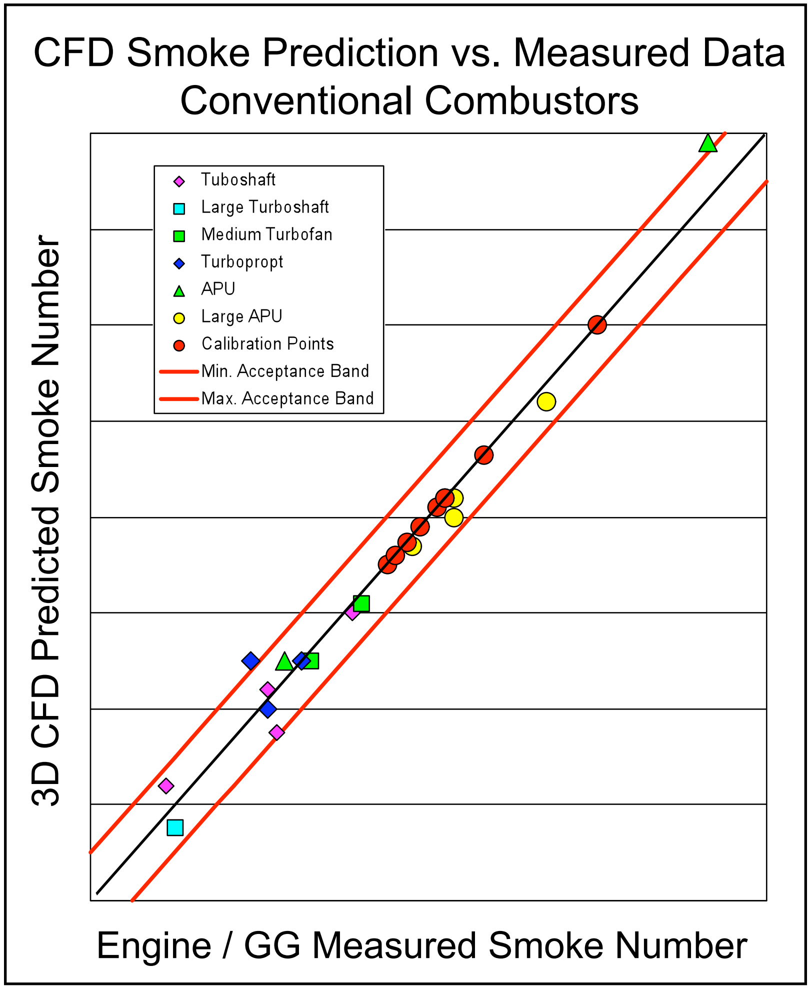
Concern to-date has been on visible carbon & regulations are based on opacity of exhaust plume (Smoke Number)

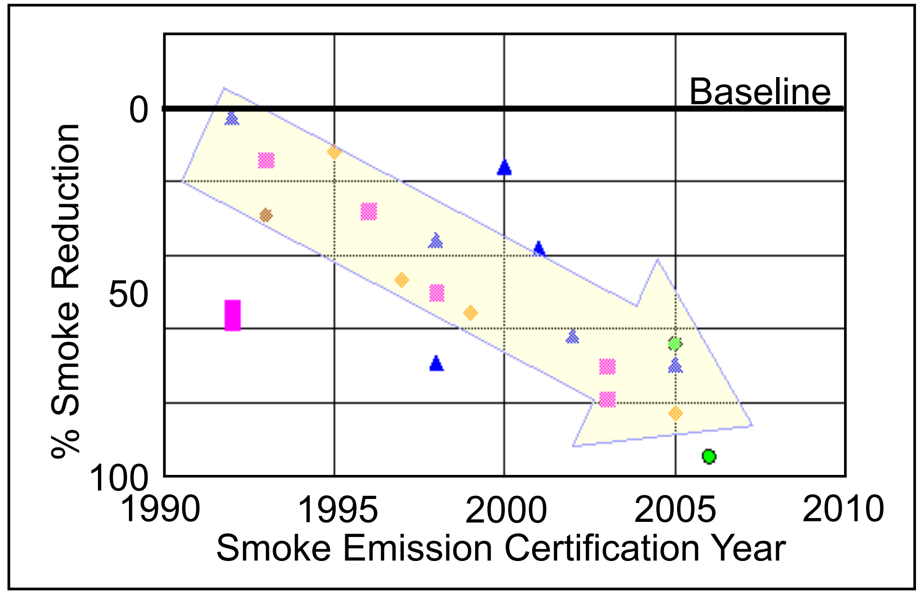
All aviation engines are regulated to ensure exhaust plume is not visible

More recent studies on global warming are concerned with particulate emissions in flight

- Atmospheric particulates are in the range of 5 – 1000 nM sizes
- Aviation exhaust particulates are in range of 10 –100 nM; largest portions are in 30 - 40 nM range, < 10 nM particulates are mainly volotalic species
- Circumstances creating nucleation are to be investigated including effect of sulphur

# SMOKE EMISSIONS REDUCTION




- Semi-empirical prediction method
- CFD post processing for smoke index
- Anchored prediction model

Key technologies are advanced computational analysis (CFD) and improved fuel injectors

# CARBON TRADING

**Key elements of EU proposal and ICAO guidelines**

As of 2011-2012, all flights between community airports will be subject to emissions trading systems

As of 2015, non-EU country flights will also be subject to emissions trading systems

Carbon allowances will be determined on basis of historical aviation emissions in years 2004 to 2006

Guidance on emissions trading for aviation was a key subject of ICAO/CAEP meeting in Montreal, February 2007

There is no agreement between EU and rest of the world on an acceptable emissions trading system

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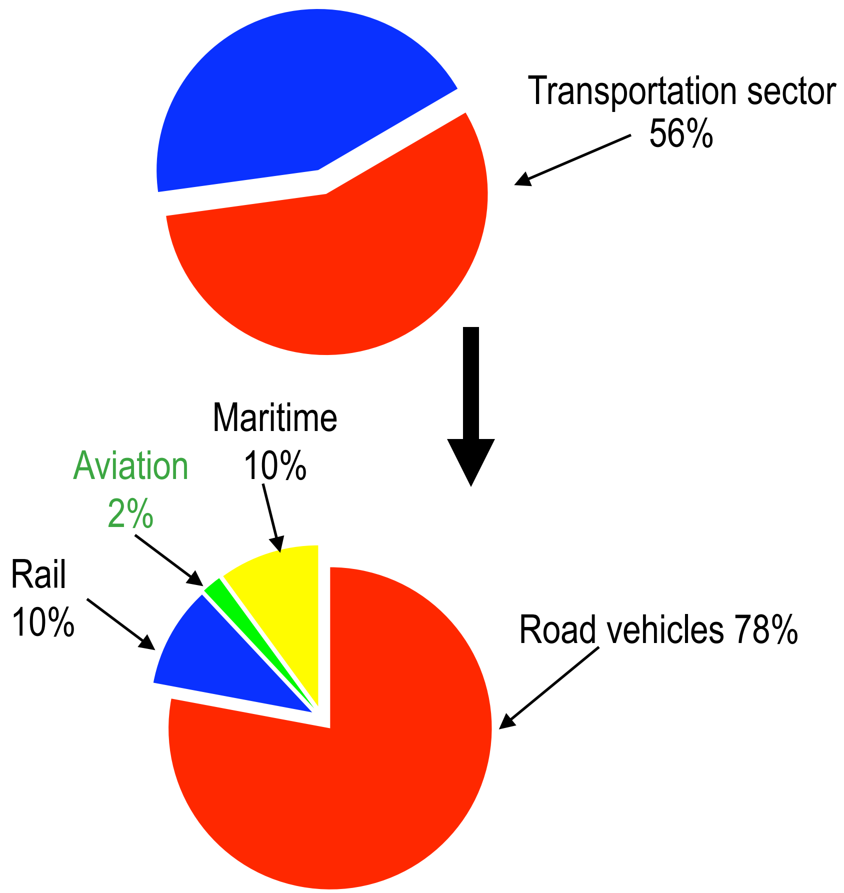
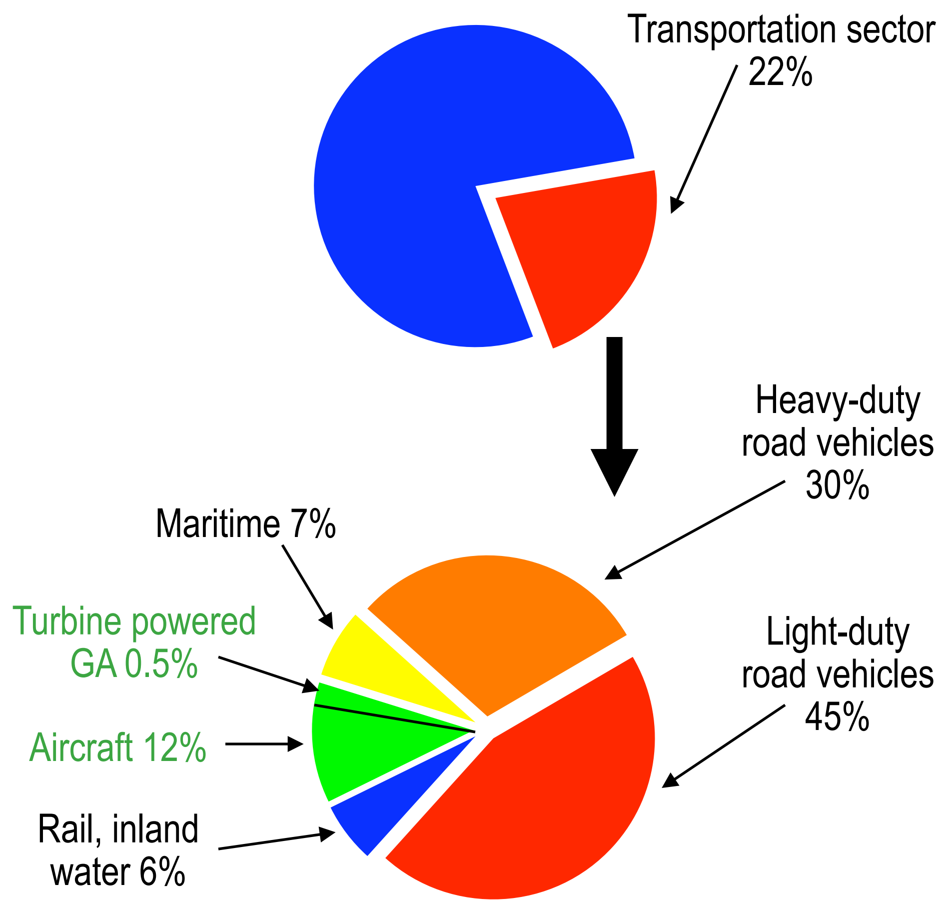
# ENVIRONMENTAL IMPACT FROM AVIATION

## Global $NO_X$ emissions



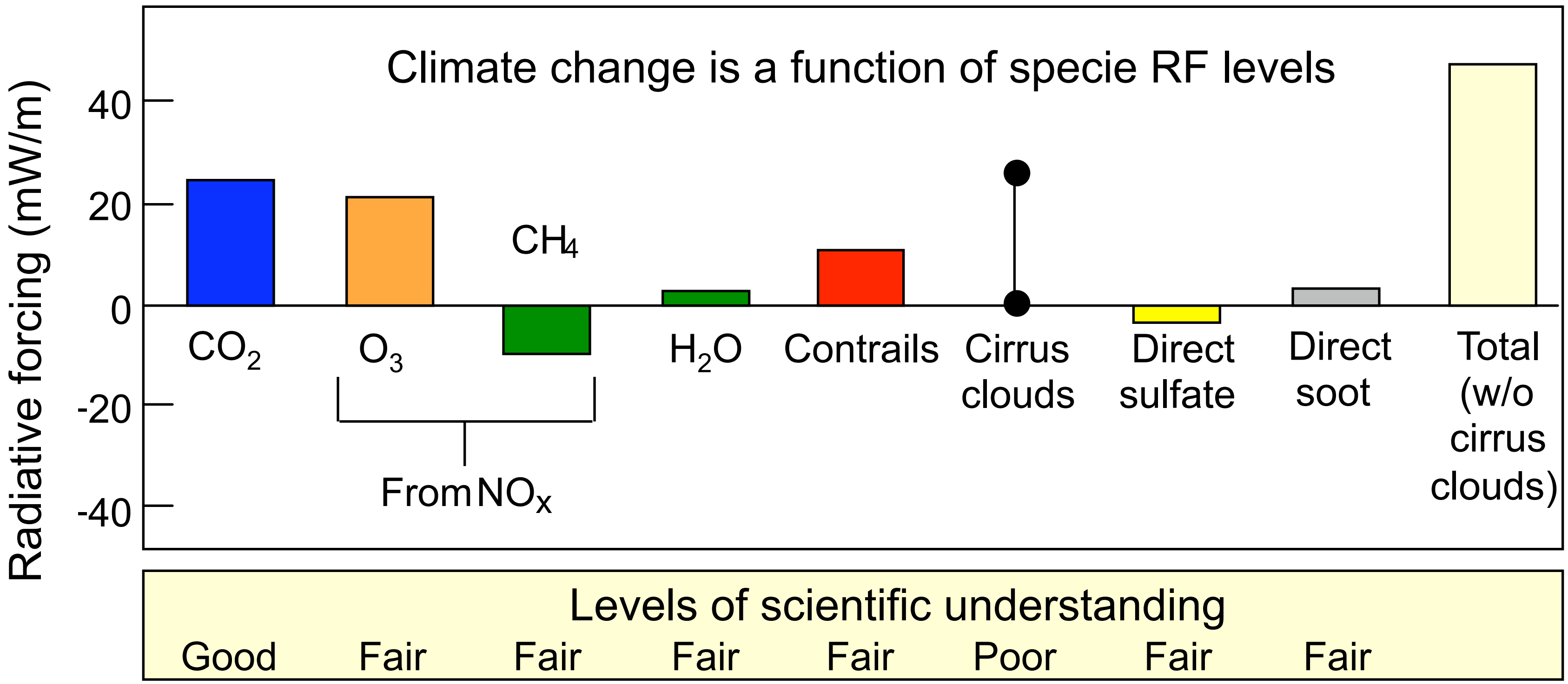

## Global $CO_2$ emissions




**Aviation contributes <1.5% $NO_X$ and <3% $CO_2$ of global emissions**

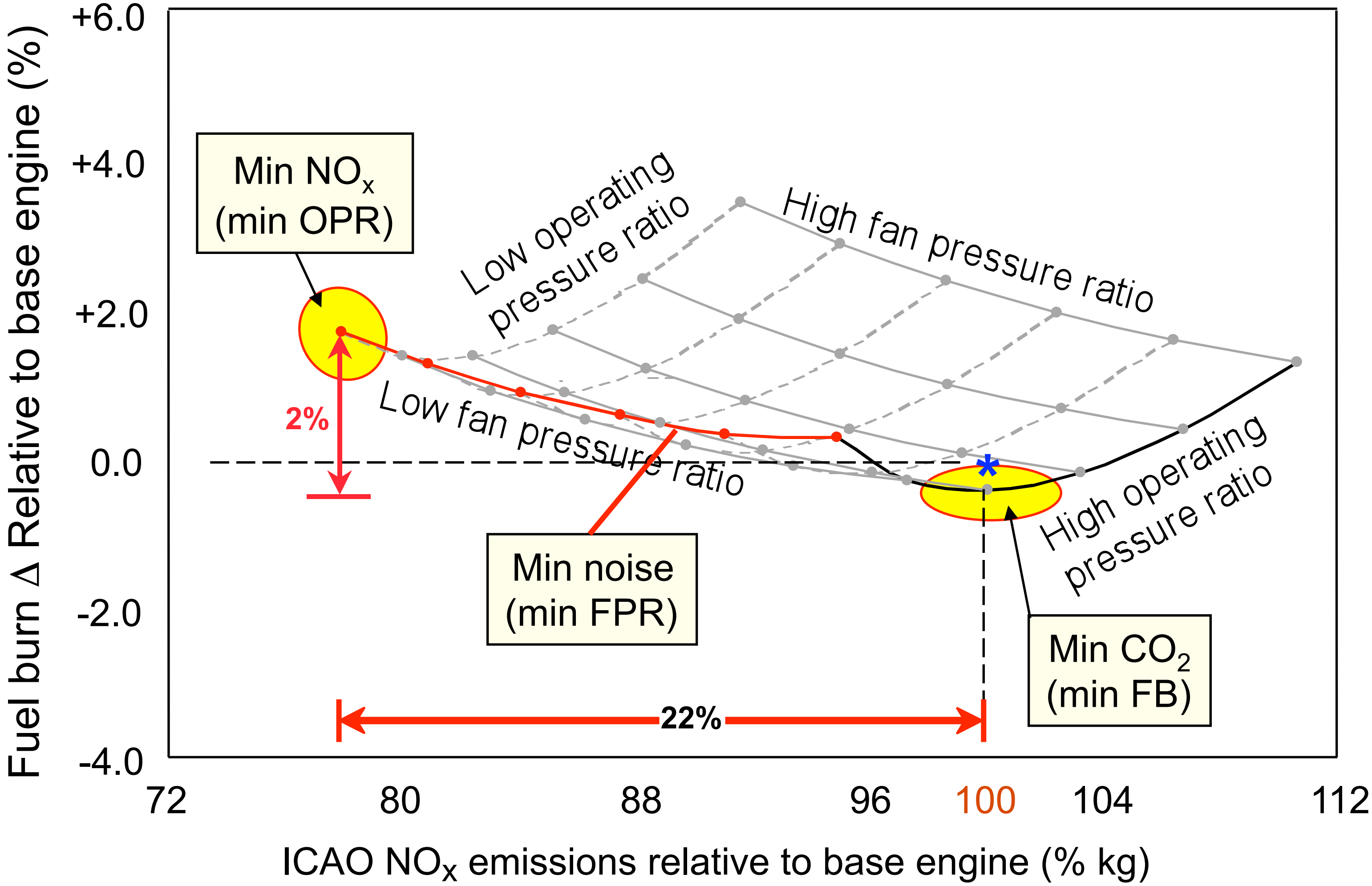
# ESTIMATION OF GLOBAL WARMING FROM INDIVIDUAL SPECIES IN AIRCRAFT EXHAUST

Radiative forcing levels from aviation species for Y2000




Impact on global environment from $NO_X$ can be as significant as from $CO_2$

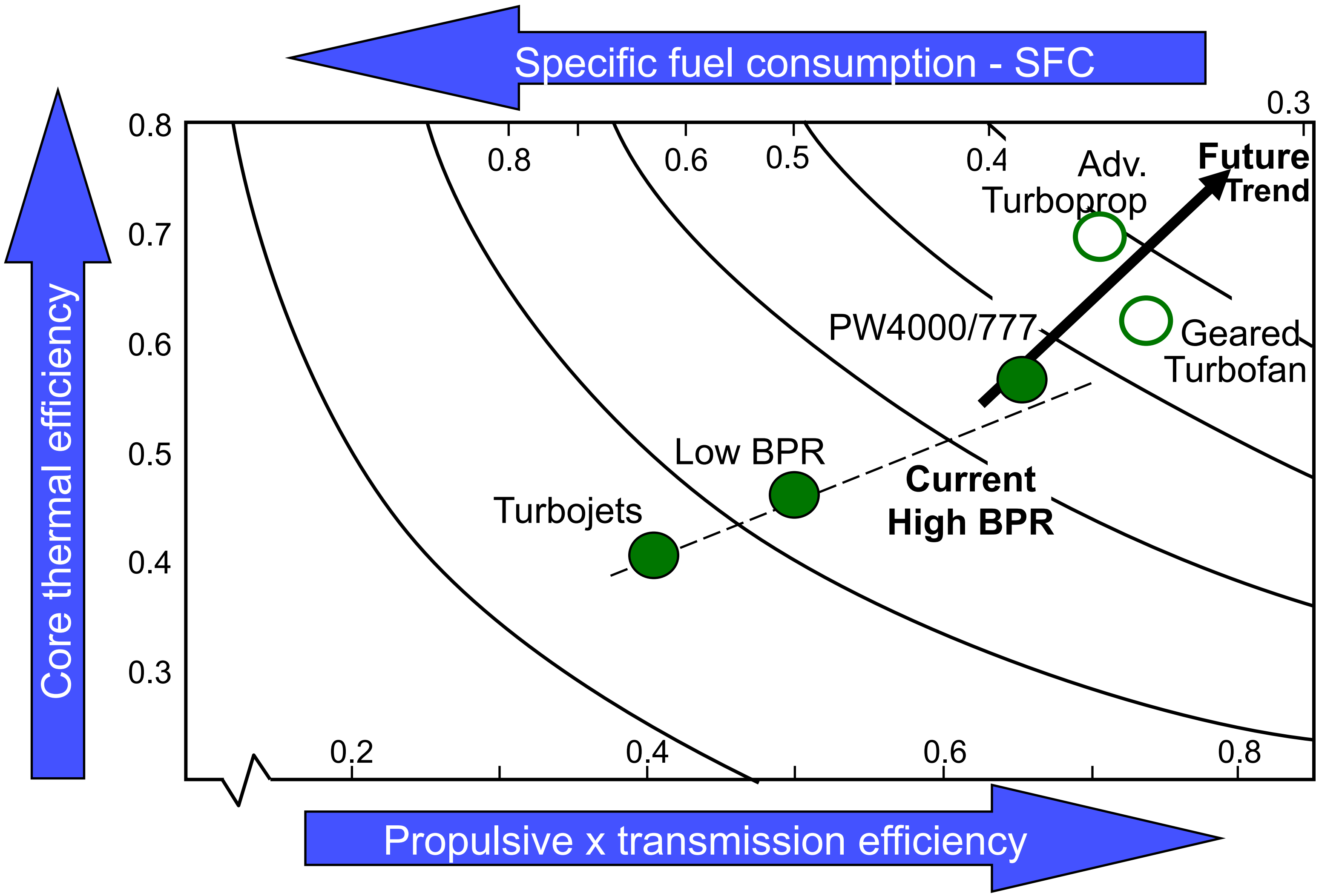
# ENGINE CYCLE OPTIMIZATION DRIVERS INFLUENCING FUEL BURN & $NO_X$



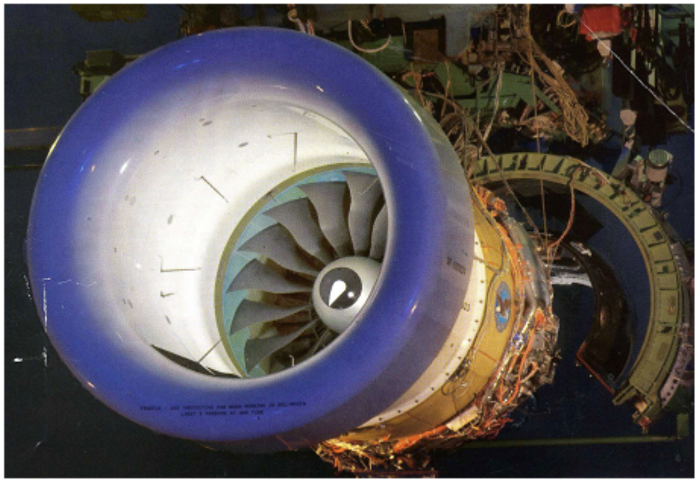

Design trade-offs required between noise, fuel burn and $NO_X$ emissions

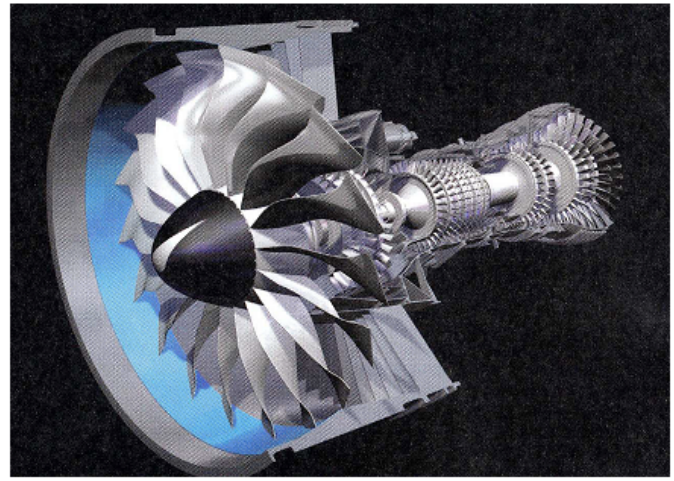
# EVOLUTION OF AERO GAS TURBINE EFFICIENCY

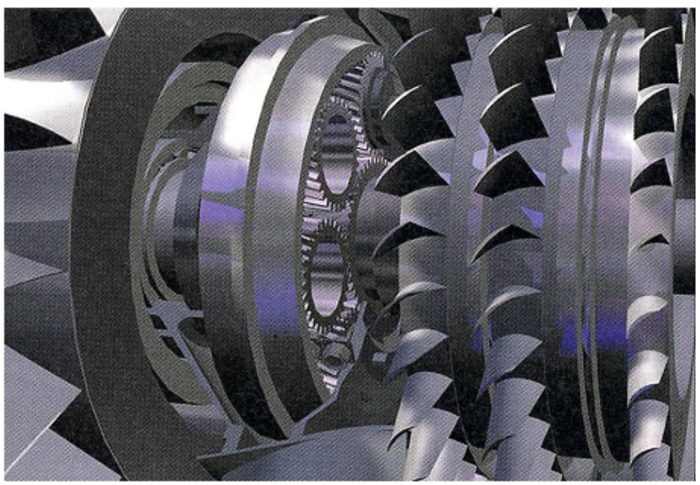




# GEARED TURBOFAN (GTF)







GTF has shown step change reduction with current core technology.  More reductions possible with GTF technology.

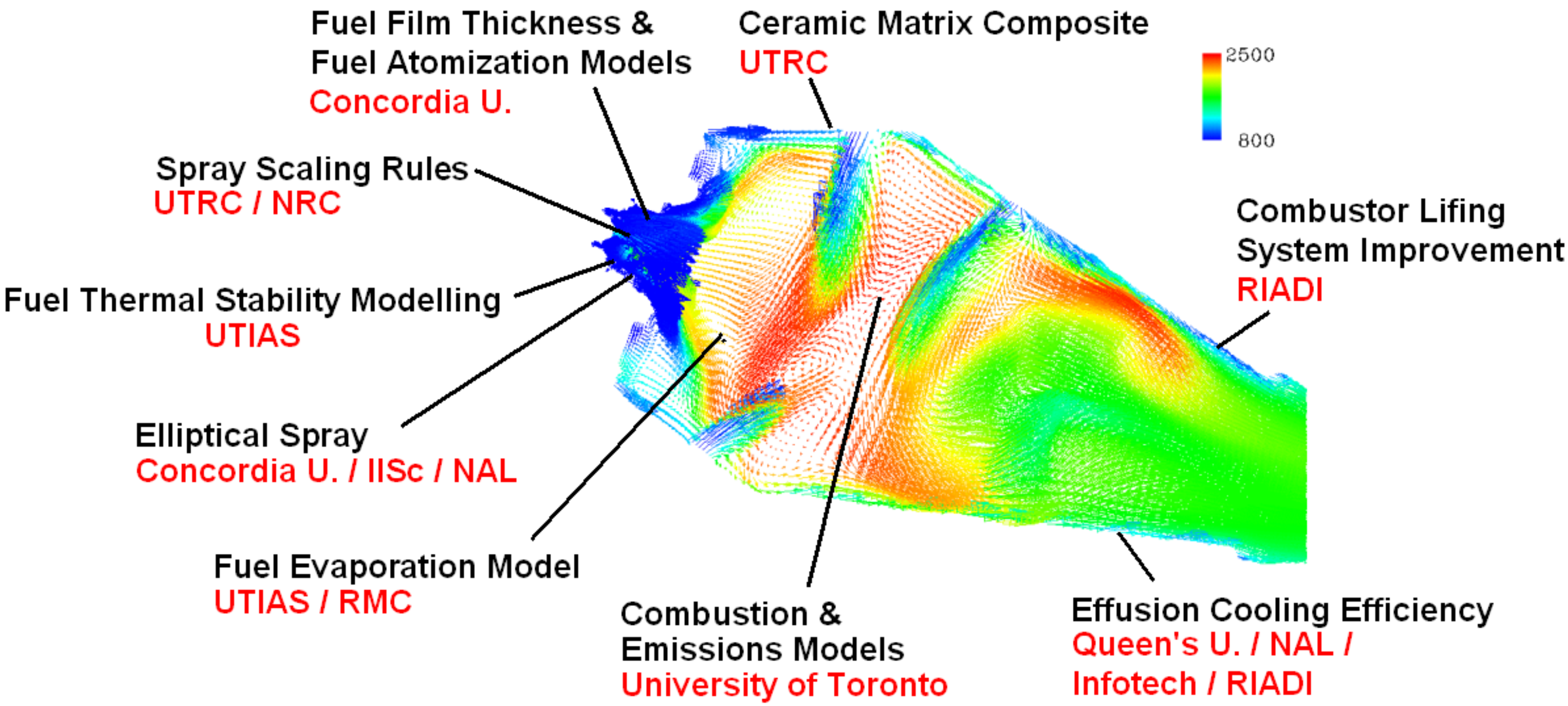
- Benefits all emissions ($CO$, $HC$, $NOx$, $CO_2$)
- Upto 20 dB reduction in noise

The geared turbofan has shown significant fuel burn reduction without compromising operability, noise or emissions

# EMISSIONS REDUCTION
# TALON™ TECHNOLOGY FOR LOW EMISSIONS

PRATT & WHITNEY CANADA

**P&WC Has Reduced NOx by Over 50% Using TALON Technologies**




P&WC Low Emissions Technology Involves Canadian University Collaboration

# ENVIRONMENTAL CHALLENGES FOR AVIATION – FUEL COSTS

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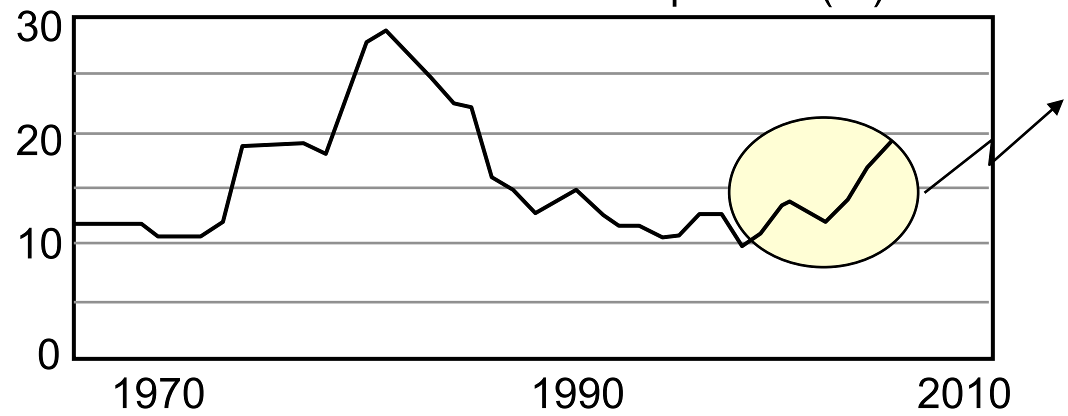
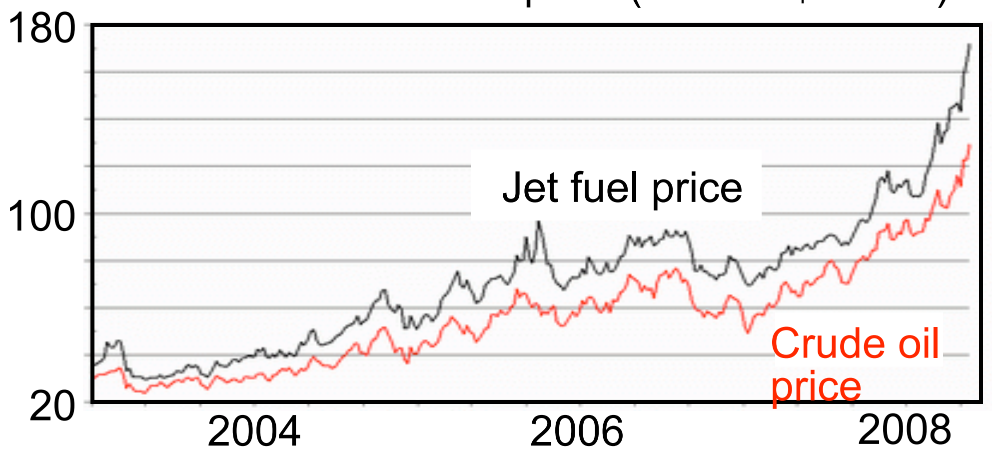
Fuel cost in total airline expenses (%)




Fuel costs as % of aviation expenses is on the rise again

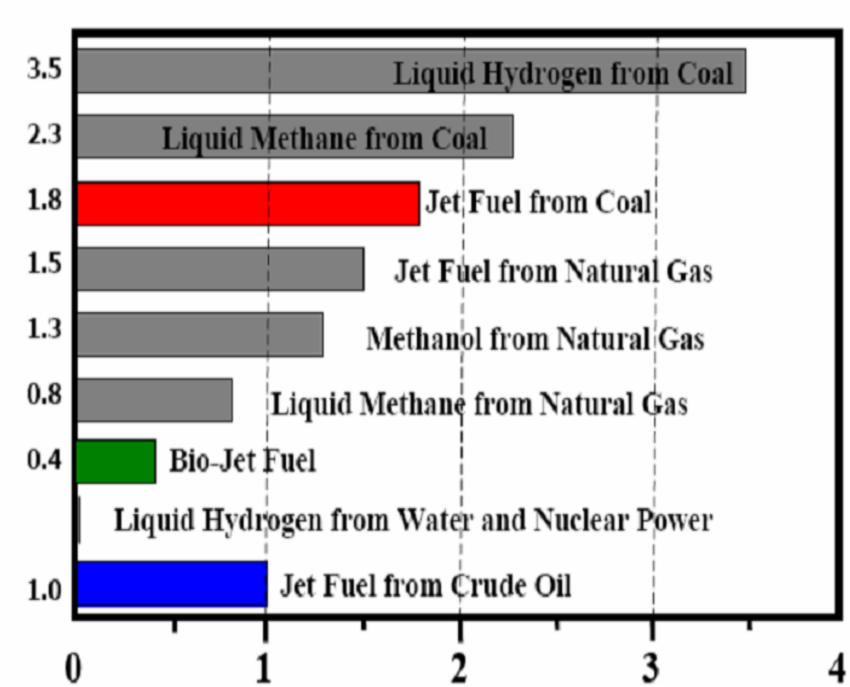
Jet fuel and crude oil price (then Yr $/barrel)




Oil price evolution

Environmental & economic concerns will drive efforts to reduce fuel consumption

# RELATIVE $CO_2$ EMISSIONS OF FUELS




**Biofuel Energy Balance**

| Fuel Type (feedstock) | Energy Balance | Fuel Type (feedstock) | Energy Balance |
|---|---|---|---|
| Gasoline (crude oil) | ~ 0.8 | Diesel (crude oil) | 0.8 - 0.9 |
| Ethanol (cellulose) | 2 - 36 | Biodiesel (palm oil) | ~ 9 |
| Ethanol (sugar cane) | ~ 8 | Biodiesel (soybeans) | ~ 3 |
| Ethanol (sugar beets) | ~ 2 | Biodiesel (sunflower) | ~ 3 |
| Ethanol (corn) | 1.23 - 1.79 | Biodiesel (rapeseed) | 1.9 - 2.9 |
| Ethanol (wheat) | ~2 | Biodiesel (Jatropha) | No Data |

# ENVIRONMENTAL SOLUTIONS FOR AVIATION - CONCLUSIONS

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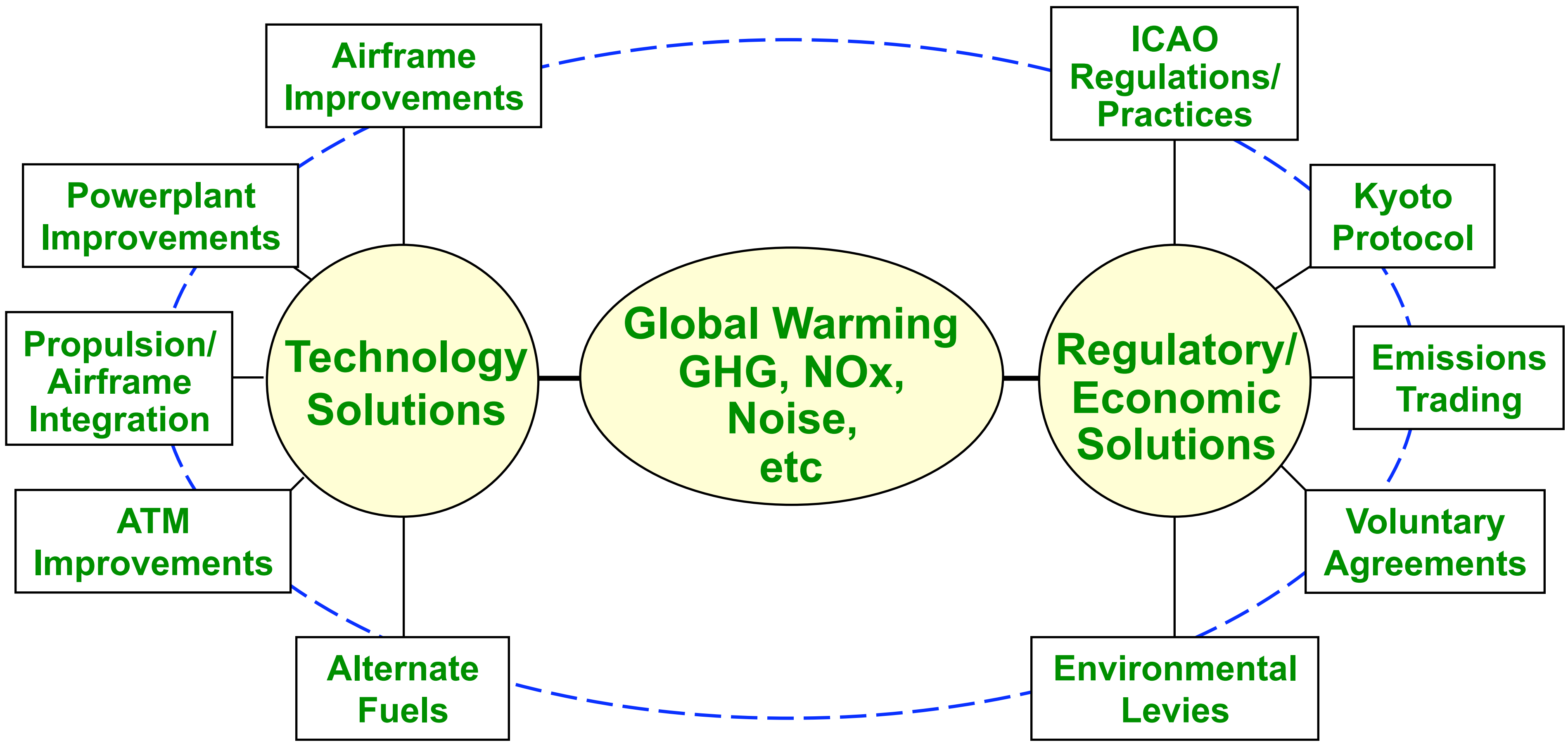
## Global environmental problems call for global solutions



# CONCLUSIONS

- Global environmental problems call for global solutions
- Aviation industry has recognized environmental issues since the 1970s
- International Coordinating Council of Aerospace Industries Associations (ICCAIA) is currently supporting solutions and balanced approaches across industries
- Good progress has been made in identifying $NO_X$ solutions
- GHG emissions require coordinated solutions involving market-based options and new technologies in aviation & alternate fuels
- All other green engine technologies - products, processes and noise – will continue to receive utmost attention
- ICAO should continue to have key role in determining global environmental regulations