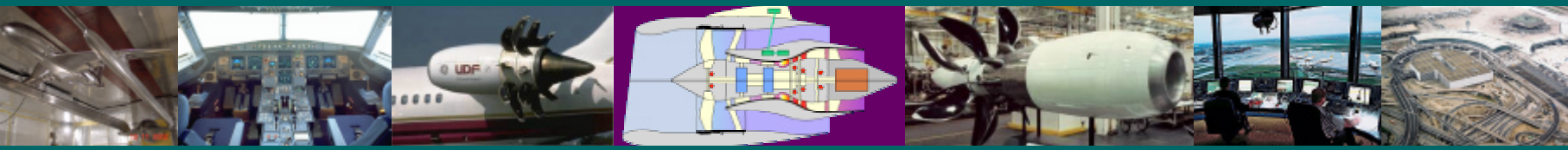
Reducing Aviation Emissions



The Manufacturers' Perspective

International Civil Aviation Day

7 December 2005

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OVERVIEW - 1: Drivers & Efficiency

- Aeronautical Manufacturers have a vocation to develop innovative technology and design highly performing products
  - Permanent challenges & efforts, with prime dimension firmly established for environmental protection
  - Supported by intensive research in cooperation with the Research Community - Needs sustained research & technology funding from Industry & Governments
- Aviation industry has been able to attenuate significantly its environmental impact
  - Noise annoyance has been divided by four, and the balanced approach to noise management should protect the future
  - Fuel consumption per pass-km has been divided by three
  - Beyond these considerable achievements, Aviation Industry targets reductions on an average basis per year of more than 1% in fuel efficiency and ≈ 0.5 dB in noise per operation

OVERVIEW - 2 : Way Forward

- Further well supported & coordinated efforts in a coherent and stable, harmonized international regulatory framework, and in a cooperative context, are key to progress efficiently
  - This is happening but needs to be pursued & amplified
  - ICAO plays a major « facilitator » role & provides the right forum
- Design & Technology represent only a part of the solutions: all actors have to work together to address all sources (Aircraft, airport, operations, ATM)
- A global systems approach is needed to reach optimum solutions with maximum efficiency

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How aviation emissions are produced

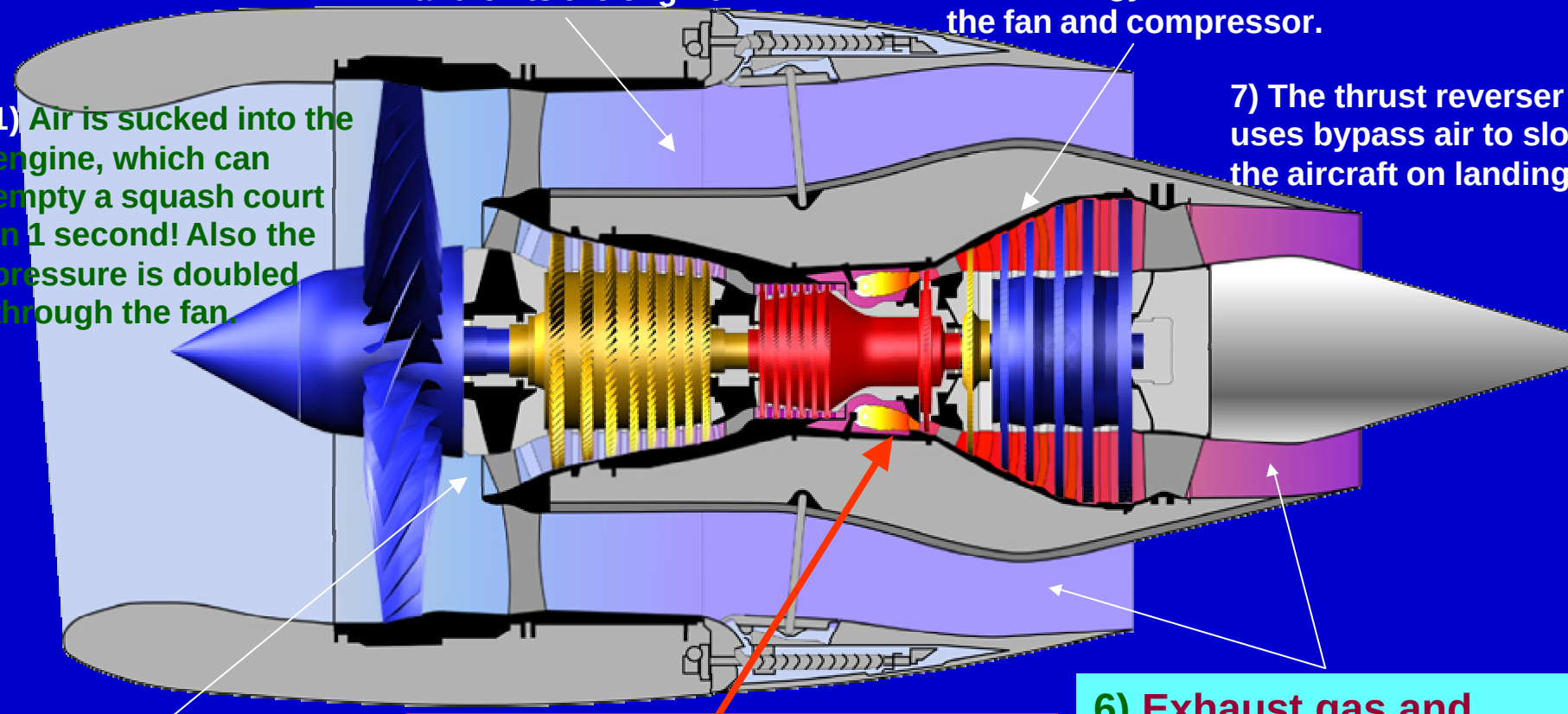
Typical Turbofan Engine

3) 85% of the air bypasses the core and exits the engine.

5) The hot gas expands through the turbine which takes energy out to drive the fan and compressor.

7) The thrust reverser uses bypass air to slo the aircraft on landing

1) Air is sucked into the engine, which can empty a squash court in 1 second! Also the pressure is doubled through the fan.

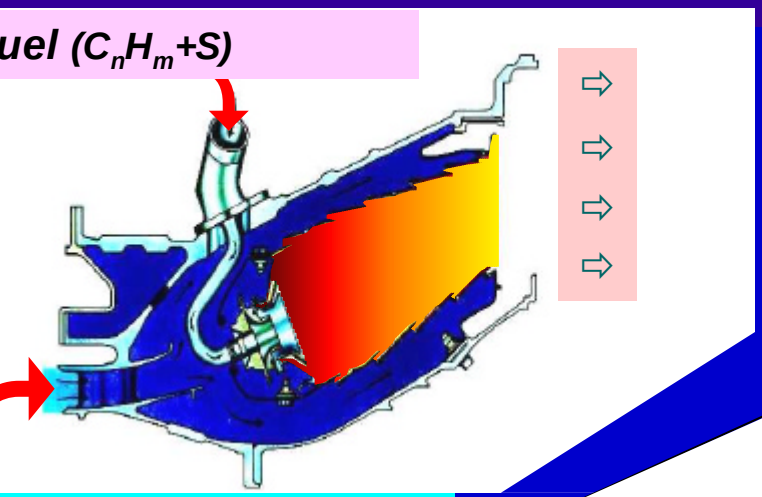


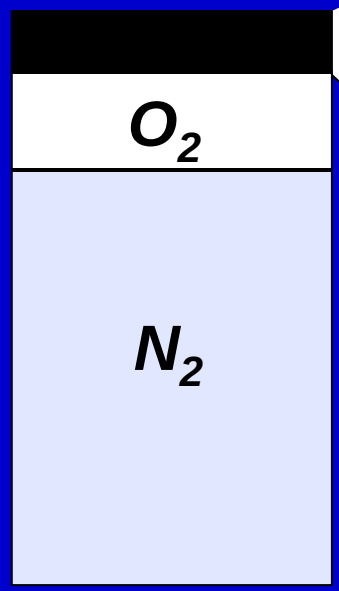
2) 15% of the air enters the core and is compressed to 40 times atmospheric pressure.

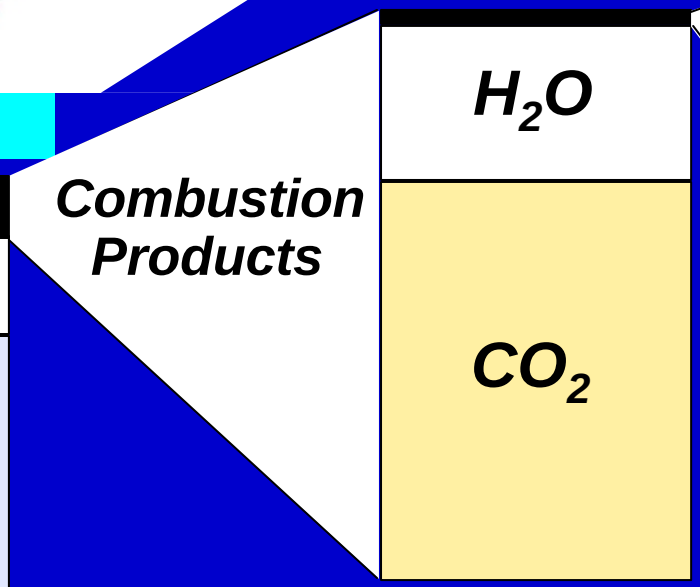
4) In the combustion chamber fuel is mixed with air and burnt at temperature » 1900 °K with peak » 2600 °K.

6) Exhaust gas and bypass air mix through hot and cold nozzles to produce thrust.

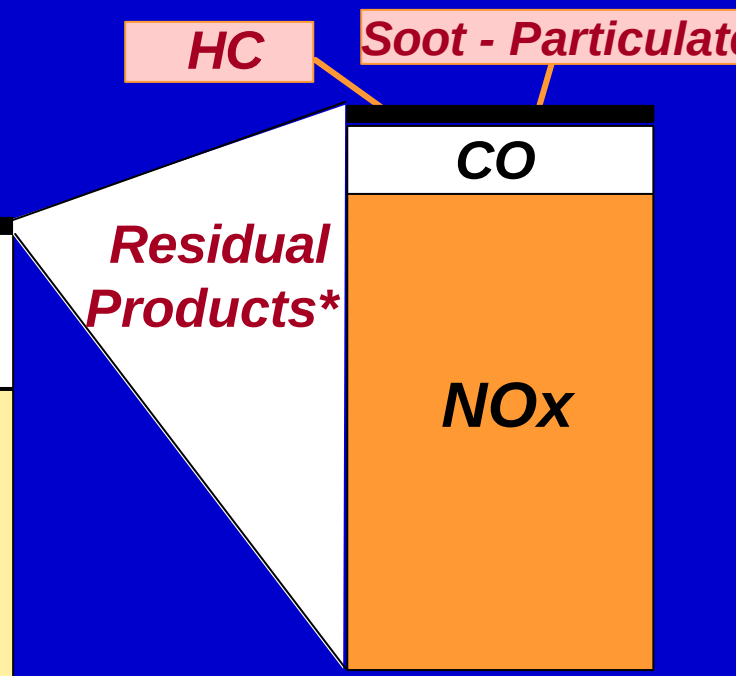
Combustion and other Exhaust Products







(+ SO_x)



* non-ideal combustion

Reducing fuel consumption tends to reduce all gaseous emissions

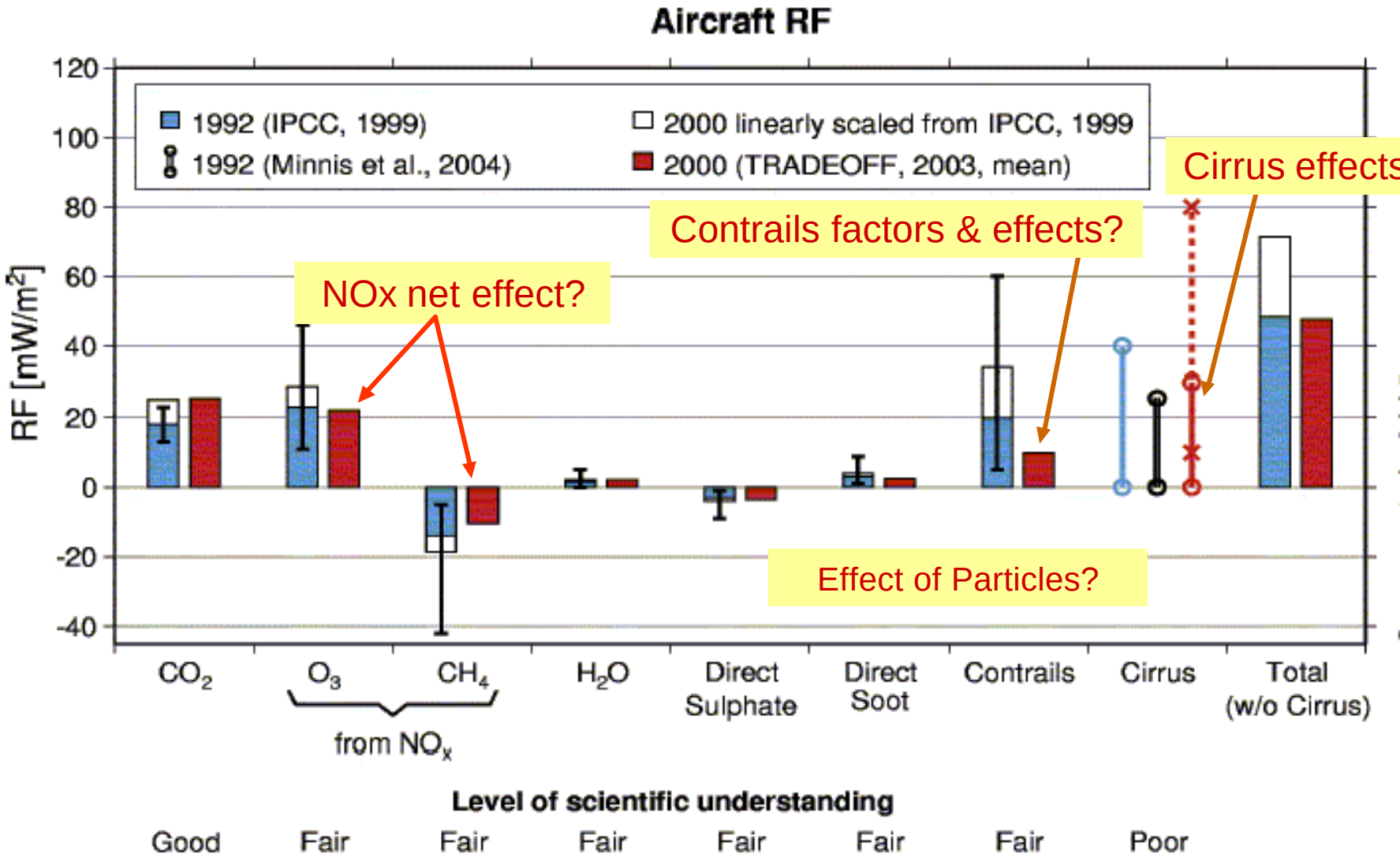
Aircraft Engine Emission Issues

Emission Category	Primary Issues	
	Local Air Quality (Ground Level)	**Climate Change (High Altitude)**
Nitrogen Oxides * (NO_X)	Ozone production - Health/Visibility	**GHG evolution (Ozone & Methane) - ↗RF**
Unburned Hydrocarbons* (CH_4, NMHC/VOC/HAPS-[hazardous air pollutants, e.g. Benzene])	Ozone production - Health/Visibility	--
Carbon Monoxide* (CO)	Ozone production - Health	---
Smoke [Smoke Number (SN)*] ⇨Soot, Particulate	Aerosols, particle matters (PM) - Health	**Contrails /Cirrus formation - ↗ RF**
Water Vapor (H_2O)	---	**Contrails/Cirrus formation - ↗RF**
Carbon Dioxide (CO_2)	---	**GHG increase - ↗RF**

* Covered by Current ICAO Regulations

RF: Radiative Forcing

Aviation & Radiative Forcing



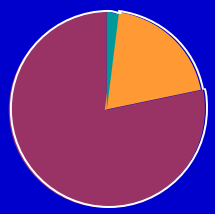
Overall radiative forcing vs CO2 emissions impact ? (RFI value?)

Relative Impact of Air Transport on GHG and Climate (1990-1996)

on anthropogenic CO_2 emissions

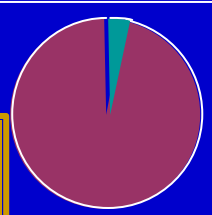
- Air Transport
- Other Trans. Modes
- Other Anthropogenic Sources

2%

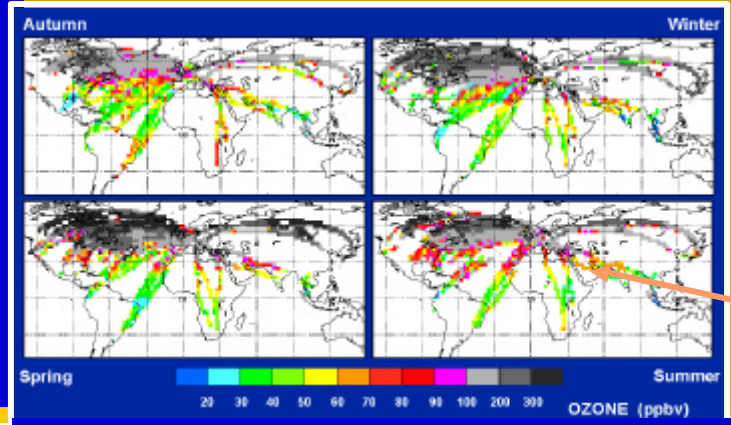


on total radiative forcing by anthropogenic activities

- Air Transport
- Other Anthrop. activities



3,5%



* « MOZAIC » project: Ex. of O_3 concentration measurements in the atmosphere

⇨ *Improving the scientific understanding of the atmosphere and the impact of aviation emissions is key to optimize priorities and weight factors in research, trade-offs and mitigation measures*

⇨ *Industry supports and participates in these efforts **

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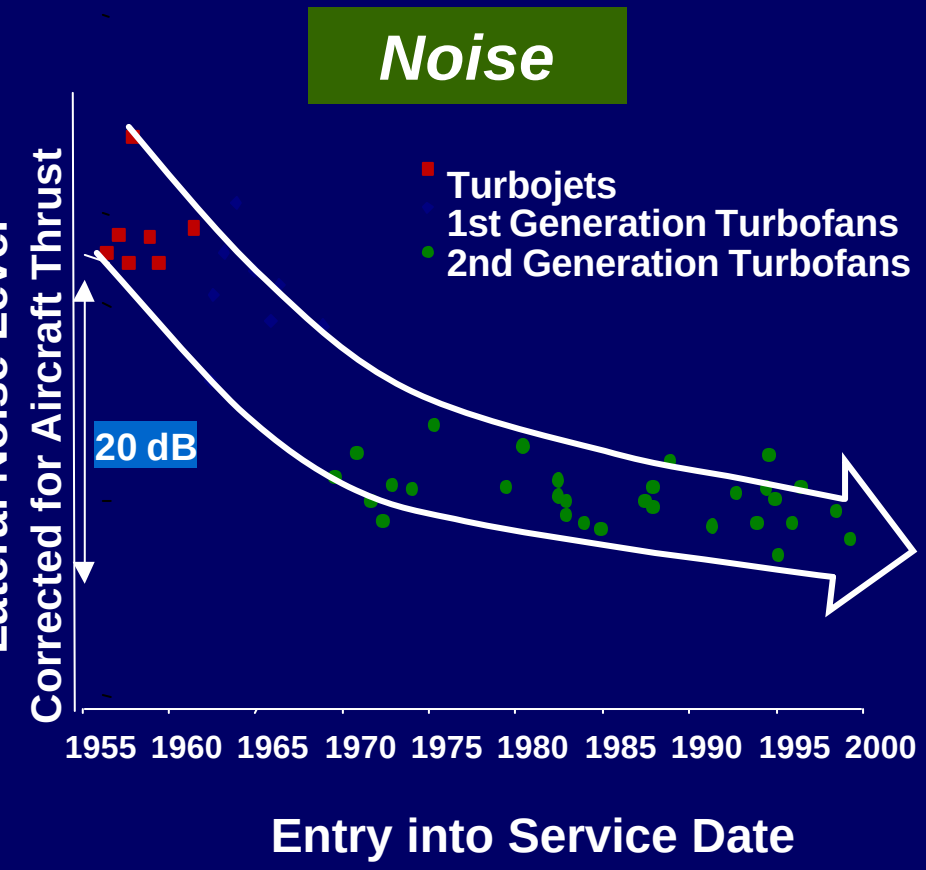
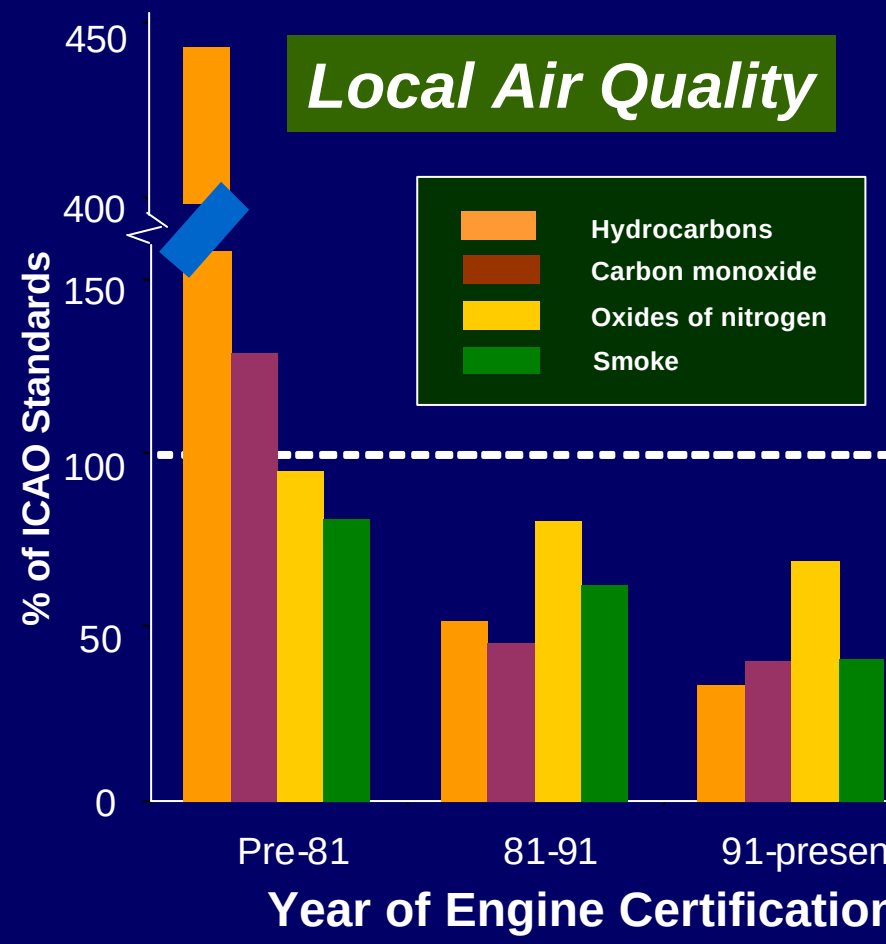
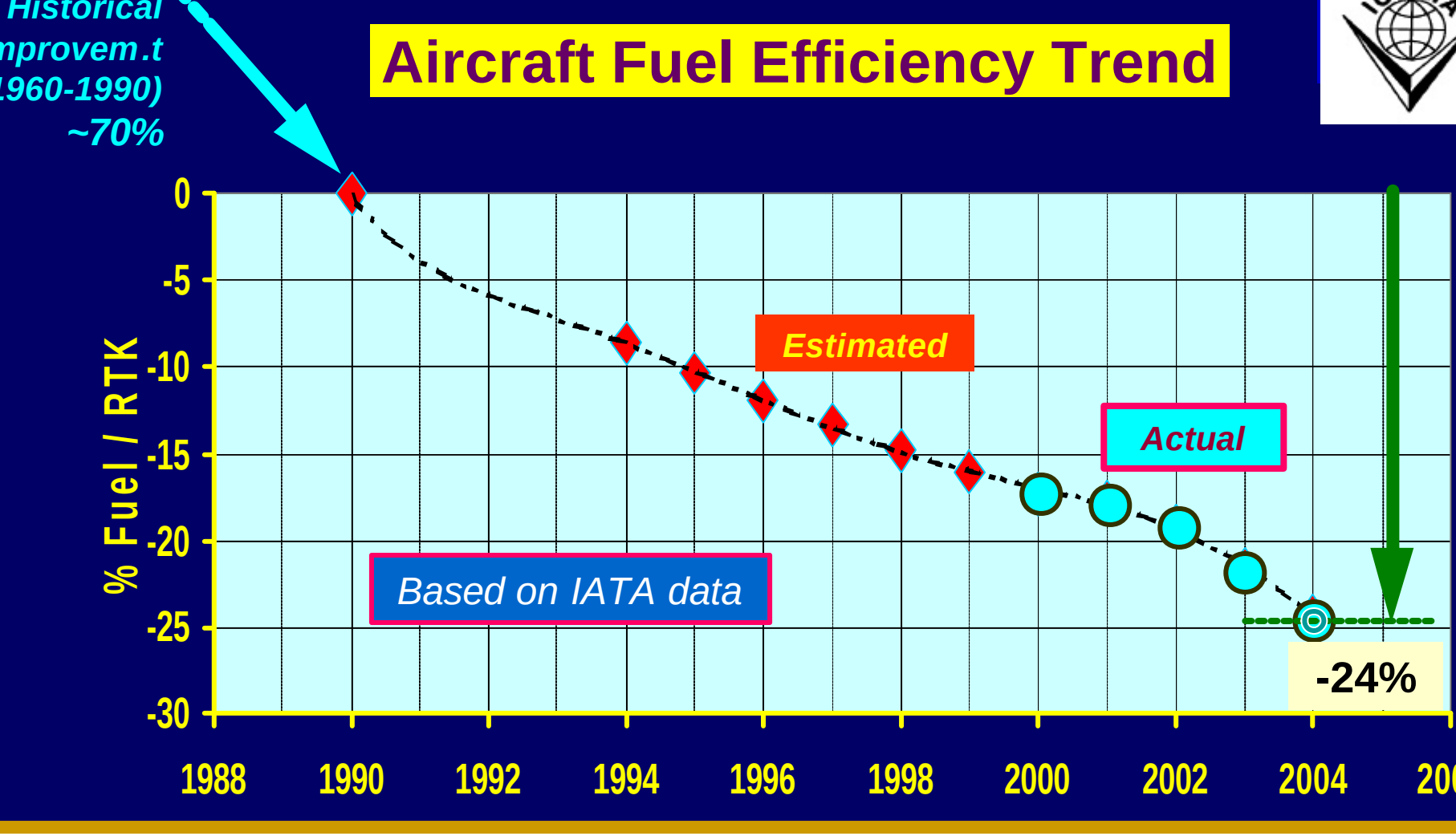
Reducing Aviation Emissions





- *Noise annoyance was reduced by » 75% (Joint Engine & Airframe Manufacturer Efforts)*
- *Emissions were continuously reduced (Engine)*

Aircraft Fuel Efficiency Trend



- ⇨ ~ 70% Fuel Efficiency improvement up to 1990 at product level
- ⇨ Continuing improvement reflected at fleet level (average > 1.5%/year)
- ⇨ Driven by strong & efficient market forces, combined with inherent fast-evolving high technology & improved operational practices
- ⇨ Needs sustained research & technology funding from Industry &

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Technology & Design

Specific Technologies

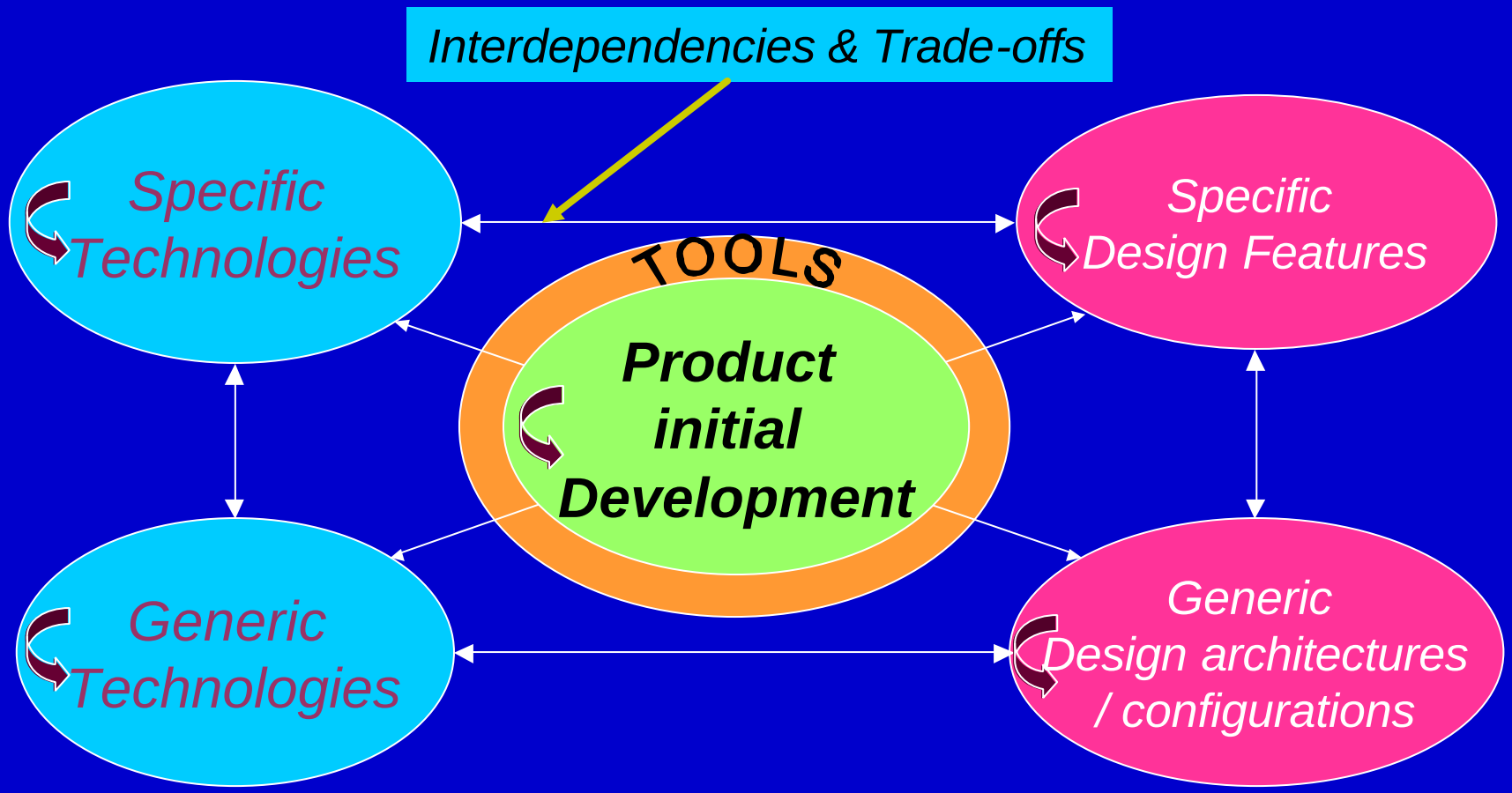
Specific Design Features

Product Concept & Requirements

Generic Technologies

Generic Design architectures / configurations

Technology & Design



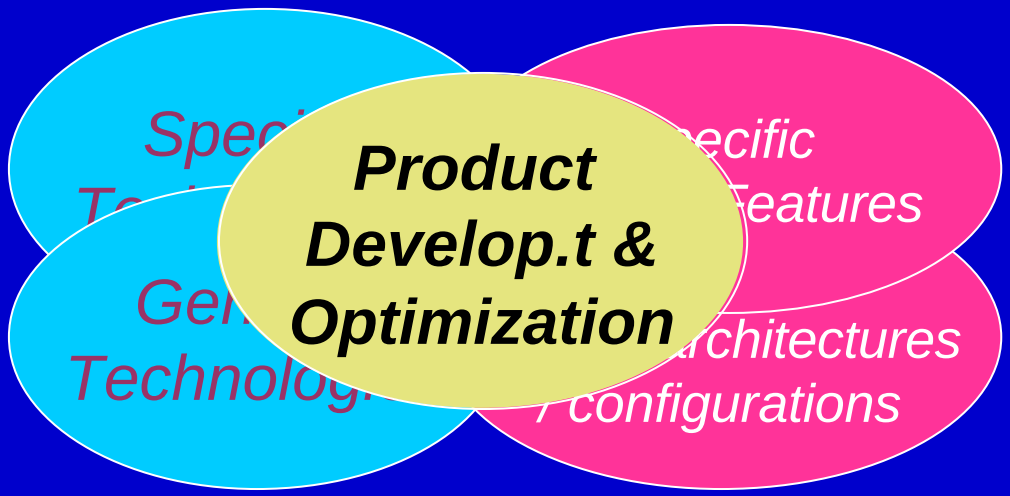
« Internal » trade-offs: within technologies & within design features, with iterations vs requirements

Technology & Design

SAFETY

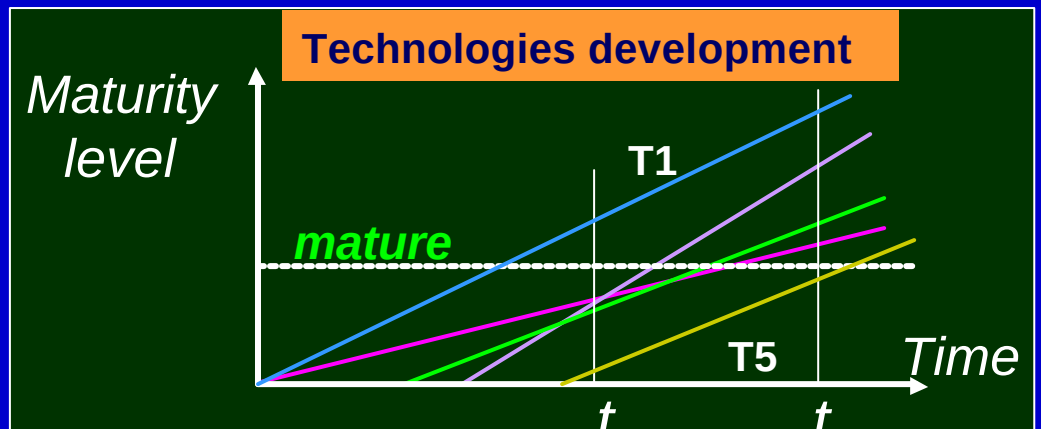
- Performance
- Operability
- Reliability

- Fuel Efficiency
- Emissions
- Noise



- Maintainability
- Durability
- Costs

- Comfort
- Capacity
- Timing



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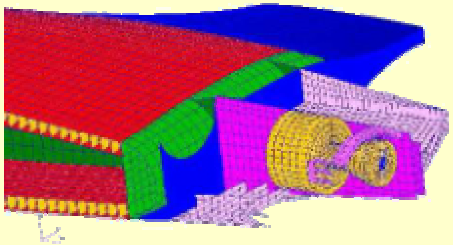
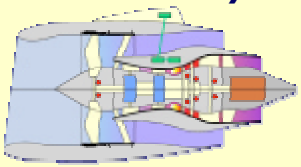
Reducing Aviation Emissions

Multiple Paths & Opportunities to reduce Emissions

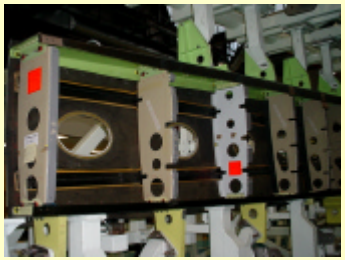
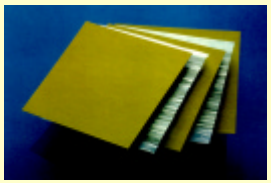
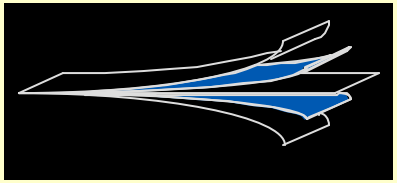
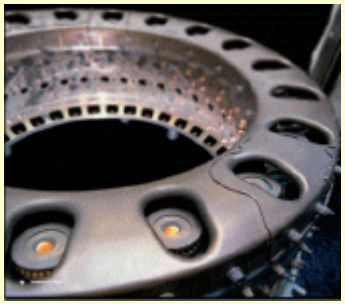
1. Propulsion System

Weight Reductions	Aerodynamic & Engine Performance Improvements	Operations
- Engine, Nacelle & Propulsion System • Advanced lightweight materials • Weight optimized Configuration 	- Engine turbomachinery efficiency (swept fans & 3D aero shapes) - Optimized cycle (Intercooler, HBPR, UHBPR, Geared Turbofan, Contra-fan)   - "Intelligent" systems/ more integrated engine - Innovative/active engine systems: heat management, cooling, power transmission - Enhanced modelling capabilities (numerical) - Low emissions combustor	- FADEC - Enhanced Controls & Sensors  - Optimized Engine Operating Procedures

BPR: High Bypass Ratio UHBPR:Ultra High Bypass Ratio FADEC: Full Authority Digital Engine Control

Multiple Paths & Opportunities to reduce Emissions

2. Materials

Weight Reductions	Aerodynamic & Engine Performance Improvements.	Operations
- Composites   - Advanced light Alloys (Ti, Al-Li, Mg), New Hybrid Alloys   - Innovative, smart materials	- High temperature Alloys in efficient engine technology and low NOx combustors 	

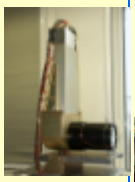
Ti: Titanium Al-Li: Aluminium-Lithium

Multiple Paths & Opportunities to reduce Emissions

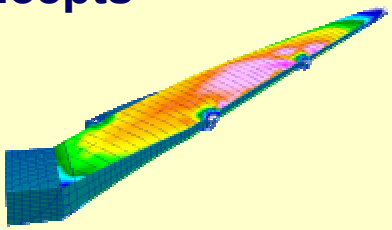
3. Structure, Aero & Systems Design & Methods

Weight Reductions

-Aero-elasticity (load alleviation & control)



- Structural optimization, integration & new concepts

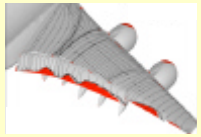


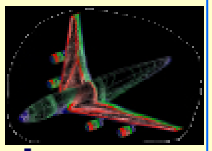
-Smart, morphing structures, nanotechnologies (future)

- Wing, fuselage, empennage, landing gear, pylon innovative features

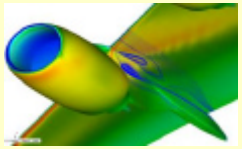
Aerodynamic & Engine Performance Improvements

- Engine, Wing, HLD, HTP, Winglets, Fuselage

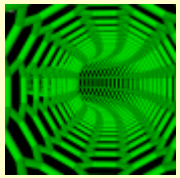




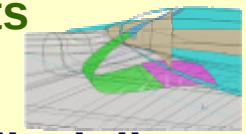
- Engine/nacelle/pylon integration



- Flow control



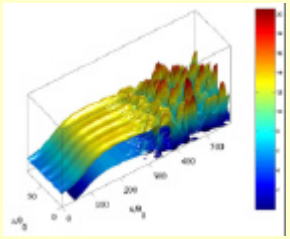
- New unconventional configurations & concepts (future)



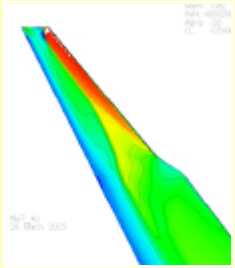
- Multi-disciplinary Design methods - Virtual Engineering

Operations

- Systems Modelling



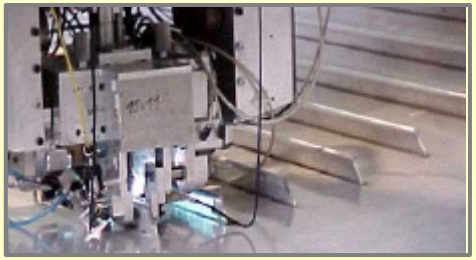
- Systems Simulation & Virtual Testing



- Adaptive flight path to reduce emissions (future)

Multiple Paths & Opportunities to reduce Emissions

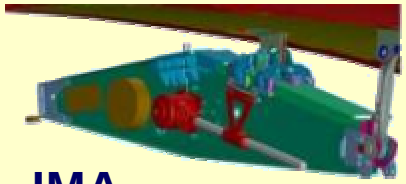
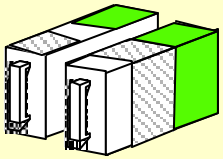
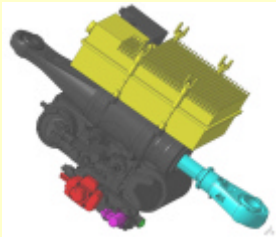
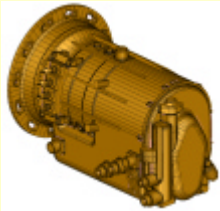
4. Manufacturing Processes

Weight Reductions	Aerodynamic & Engine Performance Improvements	Operations
- **Welding processes** (EBW, LBW, FSW)  - **Innovative structures & processes**	**- Welding Processes (drag reduction)**	

EBW: Electron Beam Welding
LBW: Laser Beam Welding
FSW: Friction Stir Welding

Multiple Paths & Opportunities to reduce Emissions

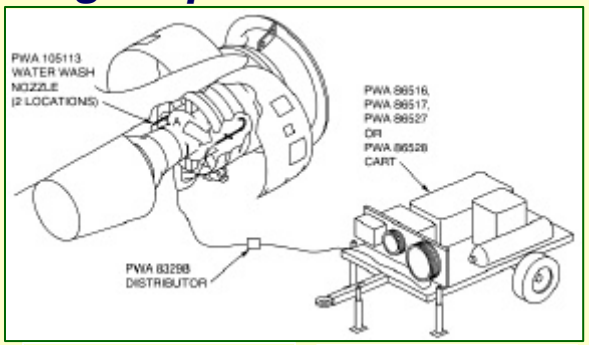
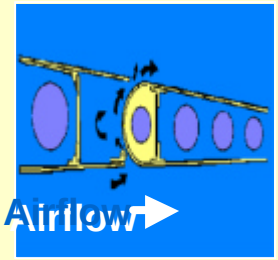
5. Aircraft Systems

Weight Reductions	Aerodynamic & Engine Performance Improvements	Operations
- Fly by Wire - Optimized, integrated & simpler electrical & mechanical systems, less components  - IMA  - Fuel transfer/load alleviation	- Advanced flight controls, more electronic systems: optimized control surface deflections, level & trajectory control 	- Advanced Cockpit, Flight Management & Navigation Systems  -Optimized Energy & Electric Power management (generation / distribution) 

IMA: Integrated Modular Avionics

Multiple Paths & Opportunities to reduce Emissions

6. Operating Procedures

Weight Reductions	Aerodynamic & Engine Performance Improvements	Operations
Some procedures are linked with minimizing TOW 	***Several procedures optimize operations based on Aircraft & Engine performance***   	**- Optimized ground & flight, Maintenance procedures**  **- ATM** 

Example of Aerodynamics Performance Improvement
Winglets

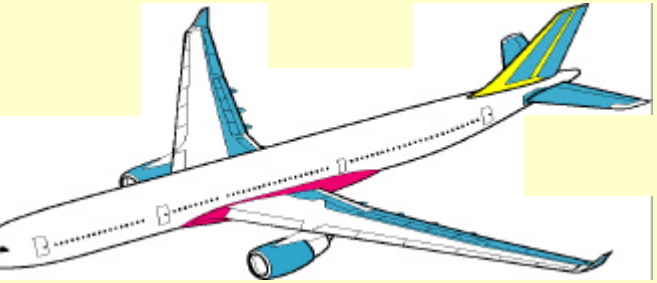
- Design range: » +130 nm
- **Fuel burn:** » - 2.5% (500 nm mission)
  » - 3.5% (1,500 nm)
- **NOx Emissions:** » - 4.6% (1,500 nm)
- Payload at fixed range: » + 6,000 lb at fuel capacity limit
  » + 1,000 lb at maximum takeoff weight
- Takeoff noise: » - 0.5 to - 1.0 EPNdB at cutback

The improvement depends on the individual mission

Examples of Structural Weight Reductions

Composite + Advanced Materials

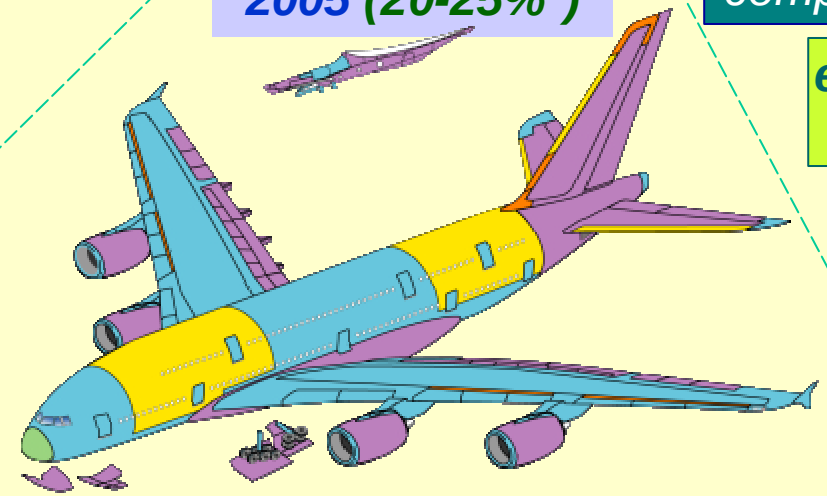
1990 (10-12% *)



« Materials Baseline »

** Percentage of composites in structural weight*

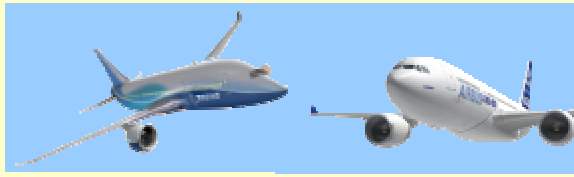
2005 (20-25%*)



- GFRP (Glass)
- QFRP (Quartz)
- CFRP (Carbon)
- Metal
- Glare

est. structural weight saving » 8%

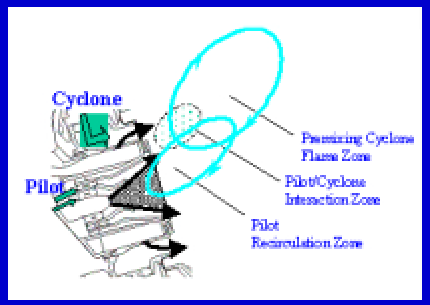
2010 (40-50%*)

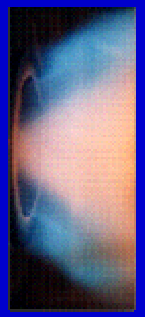


- wing: composite
- fuselage: composite or composite + advanced allo

est. structural weight saving » 12%

Examples of Combustor Technologies



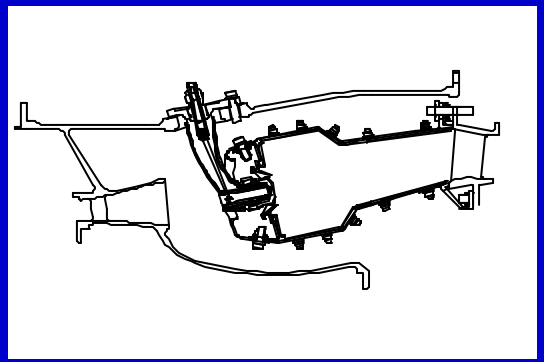


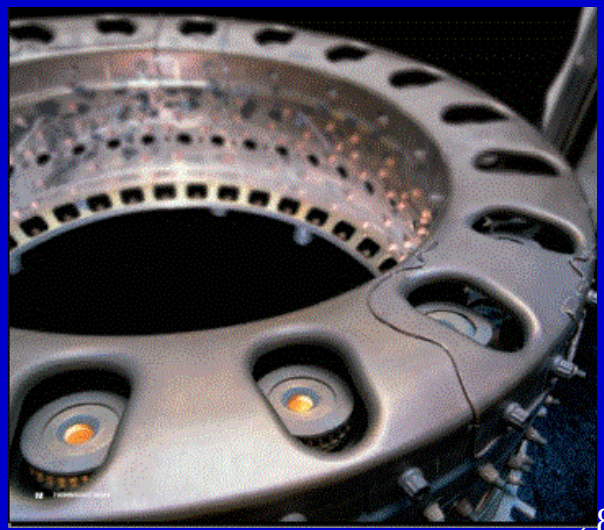
Lean Premixing Combustor:

Reduced NOx and Smoke Emissions

Rich-Quench-Lean Combustor:

Reduced NOx & HC Emissions





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Reducing Fuel Burn in Operation

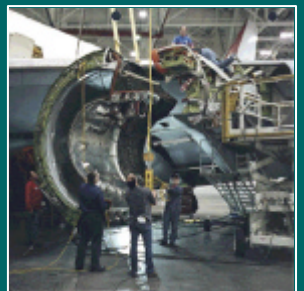
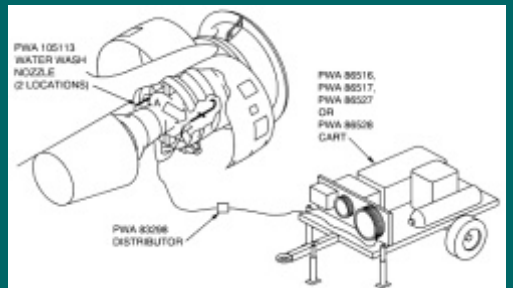
- The Scope
  - Manufacturers minimize fuel burn in the **full aircraft life cycle:** design manufacturing, transport, ground & flight operations, maintenance, refurbishment, end-of-life
  - All operational and maintenance procedures are subject to recommendations for potential fuel consumption reduction, well disseminated by the Manufacturers & ICAO
  - Current technologies are used to minimize fuel consumption in aircraft operation & induced airport activities
  - On-going research activities address the joint development of operational procedures & technologies
- The Way Forward
  - Extend Cooperation with all Stakeholders: Authorities, Manufacturers, Research Centers, ANSP's, Airports, Operators, Pilots
  - Develop Synergies between Aircraft & Infrastructures / Ground Systems Technologies / Operations

Reducing Fuel Burn in Operation
Dissemination of Best Practices

- Operating Procedures optimizing each phase of flight to minimize fuel consumption
  - Ground running and taxiing
  - Take-Off & Climb
  - **Cruise**
  - Descent, Holding & Approach

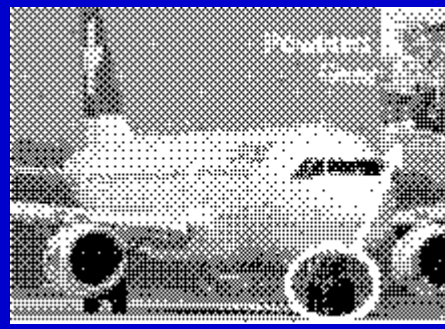



- Maintenance procedures to minimize Engine (SFC) or Aircraft performance (drag, weight) deterioration & restore it

Reducing Fuel Burn in Operation

Airports - Prospects for the future



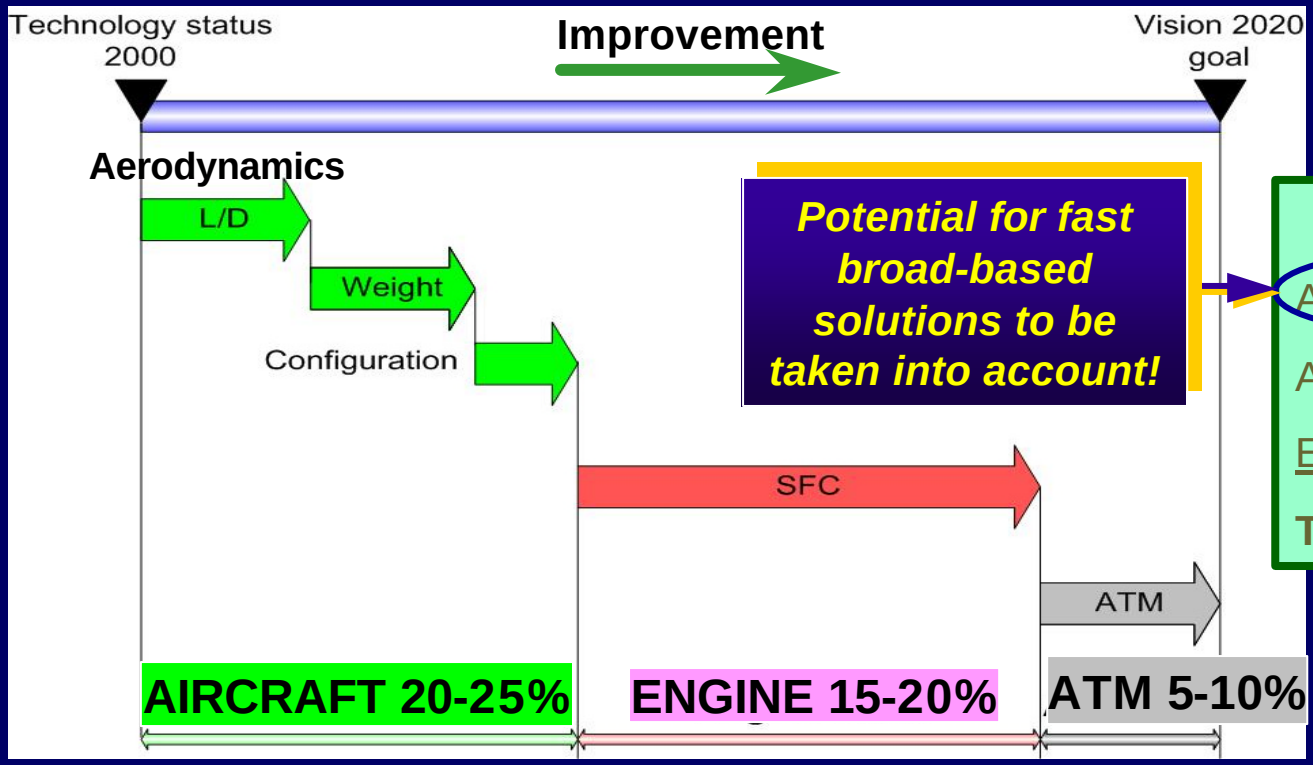
- Powered Gear / Electric Taxi
- Gate Power Supply (Electric or Alternate fuel GSE)
- Electrically powered PCA systems
- Gate Refuelling
- Airport Layout
- Airport Taxi management
- Operational towing

- Other Aircraft-related: Aircraft De-Icing, Tank Farm, Engine Test Stands, …
- Other Airport Stationary Sources
- Airport Ground Vehicles
- Airport Access & Road Traffic

CONTENTS

Example of EU Vision 2020 for Environment

⇨ *Reduce CO2 by 50% per passenger kilometre*



Potential for fast broad-based solutions to be taken into account!

CO_2 reduction	
ATM	5-10%
Aircraft	20-25%
Engine	15-20%
Total	**50%**

⇨ *Reduce Perceived Noise to one half of current average levels*

⇨ *Reduce NOx emissions by 80%*

⇨ *Minimise the impact of industries on the global environment*

➔ **Similar Vision in the US**

Manufacturers and Environmental Protection

- Participate actively in elaborating a broad, global & long-term vision and apply it to programmes, products, investments & partnerships
- Work to meet ambitious environmental-related targets addressing climate change, community noise, local air quality & trade-offs
- Support research for better understanding of environmental impacts & benefits
- Participate in extensive research programmes to foster environmental advances for aviation (optimized combined scenarios)
- Ensure that environmental advances get continuously introduced into design & operating practices, and into products, balancing early introduction of mature technologies & long development & life cycles
- Expand cooperation, coordination and synergies at all levels with all actors involved in all relevant domains (using the ICAO platform)

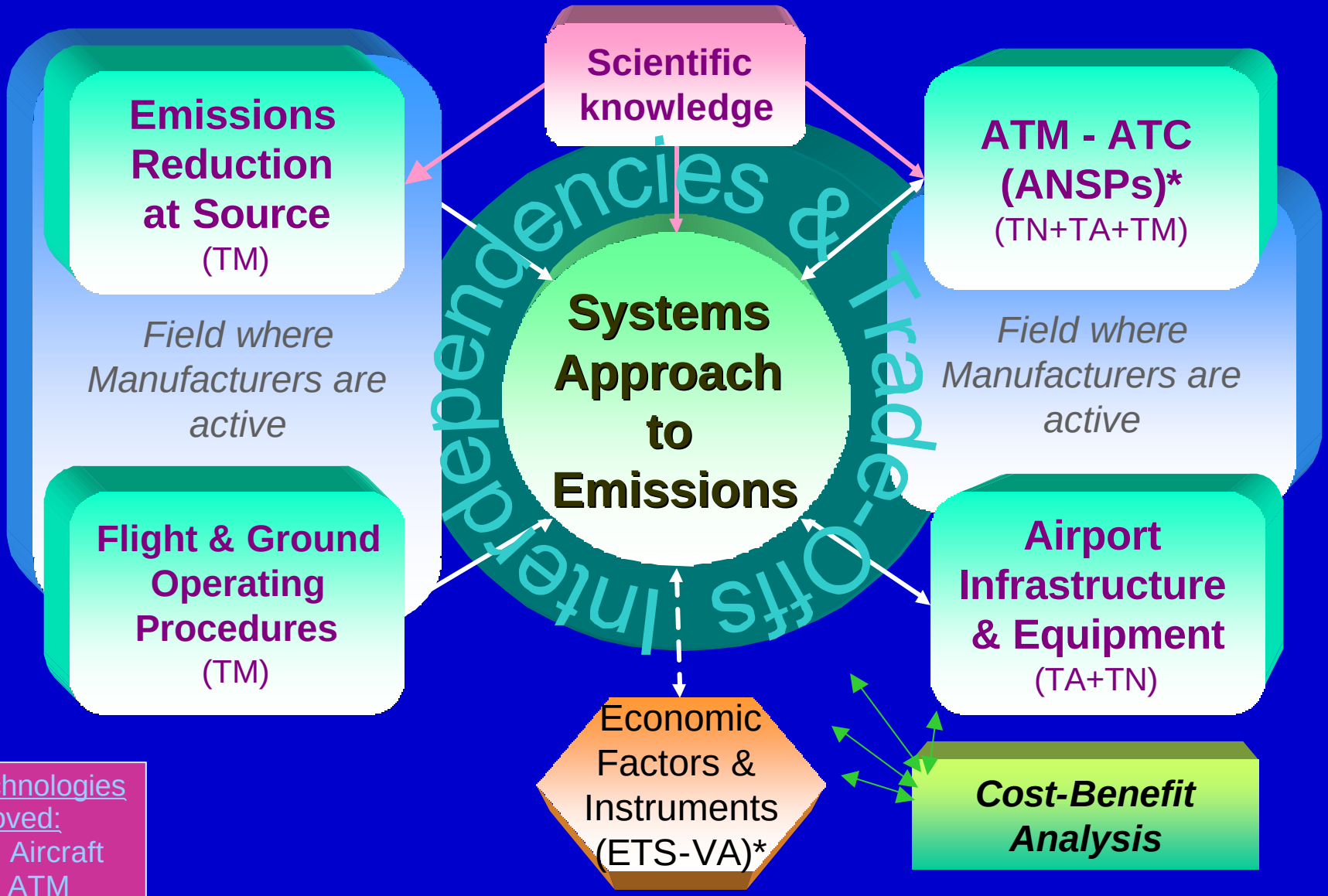
Manufacturers despite facing multiple challenges are resolutely engaged in tackling environmental issues; they only hold some of the keys, but they are willing to work with others in order to best address these issues

Systems Approach to Environment

- To maximize the benefits from the large investments in developing emission (and noise) reduction technologies, it is essential for all stakeholders to work together on the multiple, interdependent factors involved, in a global system approach
- This implies a **permanent productive dialogue** and a **high level of cooperation** between all stakeholders
- **Technology will not be enough** - All possible cost-effective means to improve the environmental situation should be explored, including operating procedures, land use management, airport infrastructure and equipment, ground systems and ATM

Technology Cannot Be Considered in Isolation

Emissions Technology in a global system perspective



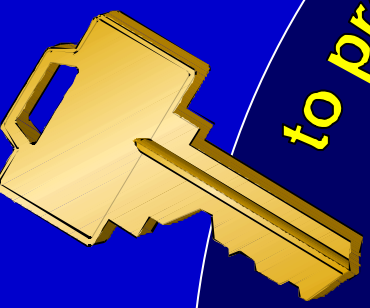
echnologies
voved:
M: Aircraft
N: ATM

ICAO/CAEP is a Unique Framework

- Provides an international forum for sharing and consolidating data, visions & prospects
- Provides & best uses resources to develop & maintain international policies, standards, databases, tools, models, practices & guidelines
- Brings together all stakeholders to balance their needs
- Brings together scientific and engineering resources to help finding & optimizing the environmental solutions, taking into account interdependencies and trade-offs
- Facilitates safe, coordinated, harmonized, efficient and consistent approaches & processes

Provides Global Coordination for a Global Industry

In Conclusion,...



to progress in Aviation Environmental Protection

Efficient Solutions

All Actors

Balanced Systems Approaches

All Fields

Broad Vision

Cost-efficiency Priorities

High dedicated Investments & Resources

ICAO Synergies Cooperation

Knowledge-Models-Scenarios-Technology-Design-Operations
ATM-Airports Land use/Infrastructures/Equipment/Access

The future,

you do not have to foretell it,

but to enable it.

Antoine de Saint Exupery

Thank You