



ICAO

ENVIRONMENT



ICAO Environmental  
Symposium 2019

DESTINATION GREEN: THE NEXT CHAPTER



# Combustor Designs for Low Emissions Dan Carnelly

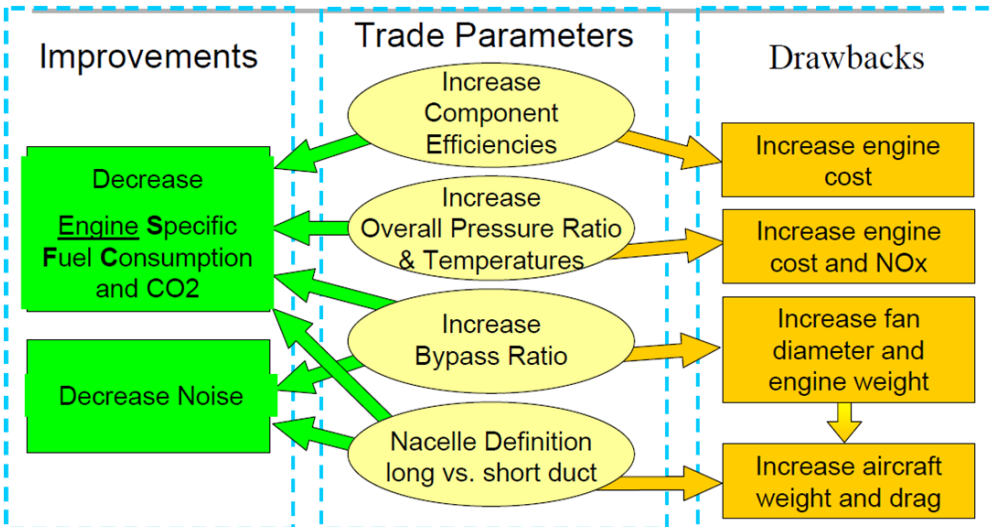
Director, Aircraft Environmental Marketing  
Airbus SAS



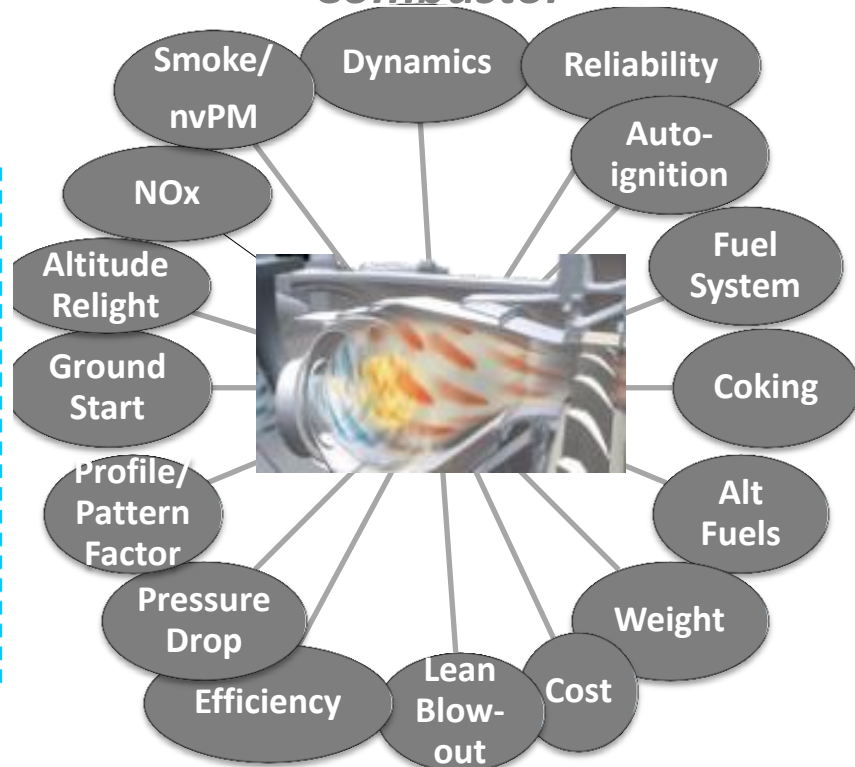


# Design requirements

## Engine

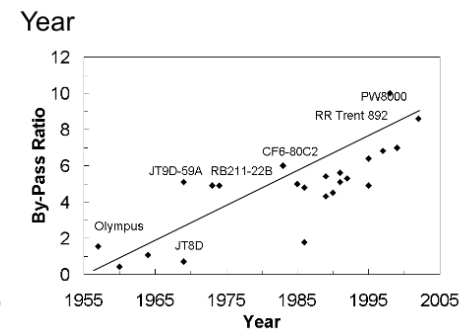
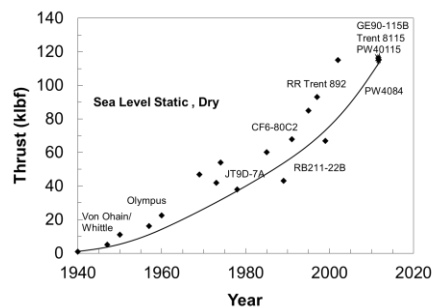
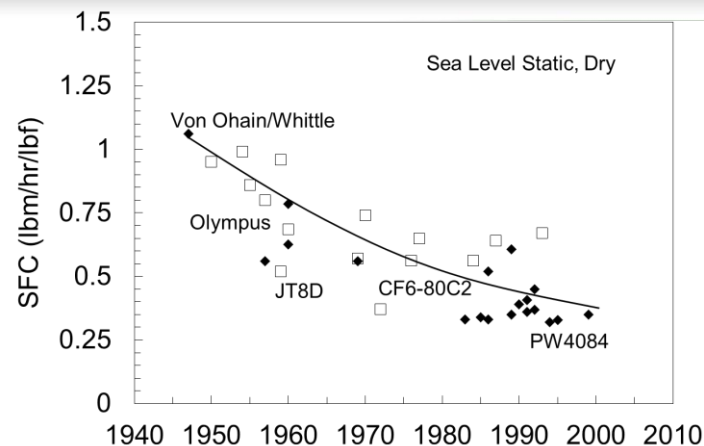
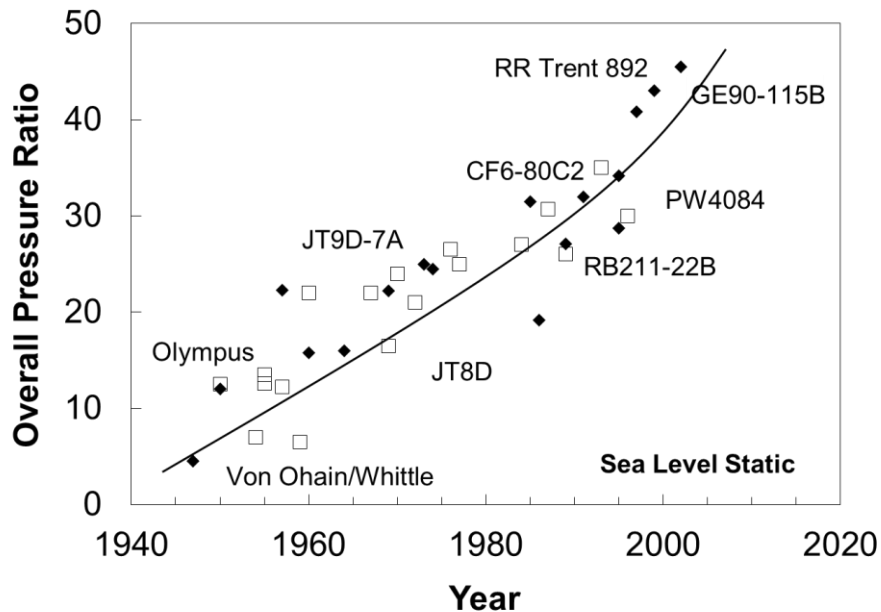


## Combustor





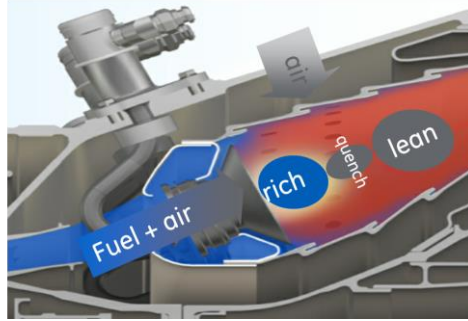
# Gas turbine engine progress



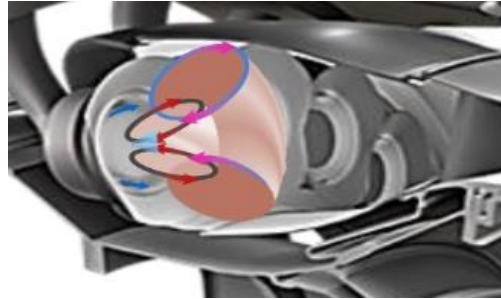
# Combustion architectures

## Rich-Quench-Lean Combustors

- Fuel-rich primary zone for good stability
- Quick lean quench zone for low NOx and pattern factor control
- Form large amounts of soot/PM in the primary zone
- Rely on dilution jet quench to reduce stoichiometry
- Need additional length downstream of jets to burn out soot/PM



- Smoke/nvPM forms in fuel-rich pockets inside the combustor
- Combustor design allows for smoke/nvPM burnout as products move through combustor
- Smoke/nvPM depend on fuel chemistry and increase with high aromatic fuels.



## Lean Combustors

- Fuel-rich primary zone for good stability
- Fuel staging to optimize NOx and operability trades
- Lean main zone to minimize NOx emissions
- Form small amounts of soot /PM in primary zone
- Use entire combustor to burn out any soot and PM
- Improved mixing early in combustor to minimize fuel-rich PM-formation zones



ICAO

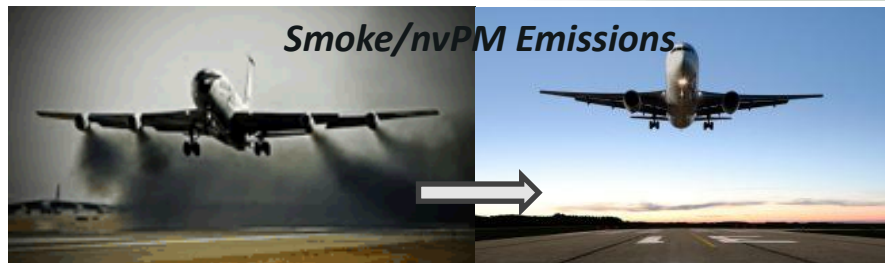
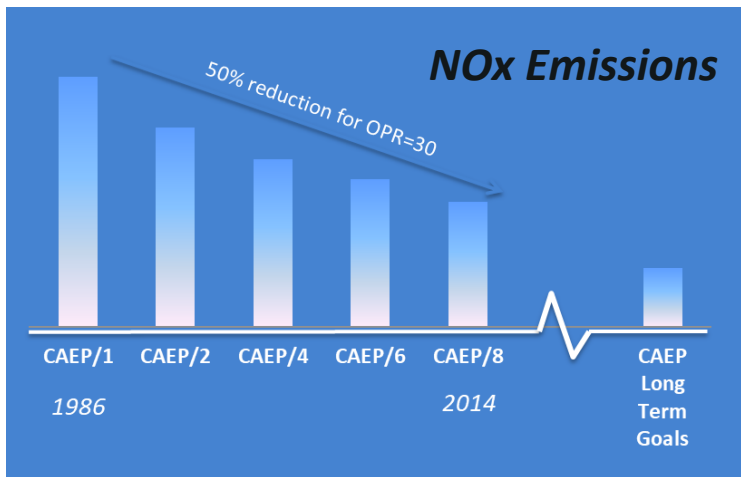
ENVIRONMENT



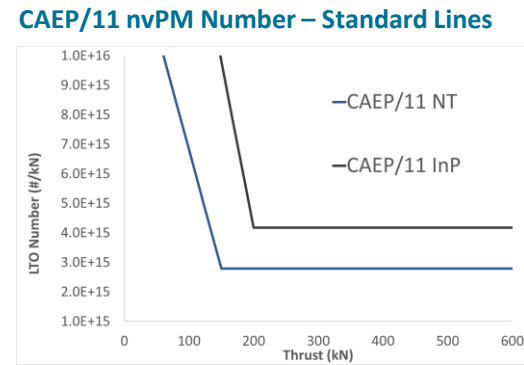
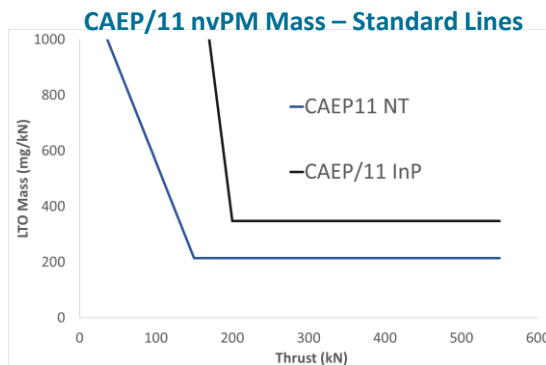
ICAO Environmental Symposium 2019

DESTINATION GREEN: THE NEXT CHAPTER

# Emissions improvements



*New non-volatile particulate matter (nvPM) engine emissions SARPs*

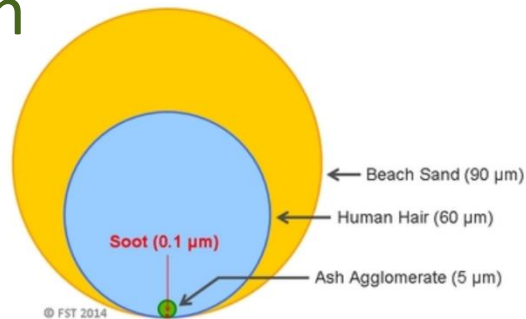
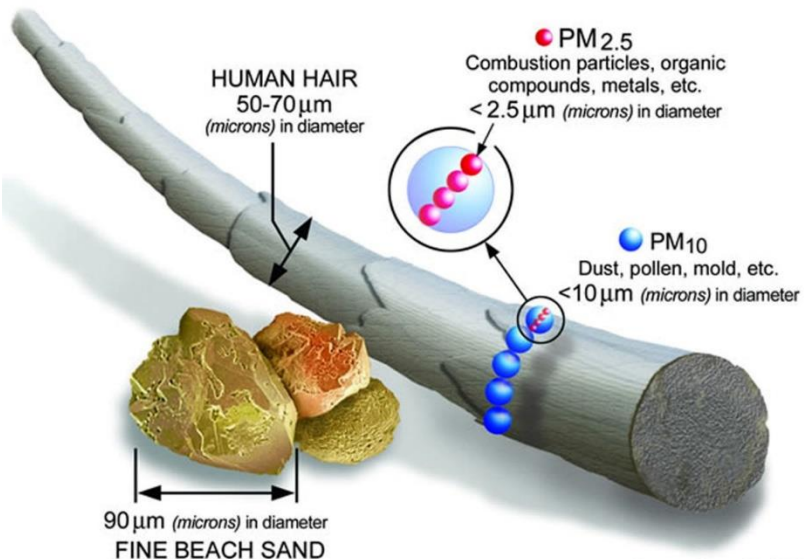


**ICAO Environmental Standards: CO<sub>2</sub>, CO, UHC, NO<sub>x</sub>, nvPM, Smoke**





# Particulate matter description



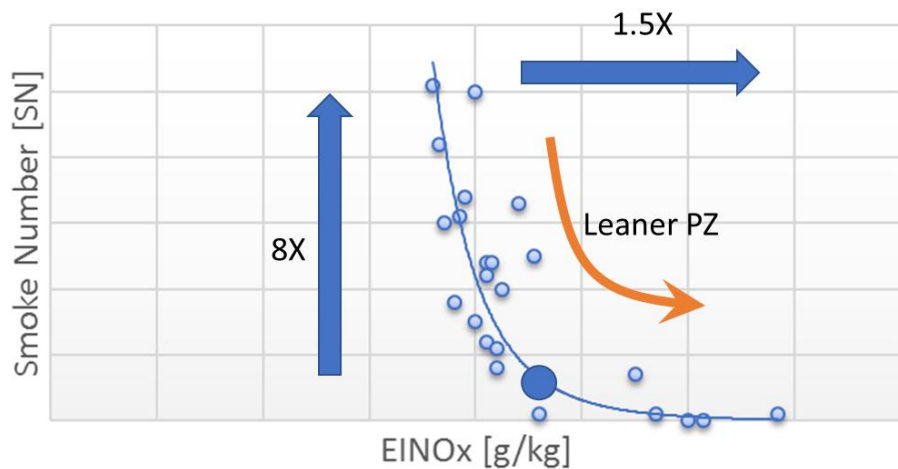
All combustion particles are less than 0.1 microns (less than 100nm), and nvPM particles are bigger than vPM particles.

EI nvPM Mass from 1-400mg/kg (0.001-0.4g/kg)  
 For comparison EINOx 5-70g/kg  
 But nvPM number  $10^{13} - 10^{15}$  #/kg  
 Except on lean burn which is at atmospheric level of Number (equivalent to  $10^{10}$ - $10^{11}$ )

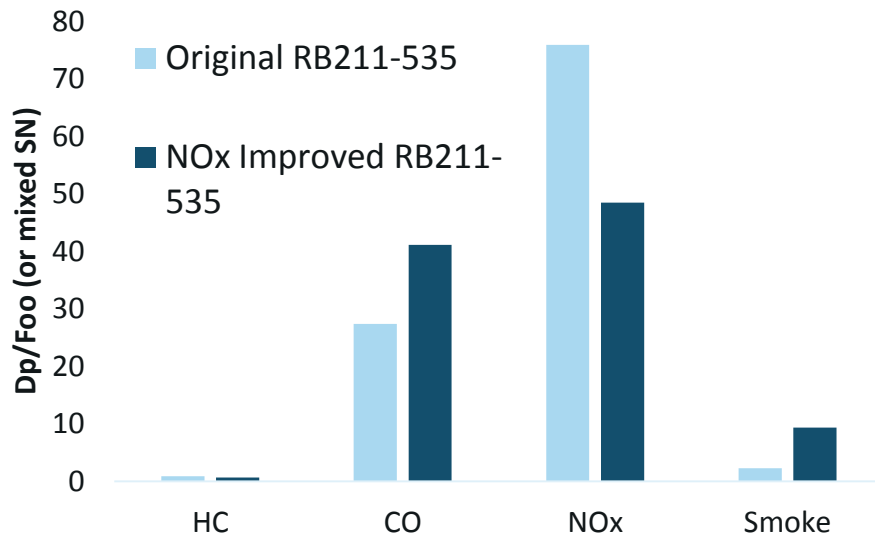
Exhaust Mass of nvPM is typically 1000 times smaller than mass of NOx and NOx trades with nvPM



# Emissions trades in combustors



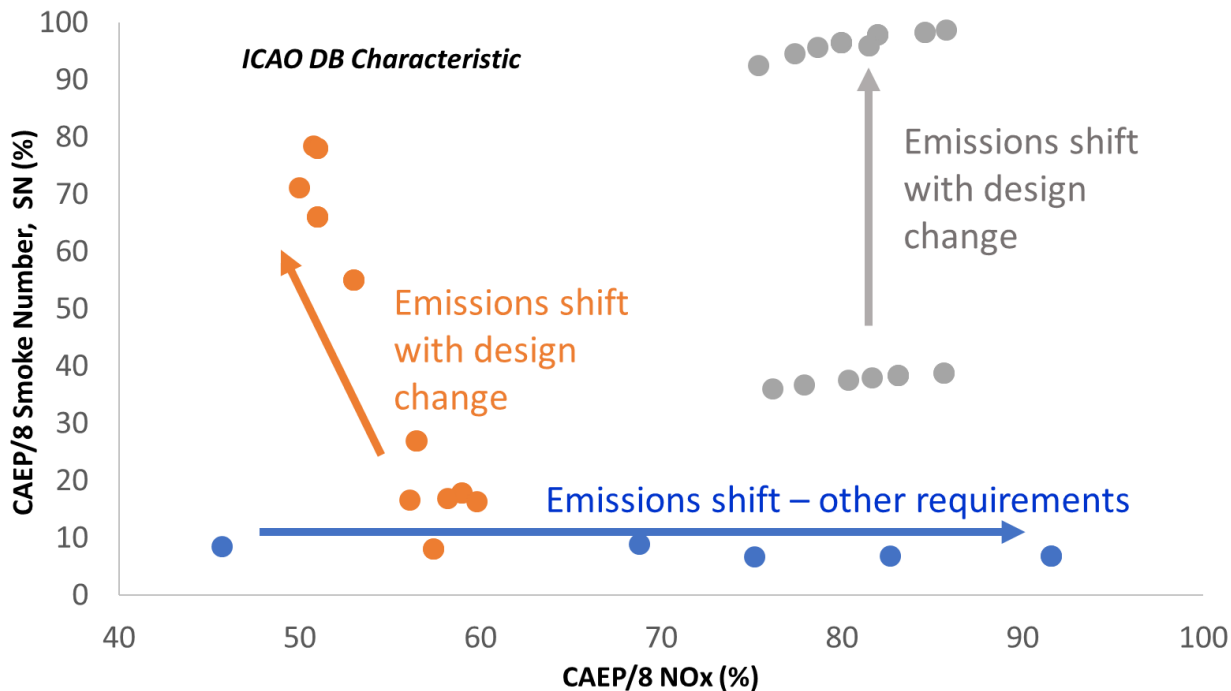
8x smoke increase for 1.5x NOx decrease



Increases in CO and Smoke when lowering NOx



## Emissions trades in combustors



Emissions trades for recently certified engines (NB and WB aircraft)





## Importance of standards

- Environmental protection
  - Air quality
  - Climate change
- Drives technology development
  - Market drives engine designs to meet future regulatory requirements
- Prevent backsliding
  - Engines are forced to improve emissions performance with time
- Global regulatory certainty
  - Manufacturers have a common design goal for emissions



## Summary

- Impressive aircraft engine emissions and fuel burn reductions achieved over the past 30 years
- Aircraft/engine/combustor trades exist, are complex and usually are conflicting
  - Emissions, operability, durability, efficiency, fuel burn, noise, cost, weight....
- Engine OEMs are in various TRL stages of rich-burn, lean-burn and staged combustor designs to meet future engine and emissions requirements



ICAO

ENVIRONMENT



ICAO Environmental Symposium 2019

DESTINATION GREEN: THE NEXT CHAPTER



ICAO

North American  
Central American  
and Caribbean  
(NACC) Office  
Mexico City

South American  
(SAM) Office  
Lima

ICAO  
Headquarters  
Montréal

Western and  
Central African  
(WACAF) Office  
Dakar

European and  
North Atlantic  
(EUR/NAT) Office  
Paris

Middle East  
(MID) Office  
Cairo

Eastern and  
Southern African  
(ESAF) Office  
Nairobi

Asia and Pacific  
(APAC) Sub-office  
Beijing

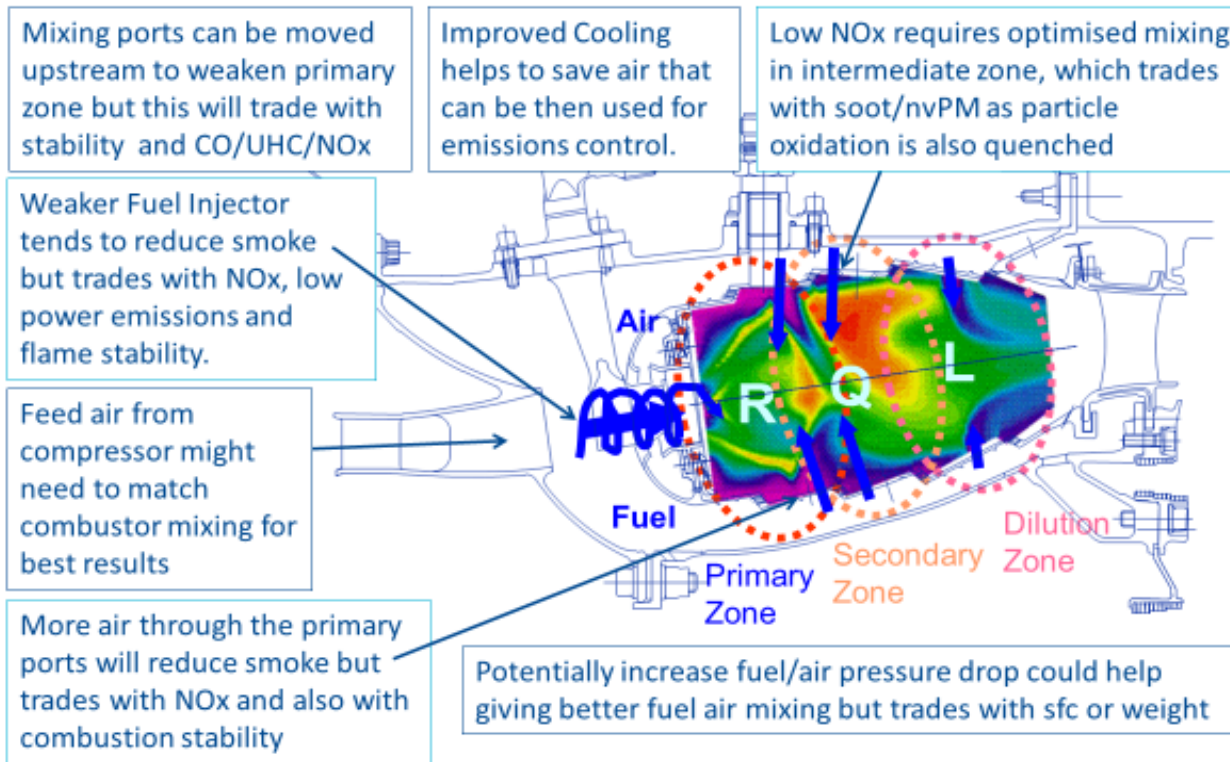
Asia and Pacific  
(APAC) Office  
Bangkok



THANK YOU



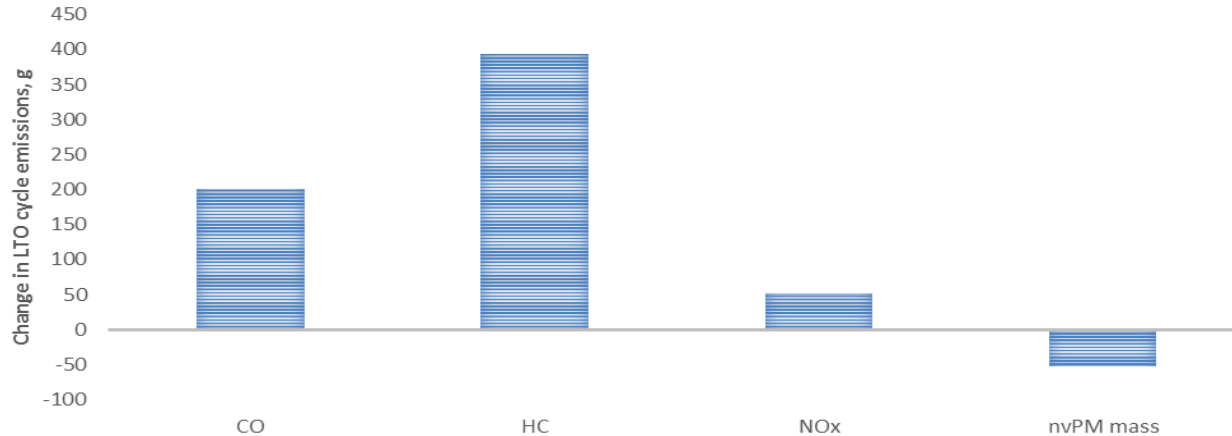
# Emissions trades in combustors





## Emissions trades in combustors

Small Engine Change in LTO Mass Emissions to Achieve More Stringent nvPM Levels



Reducing nvPM caused increases in CO, UHC and NOx