AIRCRAFT POLLUTANT EMISSIONS: FORMATION MECHANISM AND REDUCTION BY INLET AND FLAME TEMPERATURE OPTMIZATION.

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Abstract:

❖Over the past years, many scientific have tried to reduce aircraft pollution.

❖The pollutants formation mechanism is explained from taxi to climb .

❖Then the relationship between pollutant emissions and inlet temperature and flame temperature is studied

❖The analysis has shown that there is a low emission zone according to inlet and flame temperature.

❖Combustion in the low emission zone can contribute to the reduction of pollutant emissions,

Key Words: Turbojet engine exhaust, EI_{NOx}, EI_{CO} , EI_{HC}, inlet temperature, flame temperature, low emission zone

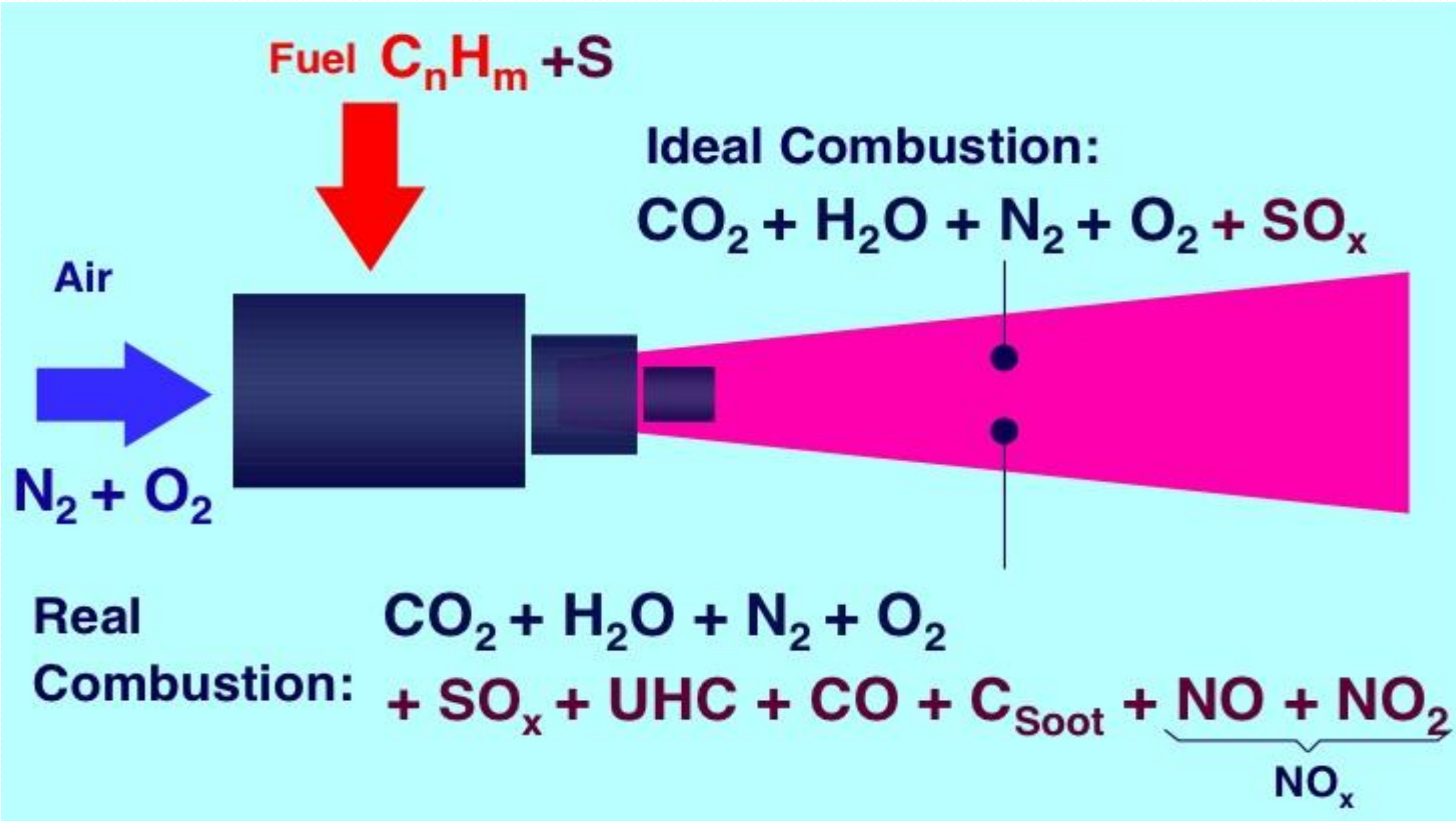
Introduction

❖Limitation regulation on aircraft exhaust pollutant emissions is more and more tightened.

❖Aircraft exhaust pollutants formation mechanism is presented.

❖Pollutant emissions according to the operational phase from taxi to climb are analyzed .
An attempt to find a suitable inlet temperature and flame temperature zone for low emission is done.

❖ With 556 turbojet engines data from a pretty piece of work done by Detlef Kretschmer on eleven gas turbine engines and ICAO data


Fuel C_nH_m +S
Ideal Combustion:
$CO_2 + H_2O + N_2 + O_2 + SO_x$
Air
$N_2 + O_2$
Real Combustion:
$CO_2 + H_2O + N_2 + O_2$
$+ SO_x + UHC + CO + C_{Soot} + \underbrace{NO + NO_2}_{NO_x}$

Materials and Methods

- ❖ The approach uses 556 experimental data from a pretty piece of work realized by Kretchmer on eleven turbojet engines and ICAO data,

- ❖ Combustion of 11 fuel types in a wide range of inlet temperatures and pressures ranged from 290 to 851K and from 0.1 to 1.4MPa, respectively.

- ❖The method used in this study is the least square method.

Turbojet engines pollutant formation mechanism

- Turbojet engines perform a kerosene combustion process in the combustion chamber according to the following chemical reaction:

$$C_{12}H_{26}+O_2+N_2+S \longrightarrow CO_2+H_2O+N_2+O_2+CO +UHC+C+NOx+SOx + Heat.$$

NO_X Formation mechanism

❖Thermal NO mechanism is the dominant source of NOx in turbojet engine.
The maximum production of thermal NOx is obtained at the equivalence ratio range of Φ=0.8~1.

❖The prompt NOx is formed in fuel rich and low temperature conditions, but it is not very significant compared to thermal NOx.

❖The four equations of the extended Zeldovich mechanism governing thermal NOx formation

$$\frac{d\left[EI_{NOx}\right]}{d\tau}=1.5*10^9 T_3^n \exp\left(\frac{-19500}{T_f}\right)$$

❖.

CO Formation mechanism

❖Carbon monoxide is formed at low temperatures due to lower reaction rates and less oxidation of CO to CO_2.

❖Too much CO is always from rich condition where there is not enough oxygen to let the burn process finish getting to CO_2.

❖The richer the conditions, the more CO one will have.

❖The CO formation mechanism has two steps.

❖The first step transforms the fuel into carbon monoxide and water and the last step oxidizes CO to CO2.

❖The combustion of JP-10 happens according to the following reactions:

$$\mathbf{C_{10}H_{16} + 9O_2 \rightarrow 10CO + 8H_2O}$$

$$\mathbf{CO + OH \rightarrow CO_2 + H}$$

UHC Formation mechanism

❖ Unburnt hydrocarbons (UHC) like carbon monoxide are associated to bad condition combustion .

❖ UHC is a result of bad combustion, raw fuel (HC) which goes into the combustion chamber, then comes out and is not burned up in the process.

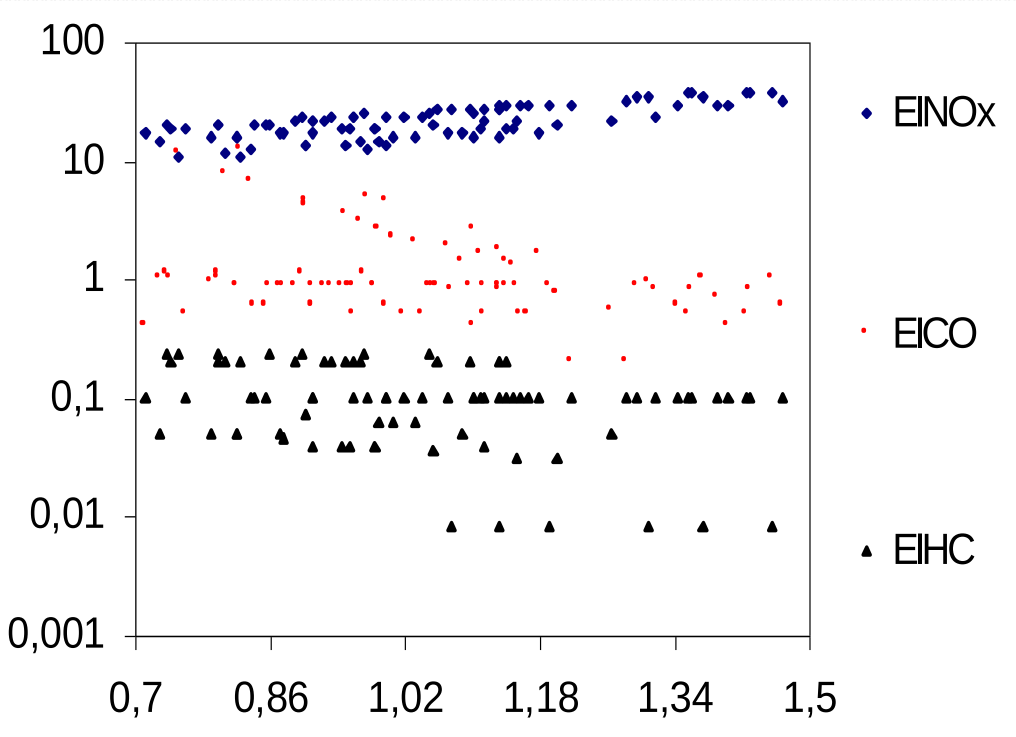
❖ Emission of UHC is a result of local fuel-rich zones.

❖ The combustion process of jet–A fuel in a turbojet engine happens produce UHC according to the following equqtion

$$\frac{d\left[C_{12}H_{23}\right]}{dt} = -10^{11.5}\left(\frac{P}{P_0}\right)^{-0.815} e^{\left(\frac{12200}{T}\right)}\left[\frac{9T}{10^4}-\frac{1}{2}\right]\sqrt{\left[C_{12}H_{23}\right]}\left[O_2\right]$$

Turbojet engines pollutants emission

- ❖ Carbon monoxide,
- ❖ Nitrogen oxides
- ❖ Unburnt hydrocarbon
- ❖ figure 1 shows the emissions of CFMI **Turbojet engines EI_{CO}, EI_{NOx} and EI_{HC} versus fuel flow at approa**



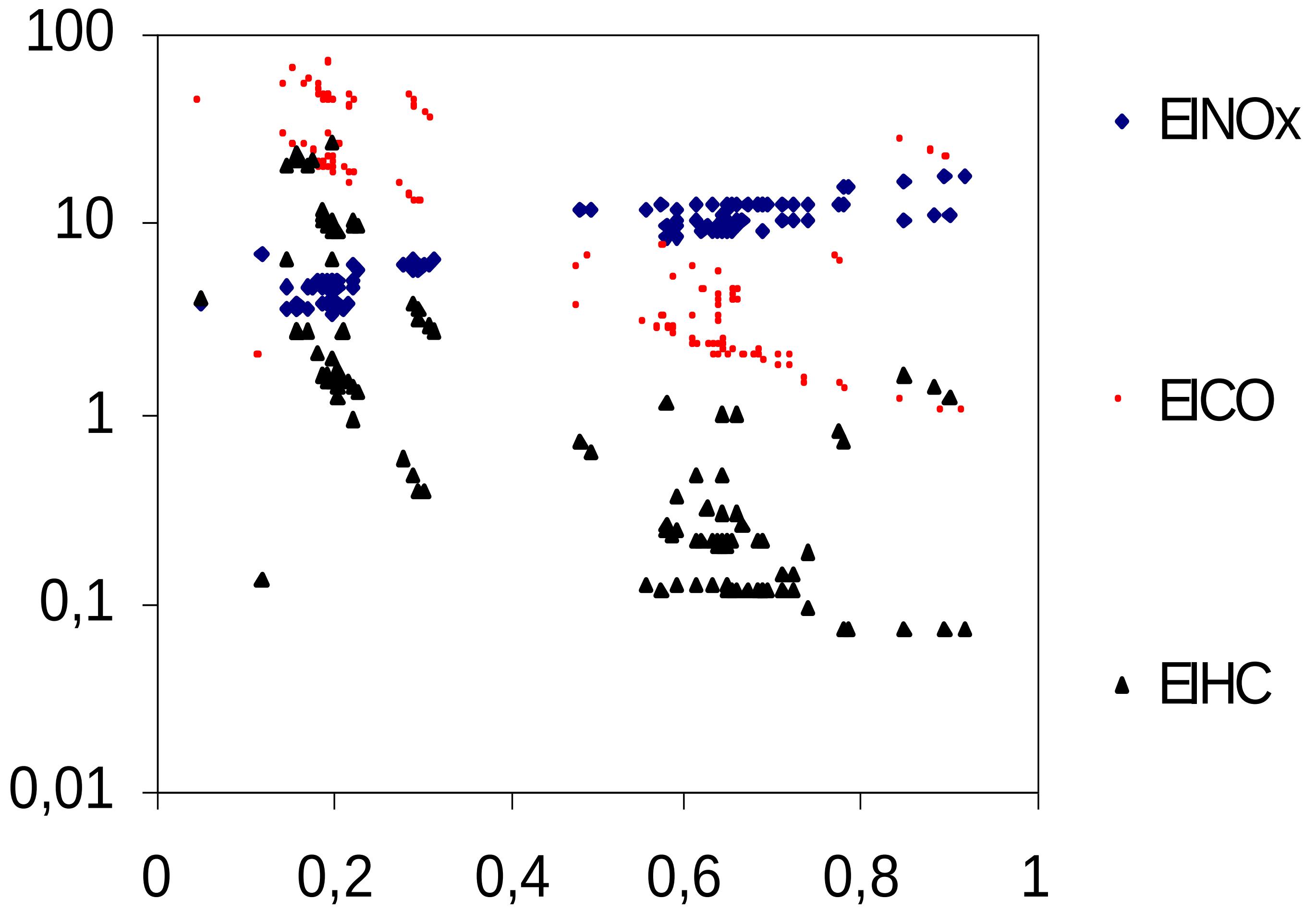


Fig 2: GE Turbojet engines EI_{CO}, EI_{NOx} and EI_{HC} versus fuel flow at approach and taxi.

Reduction of turbojet engines emission by inlet and flame temperature optimization

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❖There is a strong relationship between nitrogen oxide emissions and inlet temperature

❖Flame temperature olso has relationship with nitrogen oxide t production.

$$EI_{NOx} = \mathrm{A} T_3^{\alpha} \qquad EI_{NOx} = \mathrm{B} T_f^{\beta}$$

❖A, B, α and β are empirical constants.

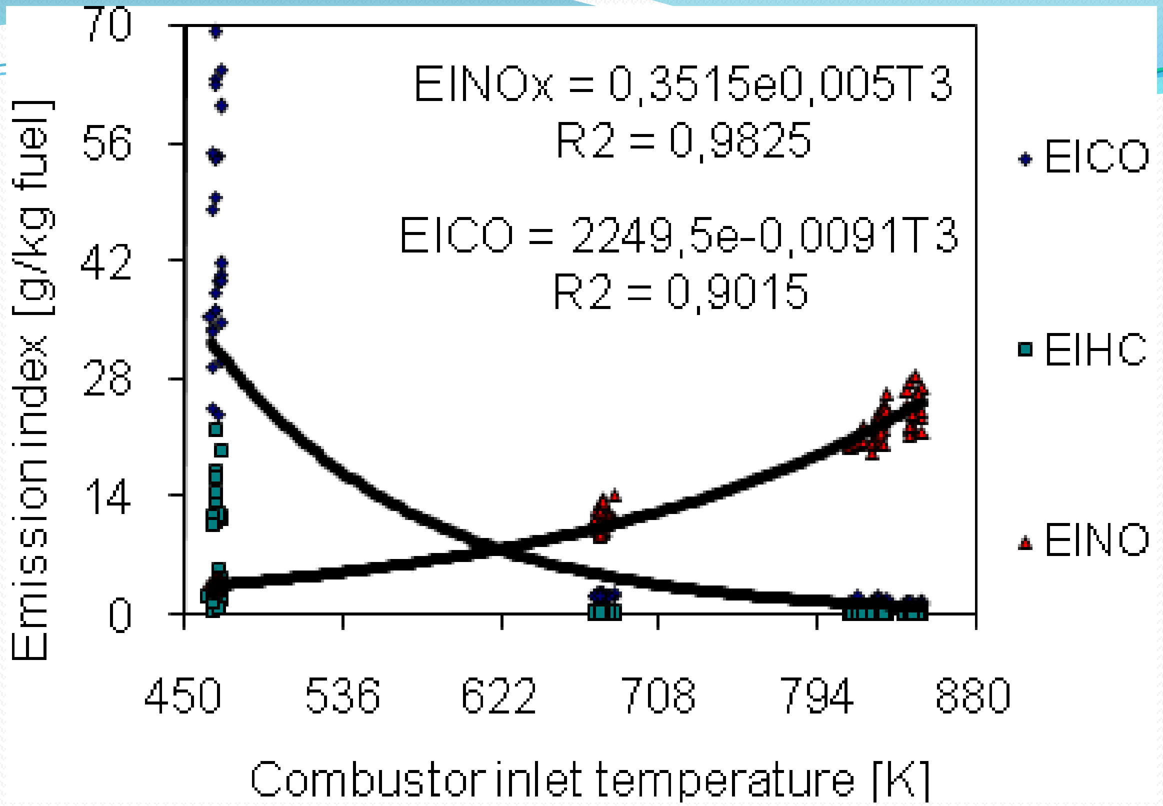

Fig 3: EICO, EI_{NOx} and EI_{HC} from J79-56C are presented according to combustion chamber inlet temperature.

Figure 3 shows that there is a zone of temperature where the emissions of all the pollutant species are less than 10g/kg of fuel burnt. This zone is situated between 560 and 640 K.

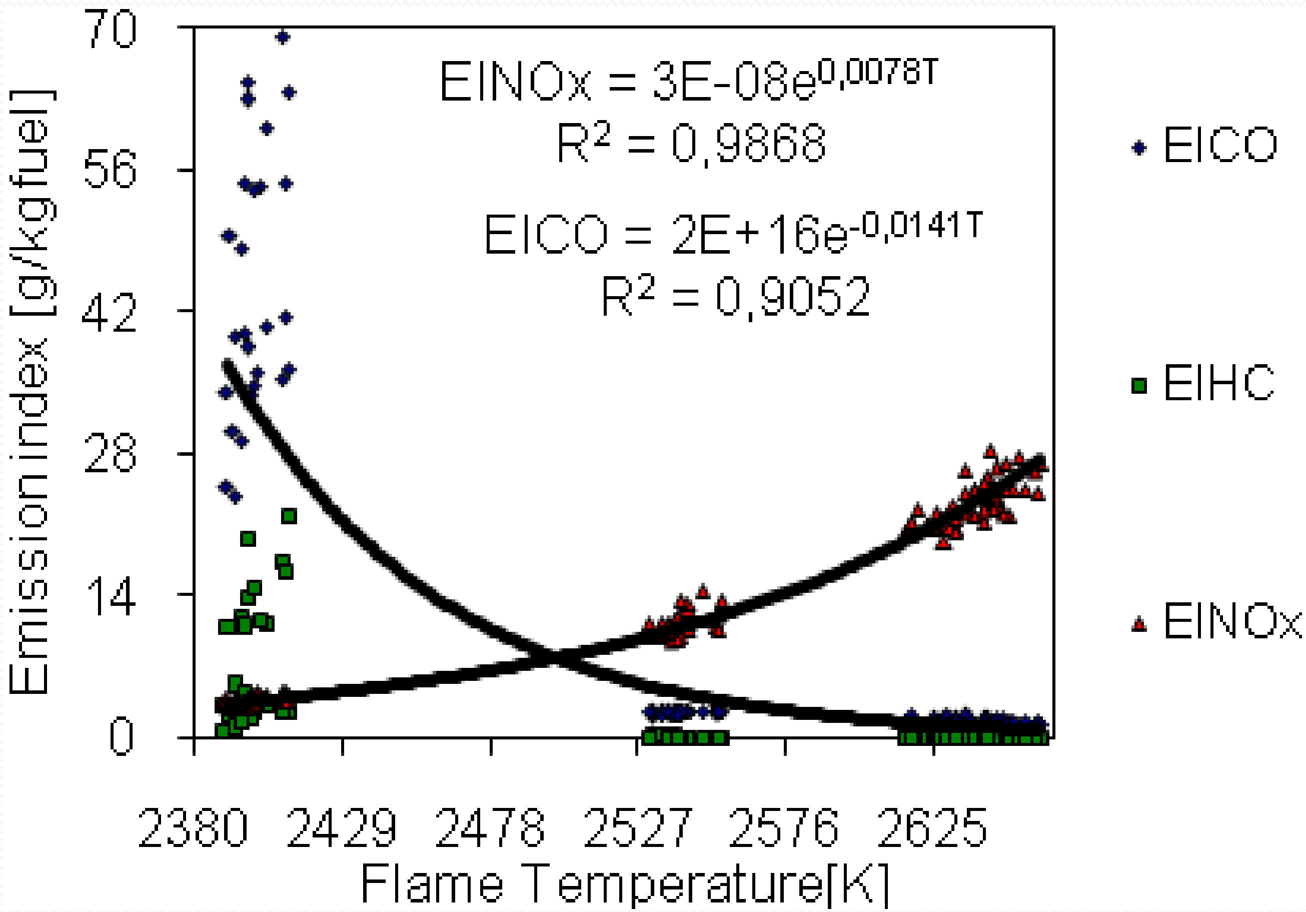

Figure 4: J79-56C EI_{CO}, EI_{NOx} and EI_{HC} from J79-56C versus flame temperature.

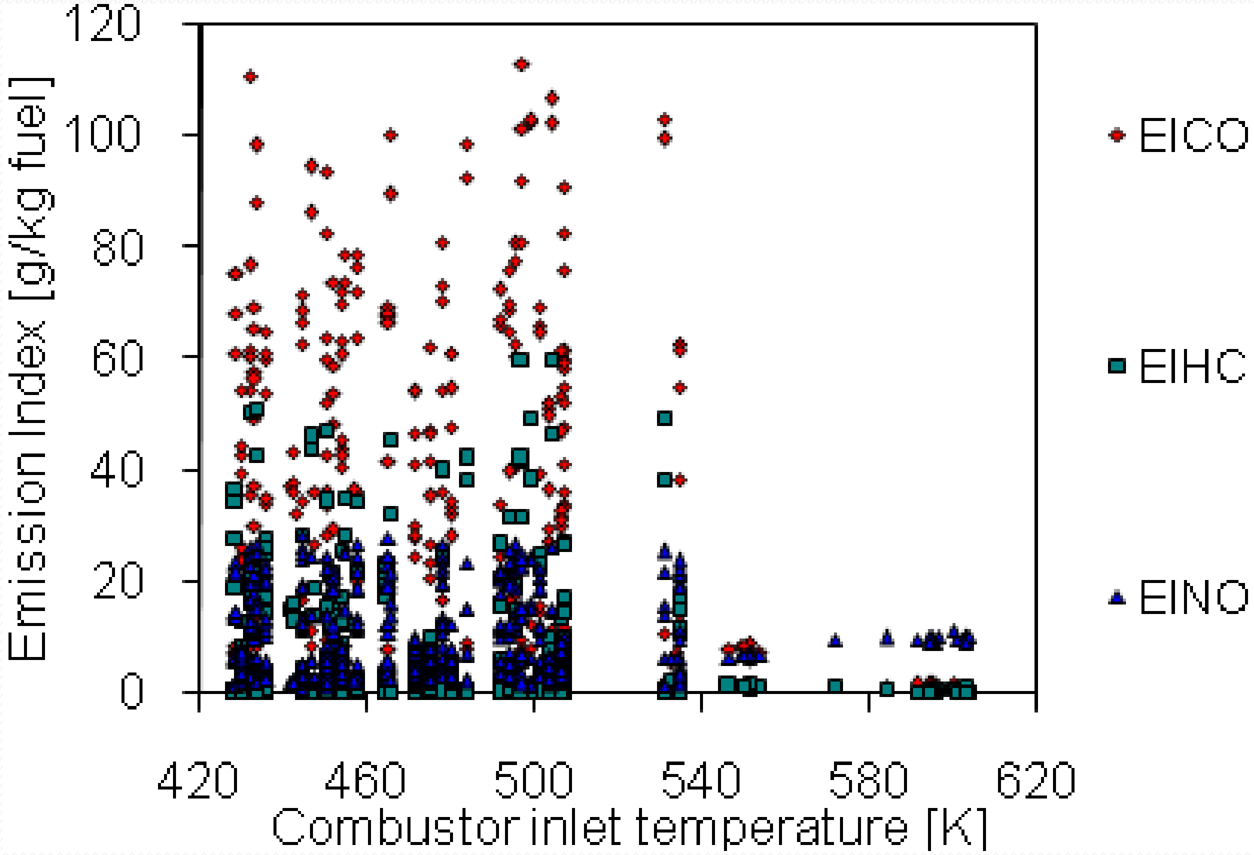

Fig 5: EI_{CO}, EI_{NOx} and EI_{HC} versus inlet temperature from F101, J79-56A, J79-56C, P&W and T56 Allison

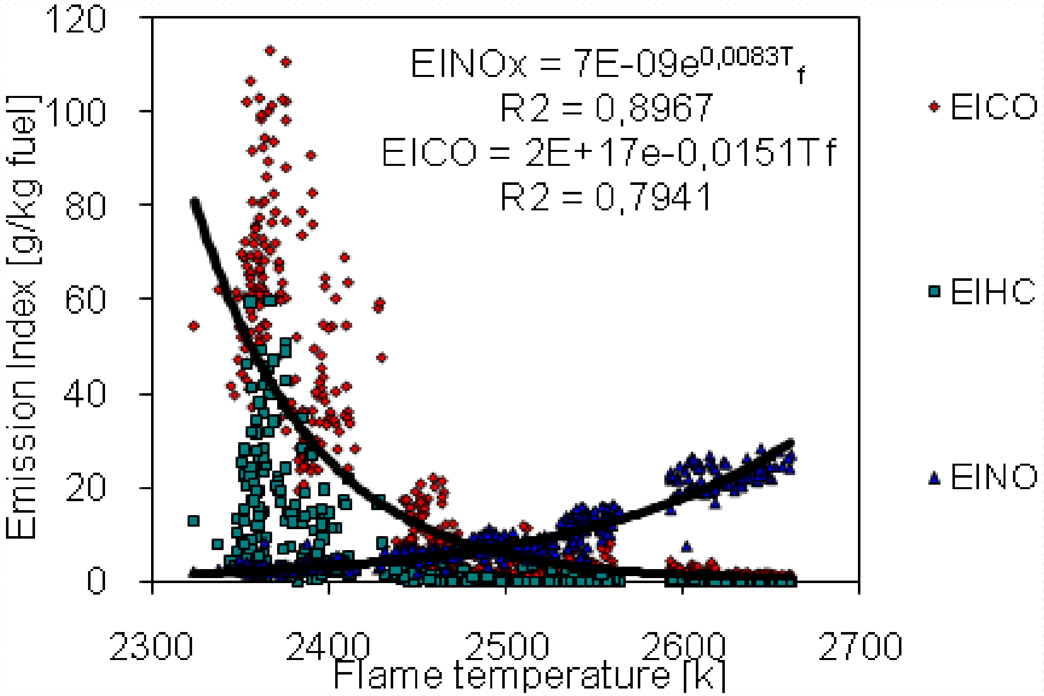

Fig 6: EICO, EINOx and EIHC versus flame temperature (F101, J79-56A, J79-56C, P&W and T56 Allison)

Methods to optimize the inlet and flame temperature

❖The air can be preheated or premixed and controlled so that it enters the combustion chamber with a constant temperature of 600K.

❖Poor combustion at low temperature could be the other way to reduce emissions .

❖ Suitable value of flame temperature for the lowest emission production is 25 00 K.

❖This flame temperature can be obtained from specific fuels .

❖Water or steam injection used in grounded gas turbine engine to decrease flame temperature can reduce nitrogen oxides.

❖This technology can not be used in aircraft turbojet engines.

Conclusion

- Nitrogen oxides emissions increase with the evolution of fuel flow and flame temperature.

- Carbon monoxide and unborn hydrocarbon decrease with fuel flow, inlet and flame temperature evolution.
- Nitrogen oxides emissions are higher than the CO and UHC emissions at take off and climb,.
- A t approach and taxi, CO and UHC emissions are higher than Nox

- The lowest emission zone in which the control of inlet and flame temperature for turbojet engines emissions reduction has been defined.
- Turbojet engine emissions have to be taken into account since the begining of aircraft design
- What about spacecraft pollutant emissions?

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