Environmentally-Neutral Aircraft Propulsion Using Low Temperature Plasma

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Motivation

- NO_x formation is a consequence of the combustion of various fuels.
- Nitric oxide (NO):
- Quickly forms nitrogen dioxide (NO_2), a respiratory irritant.
- Active participant in photochemical smog formation.

Motivation (2)

- Current methods of NO_x reduction involve catalysts used either alone (*e.g.* Rh), or in an atmosphere containing hydrocarbons (*e.g.* Cu or Fe).
- Rhodium is too expensive for widespread use, and extra hydrocarbons in fuel exhaust are undesirable.

Objective

- To reduce NO_x in turbojet emissions by an order of magnitude using a low-temperature plasma.
- "Low-temperature plasma" implies plasma excitation temperatures in the range of 3000 to 5500 K.

Previous Work

- Luo *et al*. (*J. Phys. Chem. A* 102:7954, 1998) decomposed NO in He using a low-temperature plasma at atmospheric pressure.
- The degree of NO destruction is a function of initial NO concentration, residence time, input voltage, and **additives**.

Additive Effects on NO Reduction from Previous Work

- CO_2 and H_2O inhibited the destruction of NO.
- CO, O_2, C_2H_6, and other carbon species accelerated the destruction of NO.

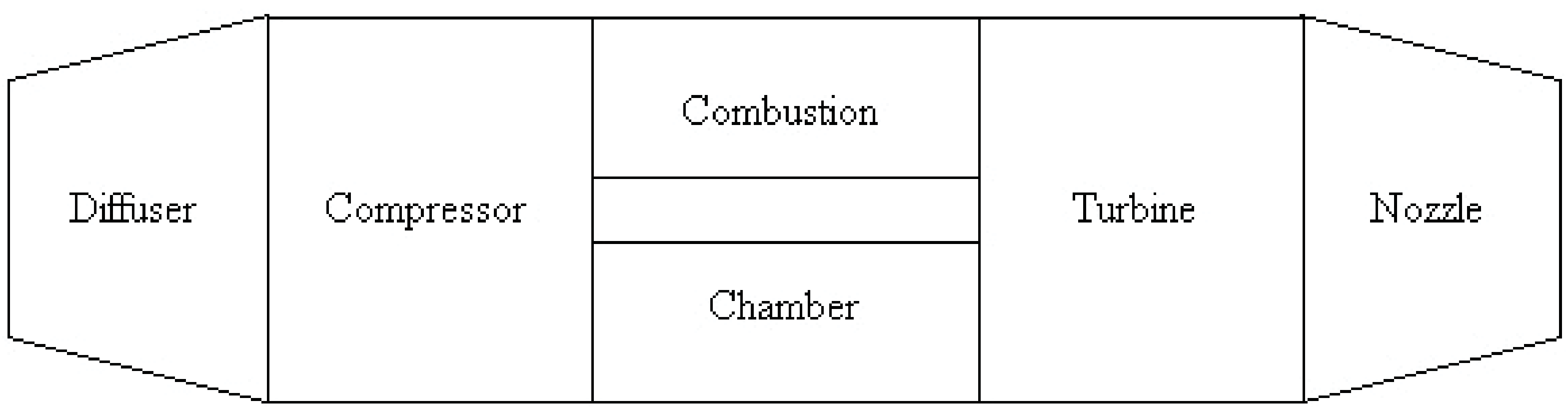
Extending This Concept to the Turbojet Engine

(Could it still work?)

- Higher temperatures (up to 1700 K)
- Higher pressures (up to 40 atm)
- Shorter residence times (~0.1 s)
- Presence of different species (O_2, N_2, CO_2, H_2O)

Turbojet Engine

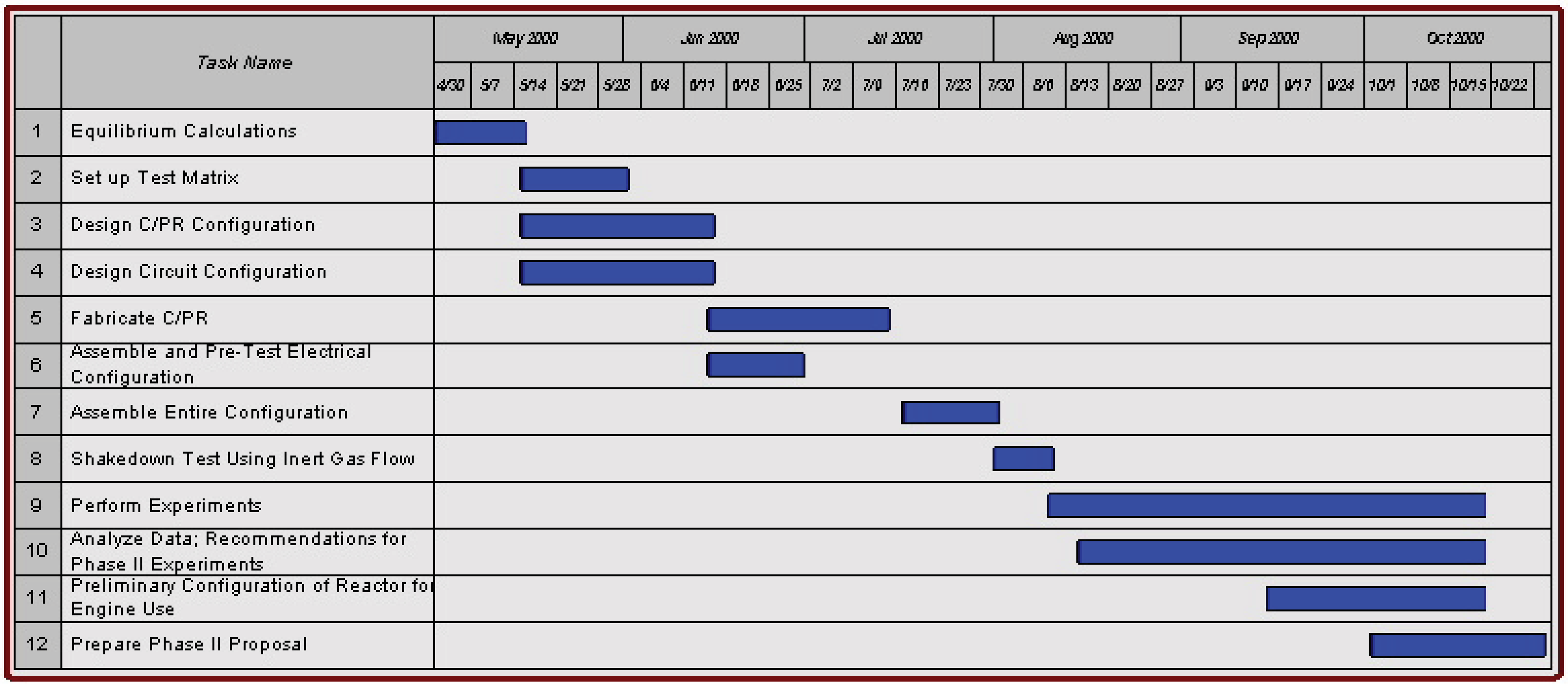
1. Air is compressed and heated in diffuser/compressor
2. Fuel mixed in and burned in combustor
3. Partially expanded in turbine to provide power for compressor
4. Expansion continues through nozzle, generating thrust



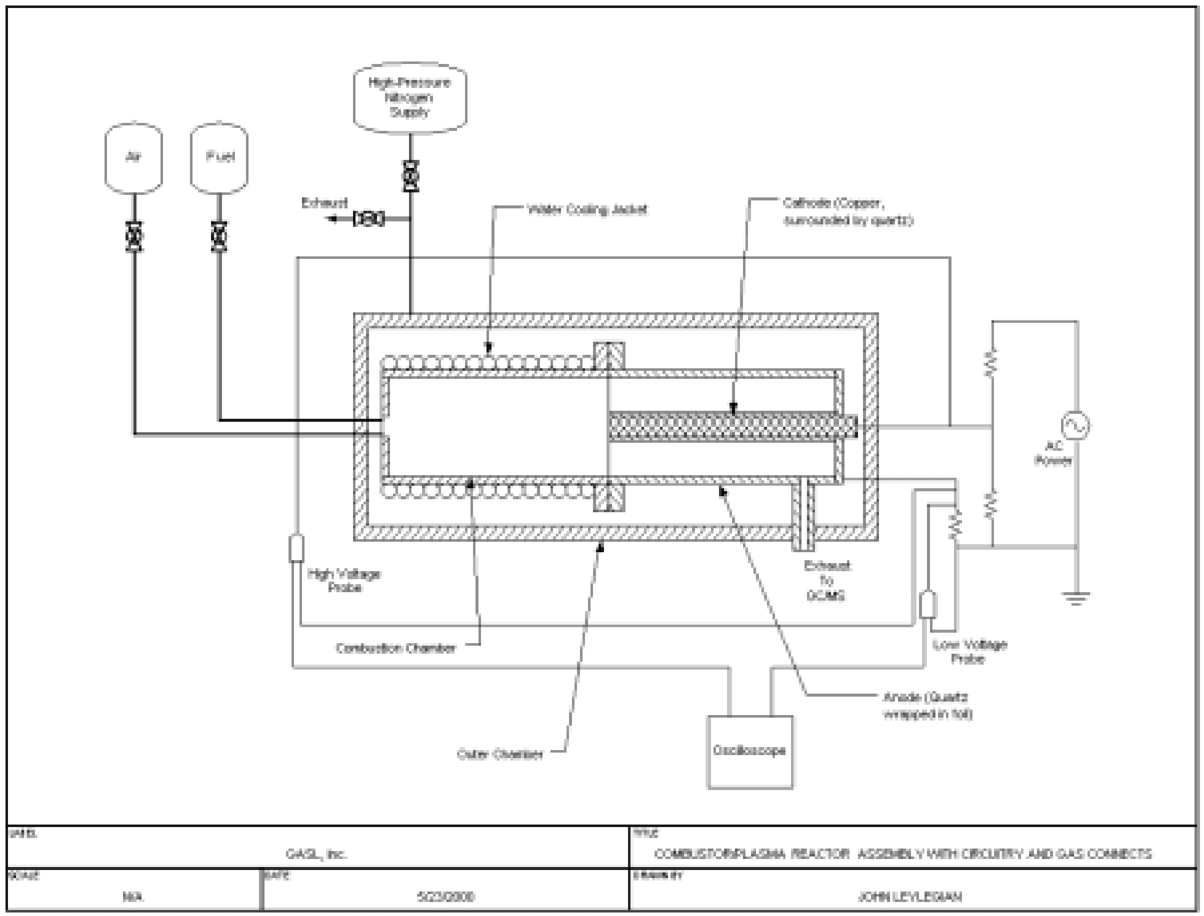
Proposed Work

- Perform experiments similar to those of Luo *et al.*, using the products of hydrocarbon combustion, at conditions similar to those encountered in a turbojet engine.

Program Outline

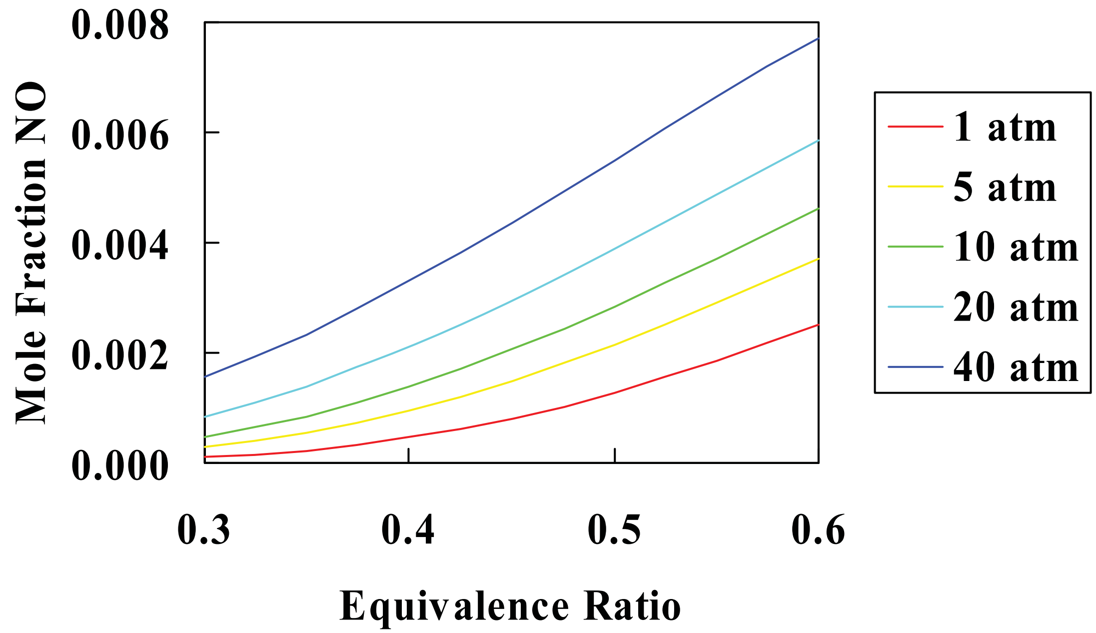


Rig Schematic



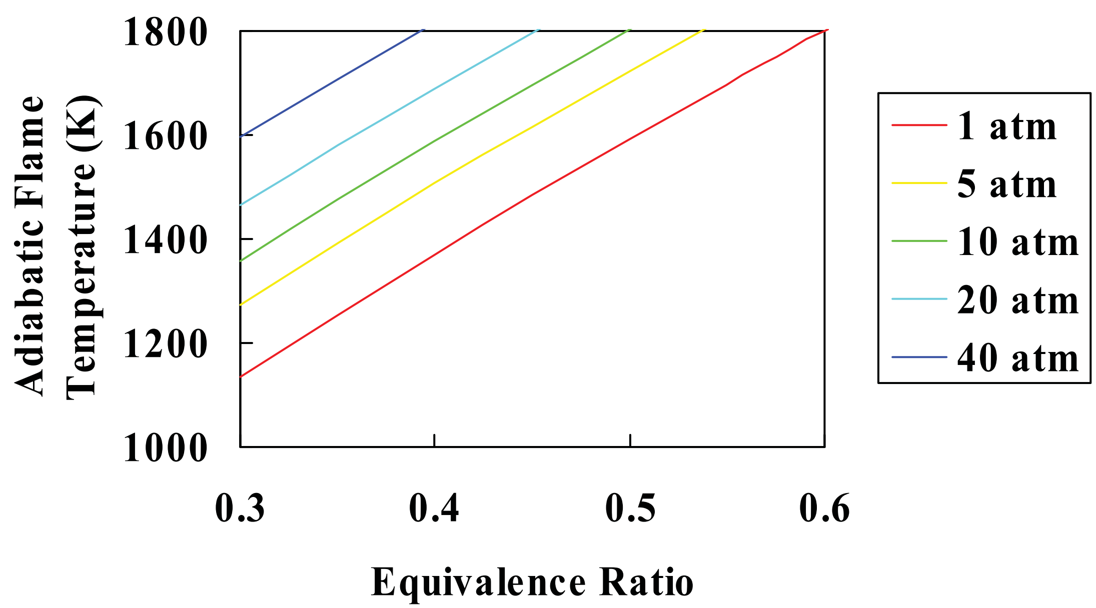
Estimation of NO Levels in Jet Exhaust

- Variation of NO in ethylene/air products with equivalence ratio:



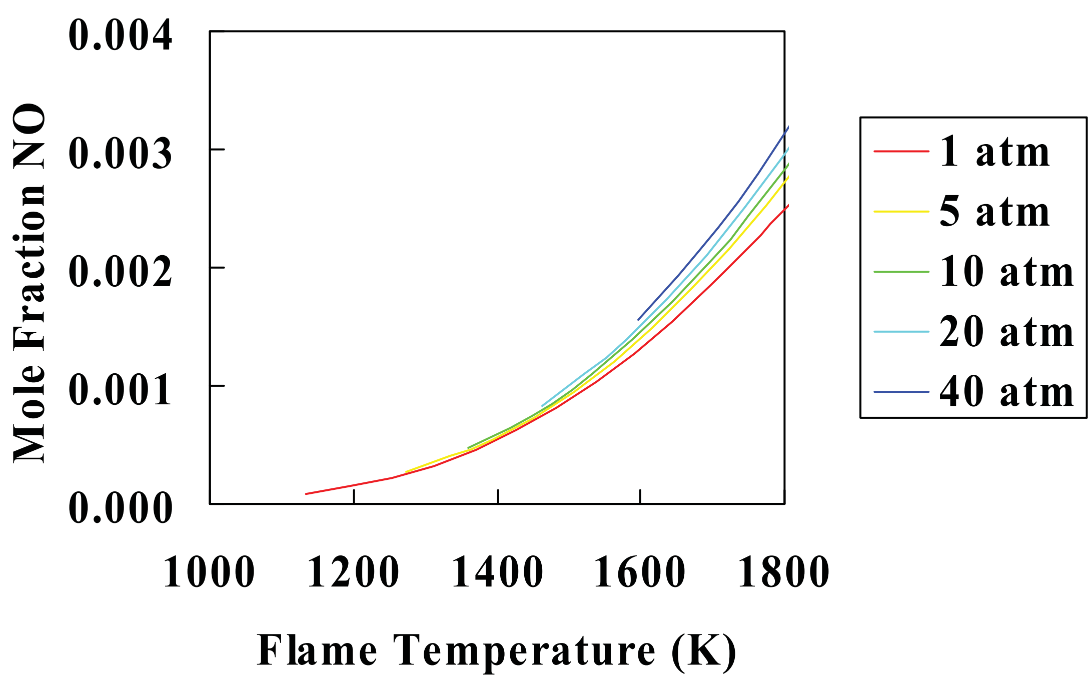
Estimation of NO Levels in Jet Exhaust

- Equilibrium temperatures of ethylene/air mixtures:



Estimation of NO Levels in Jet Exhaust

- Variation of NO in ethylene/air products with temperature:



Determination of Power Requirements (1)

Rate constant for overall reaction:

$$NO \rightarrow \tfrac{1}{2}N_2 + \tfrac{1}{2}O_2$$

converted to Arrhenius form: $k = A\, T^{0.75}$
where A is a function of the input power.

Determination of Power Requirements (2)

Using the power-rate constant data of Luo *et al*. and the LSENS code, the power required for an order-of-magnitude reduction in NO mole fraction can be determined:

$$P\ (\mathrm{W}) = 4.868\ X_{\mathrm{NO}}^{-1.0196}$$

For $X_{\mathrm{NO}} = 0.002$, $P = 2.75$ kW

Power Sources

- Fuel Cells: Automotive PEM fuel cells available up to 20 kW (if DC is required)
- Fuel Cell + Inverter (if AC is required)
- Turbine

Summary

- Oxides of nitrogen, produced by fossil fuel combustion, are environmental and health hazards.
- Use of plasmas to reduce NO levels is a clean and inexpensive method.
- A plasma generator is being designed to test this method on hydrocarbon-air combustion products at high temperature and pressure.