EFFECT OF NATURAL GAS COMPOSITION ON THE PERFORMANCE OF A MODEL GAS TURBINE COMBUSTOR

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OVERVIEW

- **THE UCICL PROGRAM IS DIRECTED AT TWO ASPECTS OF STATIONARY GAS TURBINE COMBUSTION**
  - **FUEL COMPOSITION ISSUES**
  - **DUAL FUEL ISSUES**
- **THE PRESENT POSTER EMPHASIZES GASEOUS FUEL COMPOSITION EFFECTS**
- **DUEL FUEL ACTIVITIES ARE UNDERWAY IN PARALLEL (RESULTS REPORTED AT COMBUSTION WORKSHOP VI)**
  - **MACROLAMINATE INJECTOR MODULE**
  - **DETAILED STUDY OF SPRAY INJECTED INTO CROSSFLOWS**
    - **DESIGN CORRELATIONS**
  - **EXPERIMENTS AT ELEVATED PRESSURE AND TEMPERATURE**

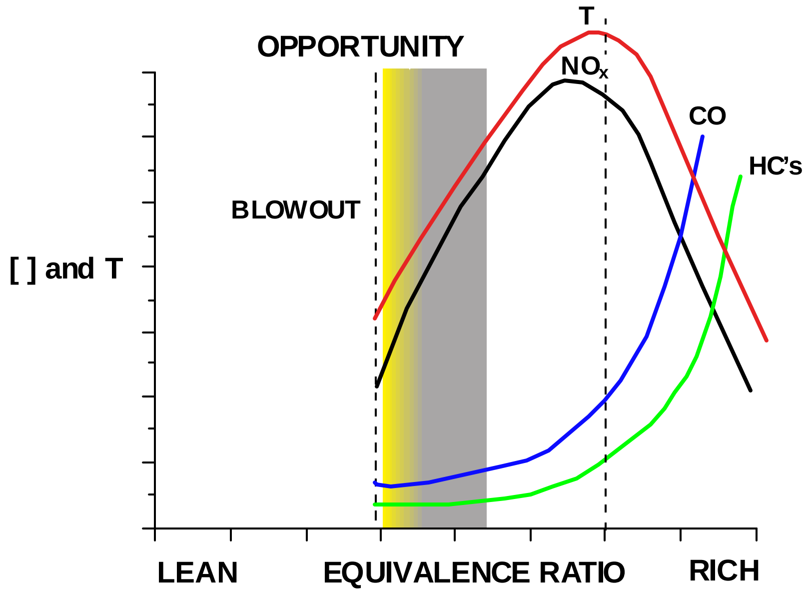
INDUSTRIAL LIASONS

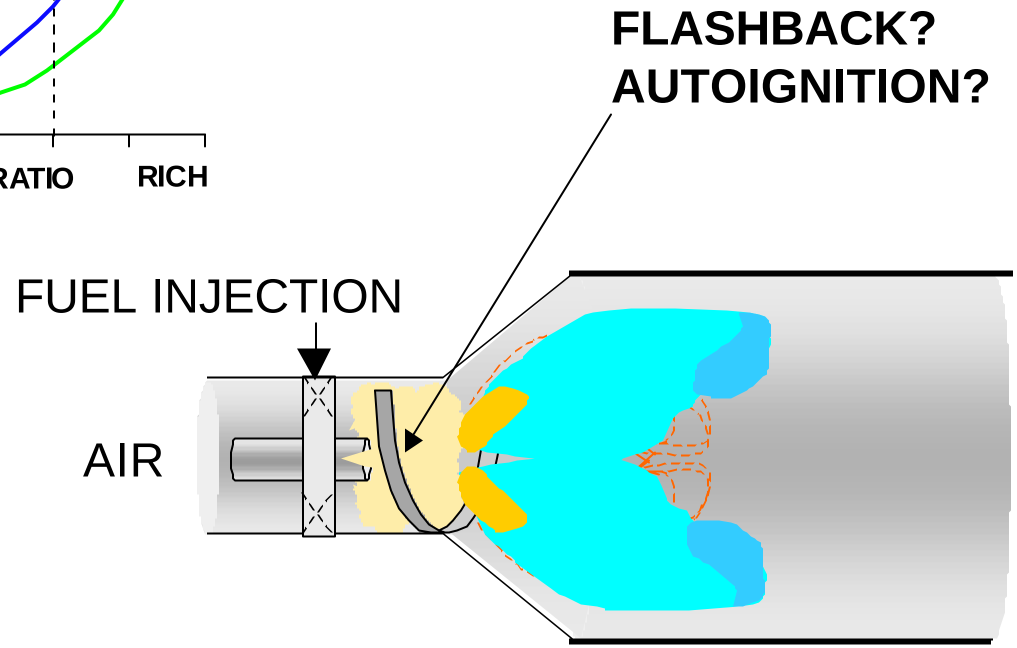
- **GENERAL ELECTRIC**
- **PARKER HANNIFIN**
- **ROLLS ROYCE ALLISON**
- **SIEMENS WESTINGHOUSE**
- **SOLAR TURBINES**
- **UNITED TECHNOLOGIES RESEARCH CENTER**

MOTIVATION

LEAN COMBUSTION SYSTEMS

– **DRIVEN TO EDGE OF OPERATIONAL LIMITS TO MEET EMISSIONS TARGETS**





VARIABILITY IN NATURAL GAS COMPOSITION

TYPICAL CONCENTRATIONS OF FUEL CONSTITUENTS FOR NATURAL GAS IN THE U.S.*

CONSTITUENT	MEAN	MINIMUM	MAXIMUM
METHANE	93.9	74.5	98.1
ETHANE	3.2	0.5	13.3
PROPANE			
WITHOUT PEAK SHAVING	0.7	0	2.6
WITH PEAK SHAVING	0.1	0	23.7
HEXANES	0.1	0	0.4
INERTS*			
CO_2		0	3
H_2O		0.05 PPM	0.2 PPM

***GRI-92/0123**

OBJECTIVES

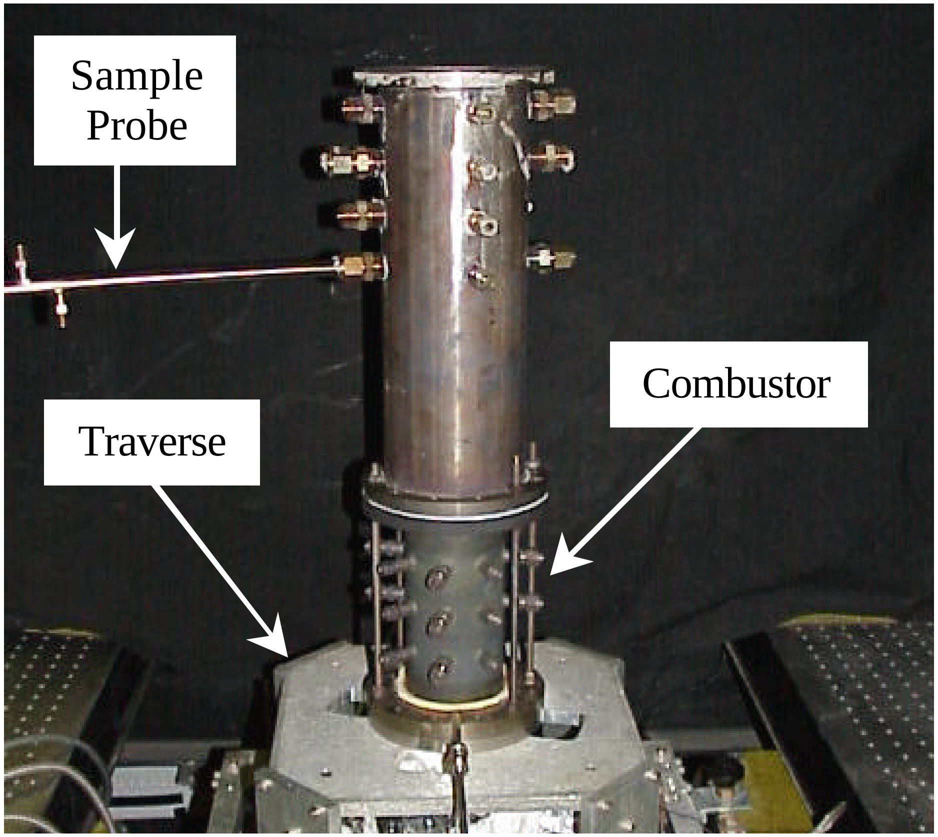
- **DELINEATE THE EFFECTS OF FUEL COMPOSITION ON THE OVERALL PERFORMANCE OF A MODEL COMBUSTOR**
- **RELATE THE VARIATION IN PERFORMANCE TO MIXING EFFECTS AND/OR CHEMICAL KINETICS**

APPROACH

- **DEVELOP AND APPLY A MODEL COMBUSTOR WITH CHARACTERISTICS SIMILAR TO THOSE IN PRACTICE**
- **FLEXIBLE FUEL INJECTION SYSTEM**
- **CO, NO_X, STABILITY AND FUEL DISTRIBUTIONS AS FUNCTIONS OF FUEL COMPOSITION AND INJECTION STRATEGY**
  - **FIXED FIRING RATES**
- **CORRELATE PERFORMANCE**
  - **FUEL PROPERTIES**
  - **FUEL DISTRIBUTION**

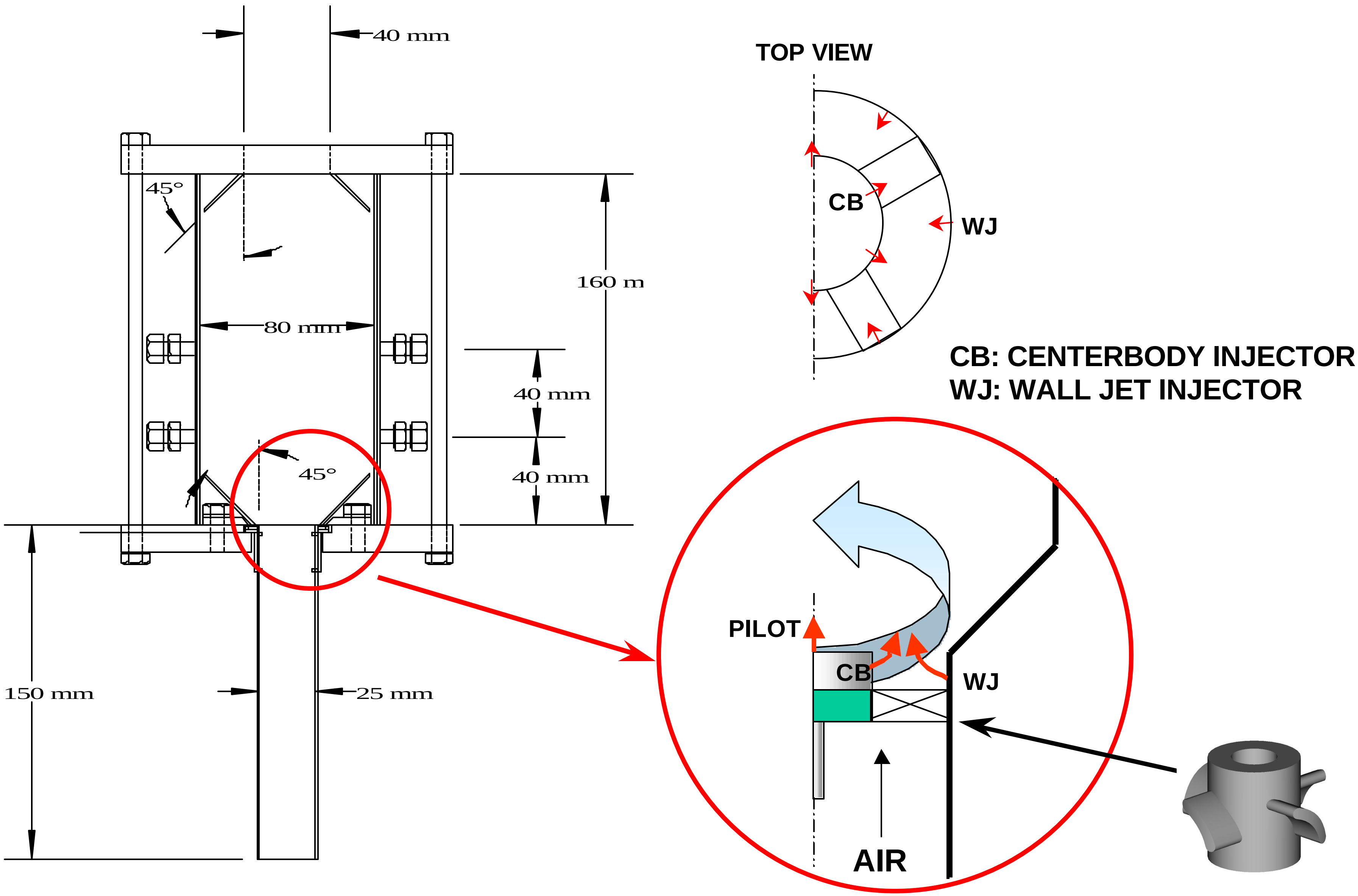
EXPERIMENT

MODEL COMBUSTOR



- **ATMOSPHERIC CONDITIONS**
- **INLET TEMPERATURE OF 700K**
- **THREE DIMENSIONAL TRAVERSE SYSTEM**
- **NOMINAL FIRING RATE OF 15 kW**

FUEL INJECTION STRATEGY

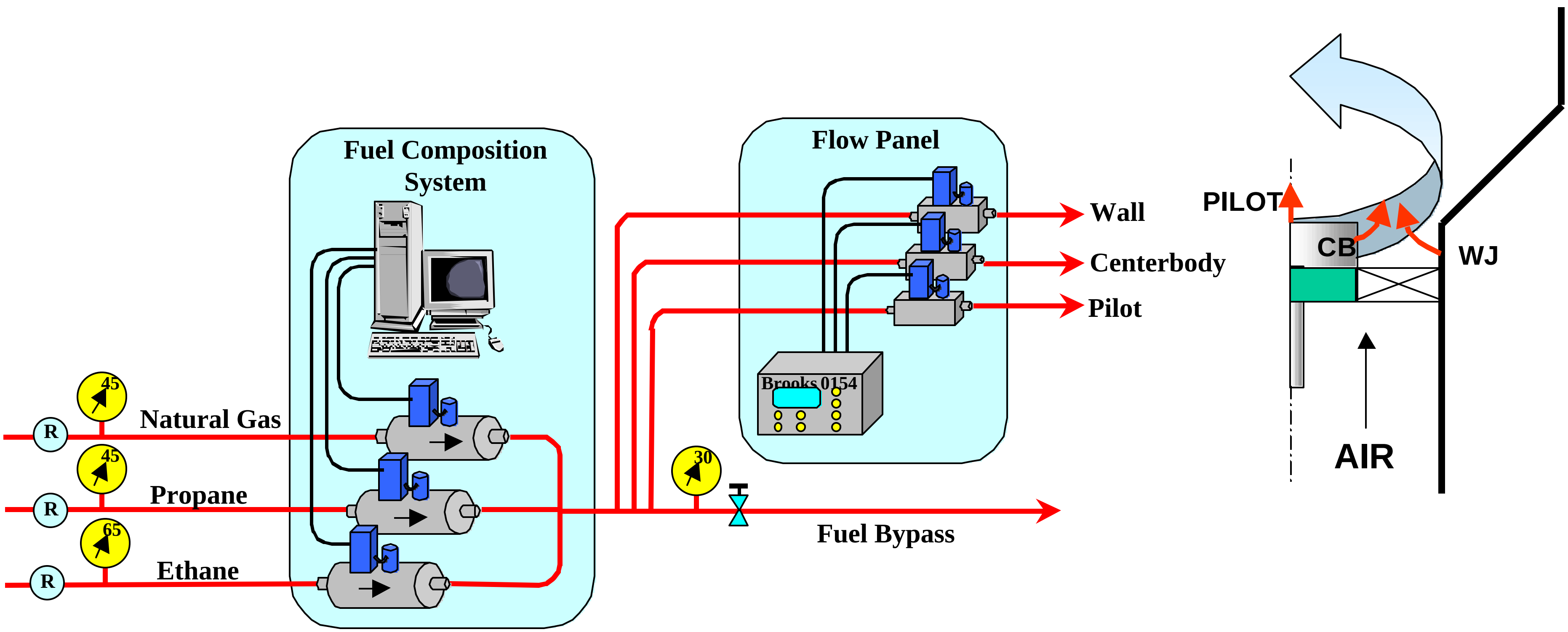


FUEL BLENDING STRATEGY

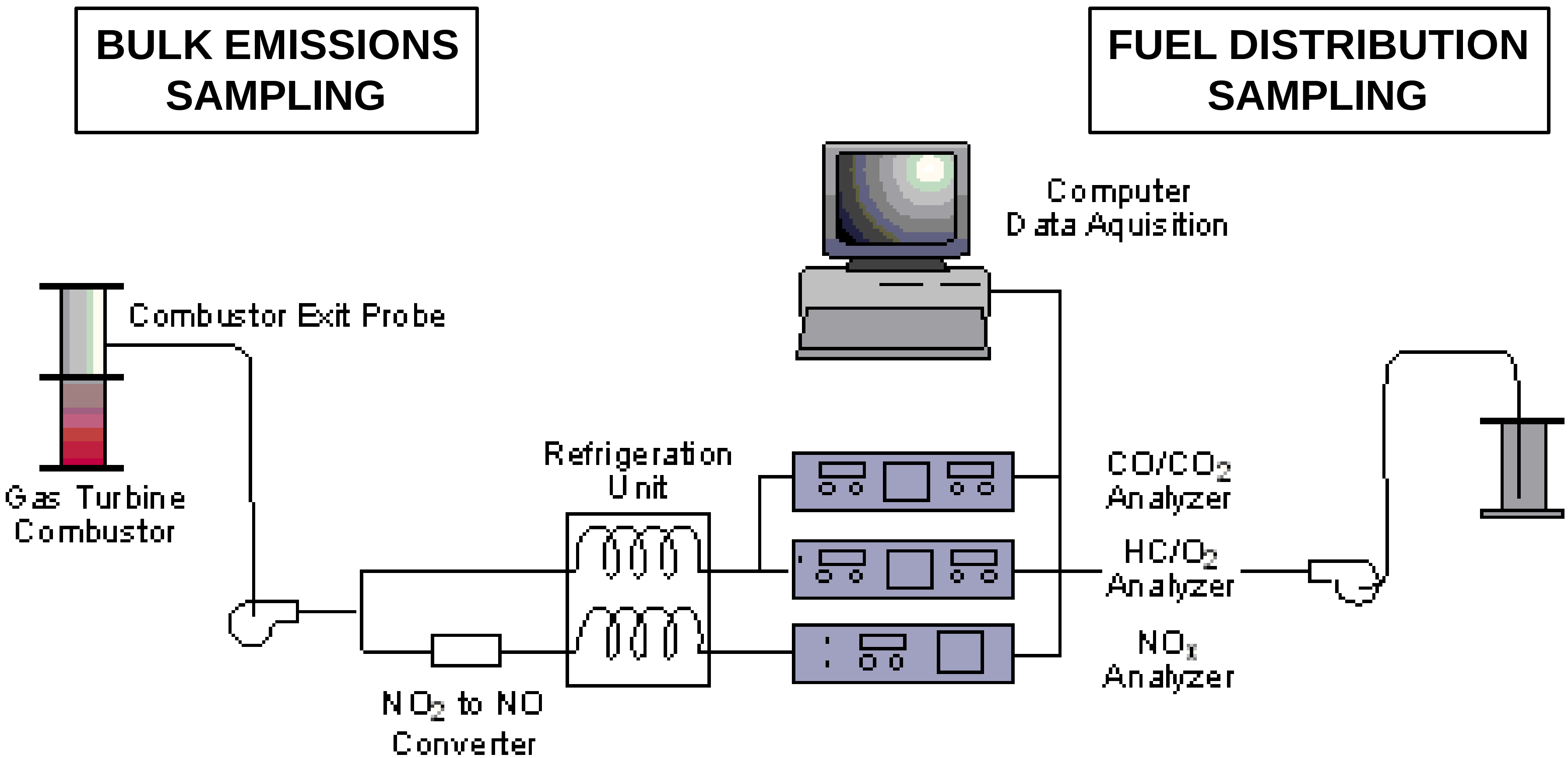
- 100% NATURAL GAS
- 85% NATURAL GAS / 15% ETHANE
- 80% NATURAL GAS / 20% PROPANE
- 100% PROPANE

UCICL ON LINE GC

n	Constituent		MF y(i) %
1	Methane	CH_4	96.975
2	Ethane	C_2H_6	0.982
3	Propane	C_3H_8	0.109
4	iso-Butane	C_4H_{10}	0.014
5	n-Butane	C_4H_{10}	0.015
6	iso-Pentane	C_5H_{12}	0.004
7	n-Pentane	C_5H_{12}	0.004
8	C6	C_6H_{14}	0.001
9	C7	C_7H_{16}	0.001
10	C8	C_8H_{18}	0.000
11	CO_2		1.574
12	O_2		0.000
13	N_2		0.322
		Totals	100.00

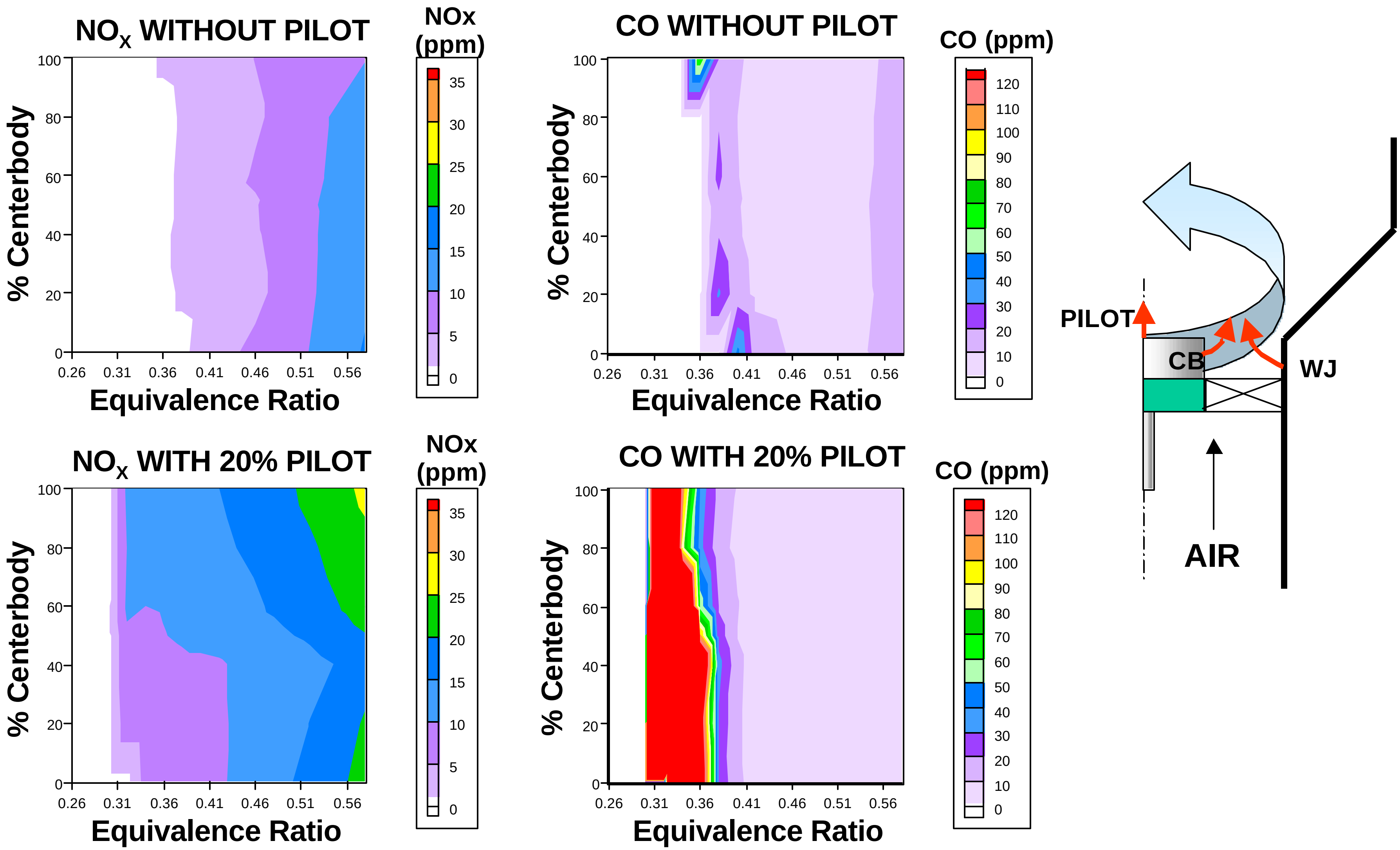


DIAGNOSTICS



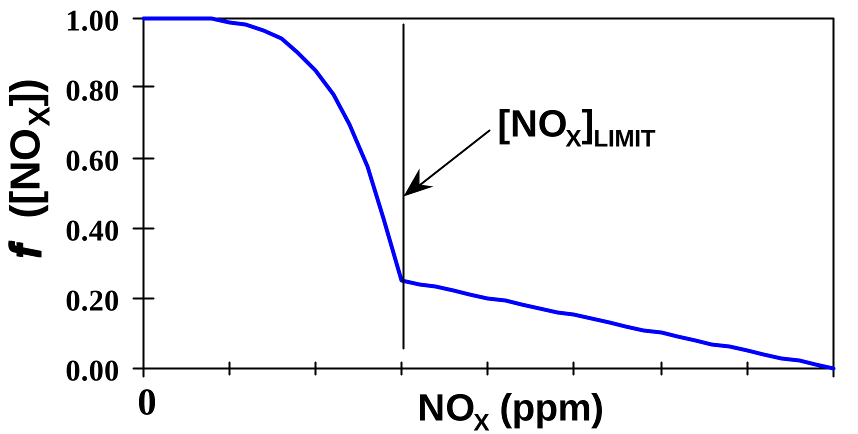
SYSTEM PERFORMANCE

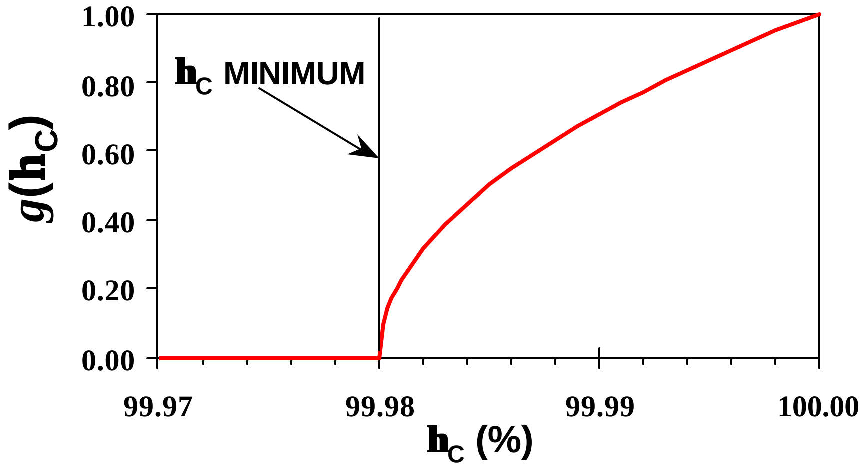
NO$_X$ AND CO EMISSIONS (AT 15% O_2) FOR 100% NATURAL GAS

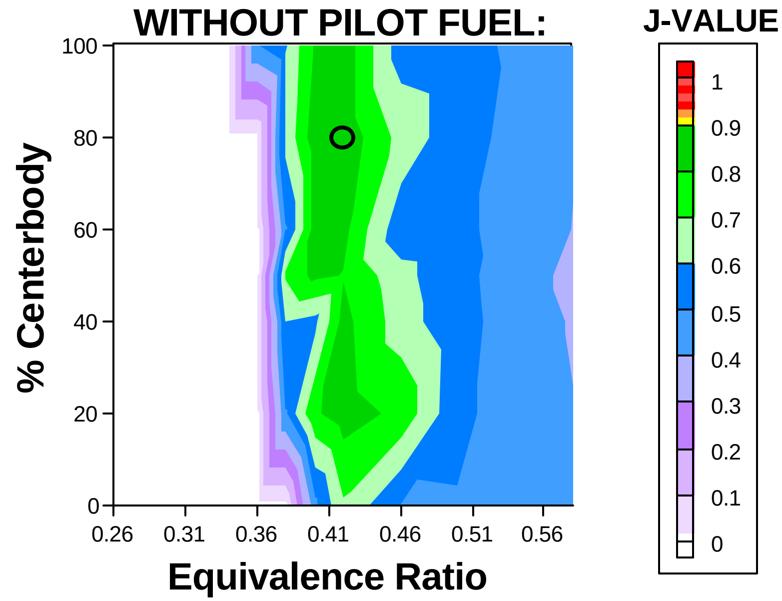


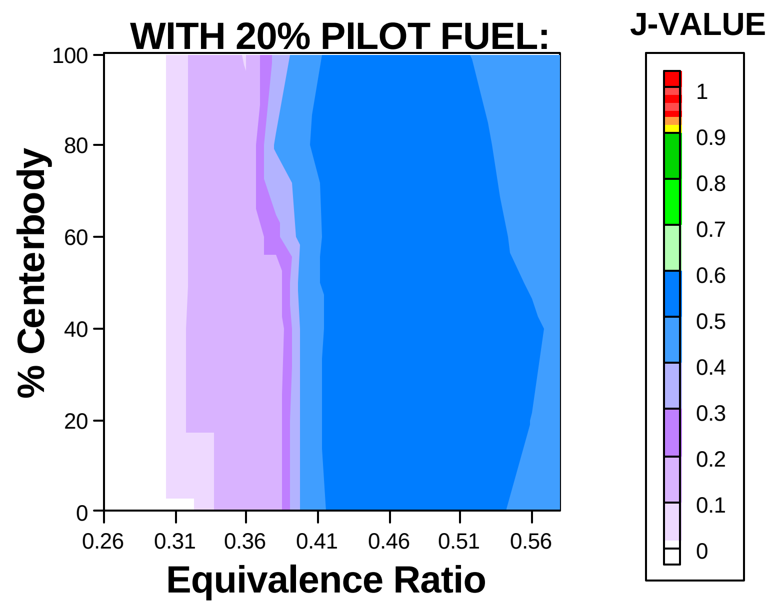
PERFORMANCE FUNCTION

$$J = w_{NO_X} \cdot f([NO_X]) + w_{h_C} \cdot g(h_C)$$



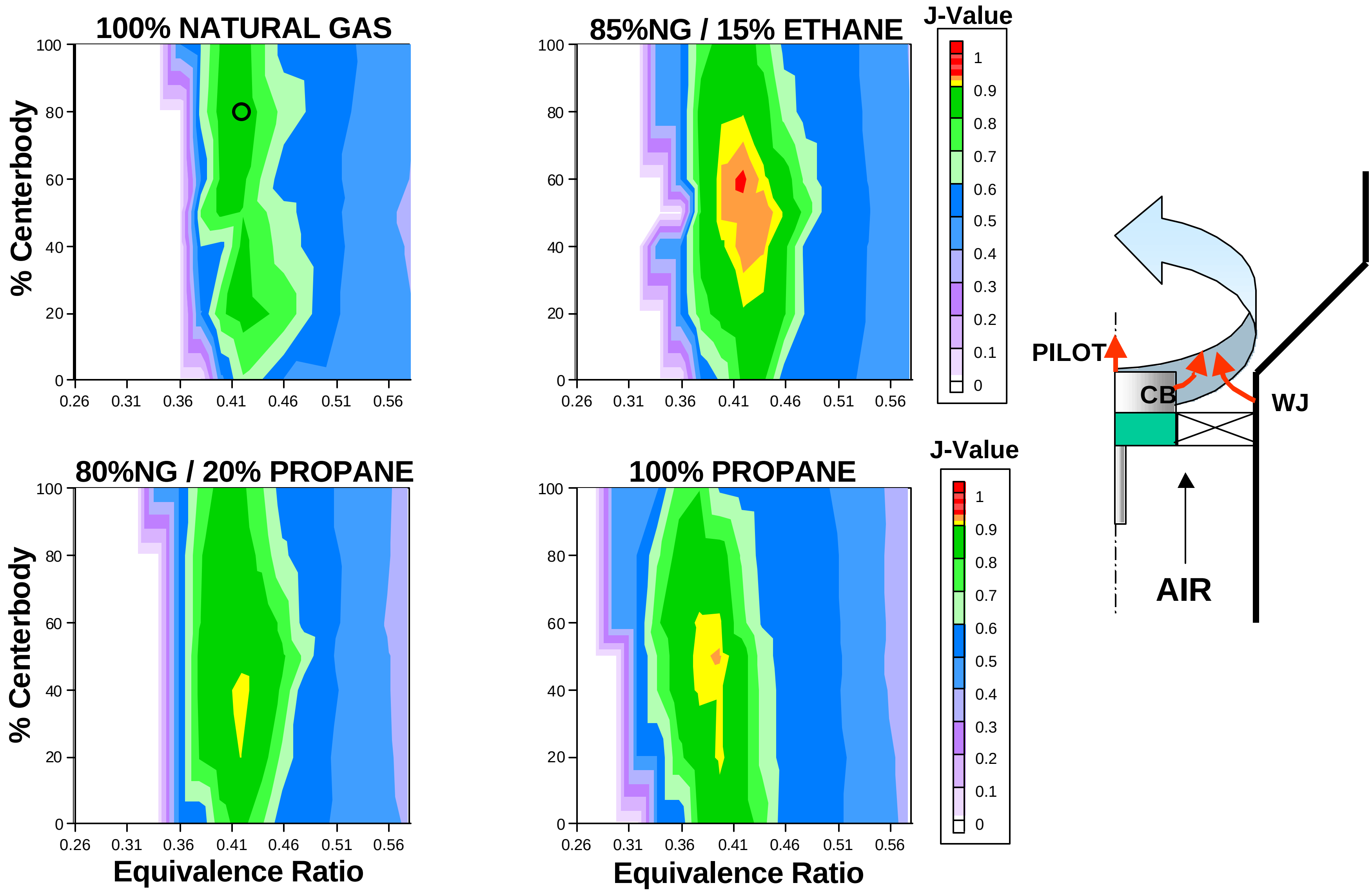






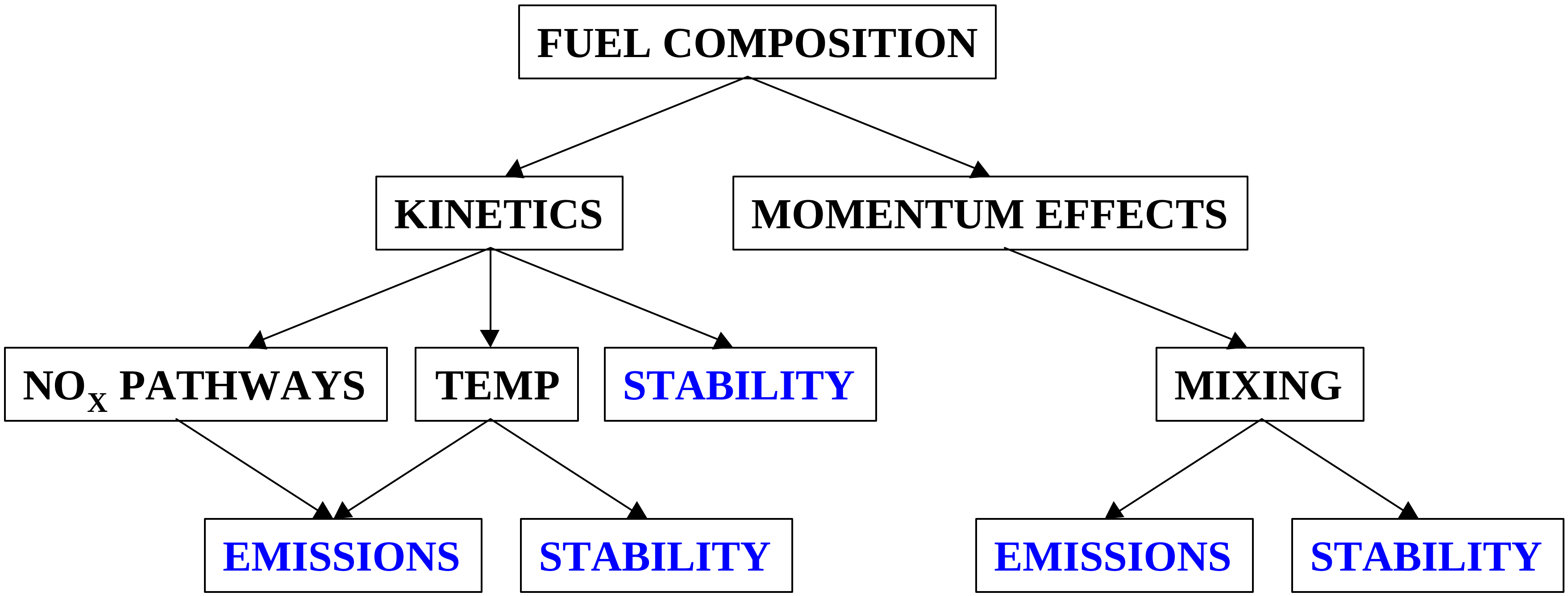
PERFORMANCE FUNCTION

- **J-VALUES AS A FUNCTION OF f, FUEL SPLIT, & FUEL COMPOSITION**



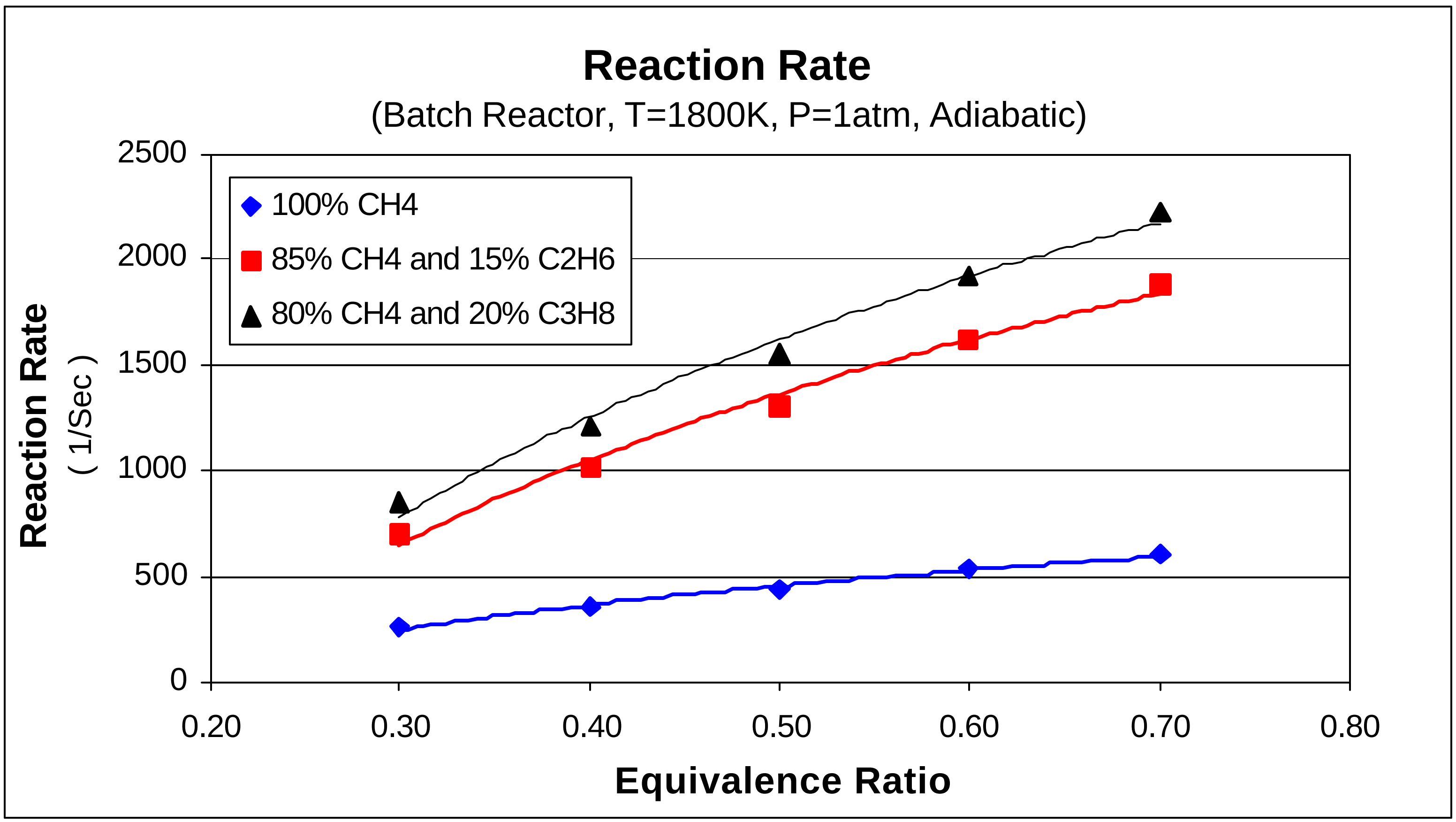
DISCUSSION

POSSIBLE MECHANISMS



REACTION RATES

- **ETHANE & PROPANE ADDITION YIELD FASTER REACTION RATES**
  - **REACTION RATES UP TO 4 TIMES FASTER**
  - **AUTO-IGNITION CONCERNS**



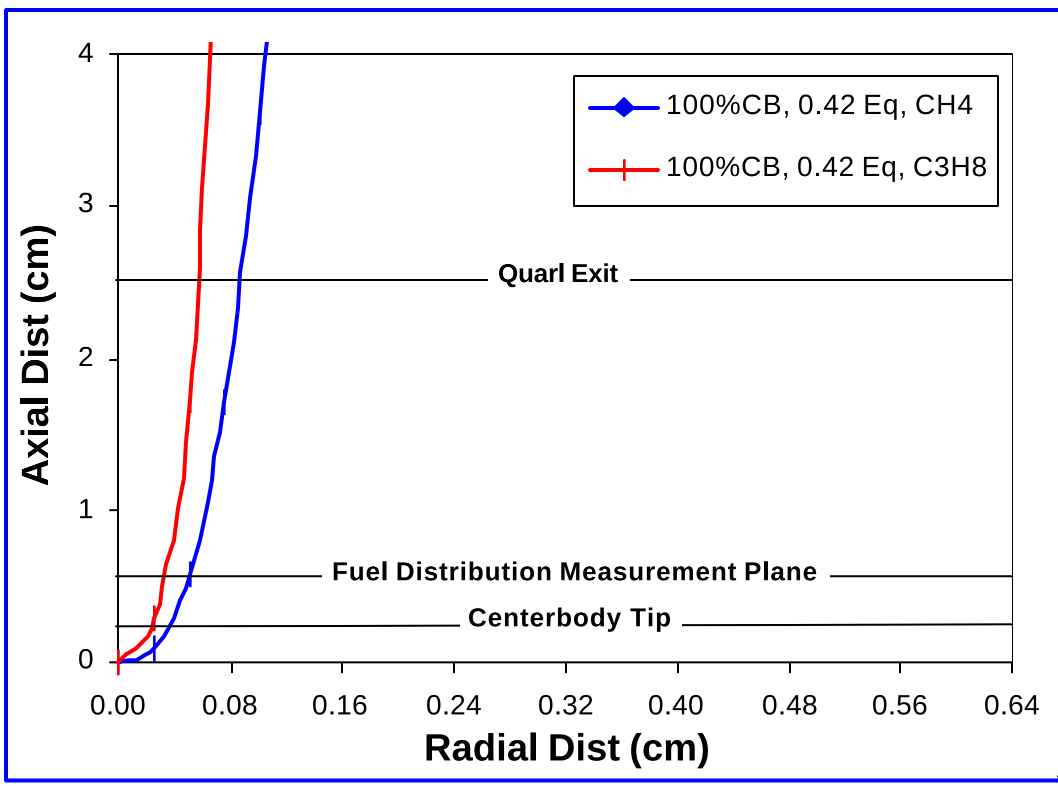
Calculated with Chemkin software, version 3.5

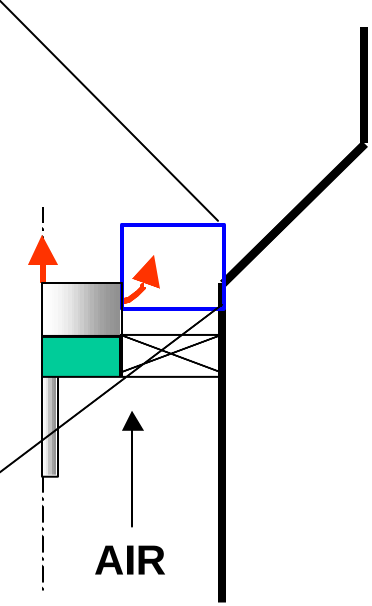
FUEL DISTRIBUTION

- **CENTERBODY FUEL JET PENETRATIONS FOR PROPANE AND NATURAL GAS**
- **LOW PENETRATION, ESPECIALLY FOR PROPANE**

$$X = D_{JET} \cdot q^{0.425} \cdot \left(\frac{Y}{D_{JET}} \right)^{0.38}$$

WHERE: $q = \frac{\tilde{n}_{JET} \cdot V_{JET}^2}{\tilde{n}_{AIR} \cdot V_{AIR}^2}$

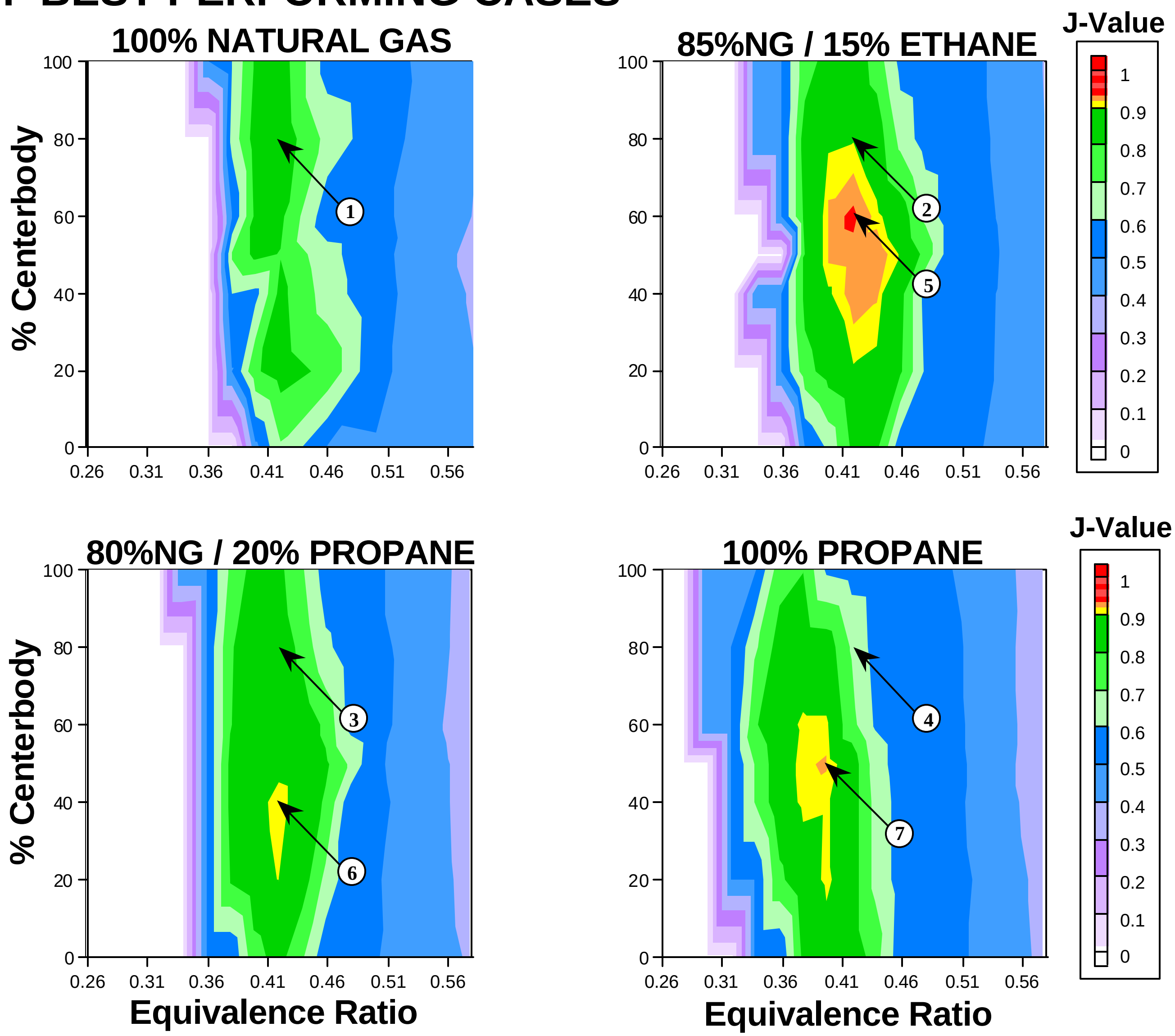




Source: Patrick, M.A. (1965). Sheffield Univ. Fuel Soc. J. Vol. 16, pp.46-61.

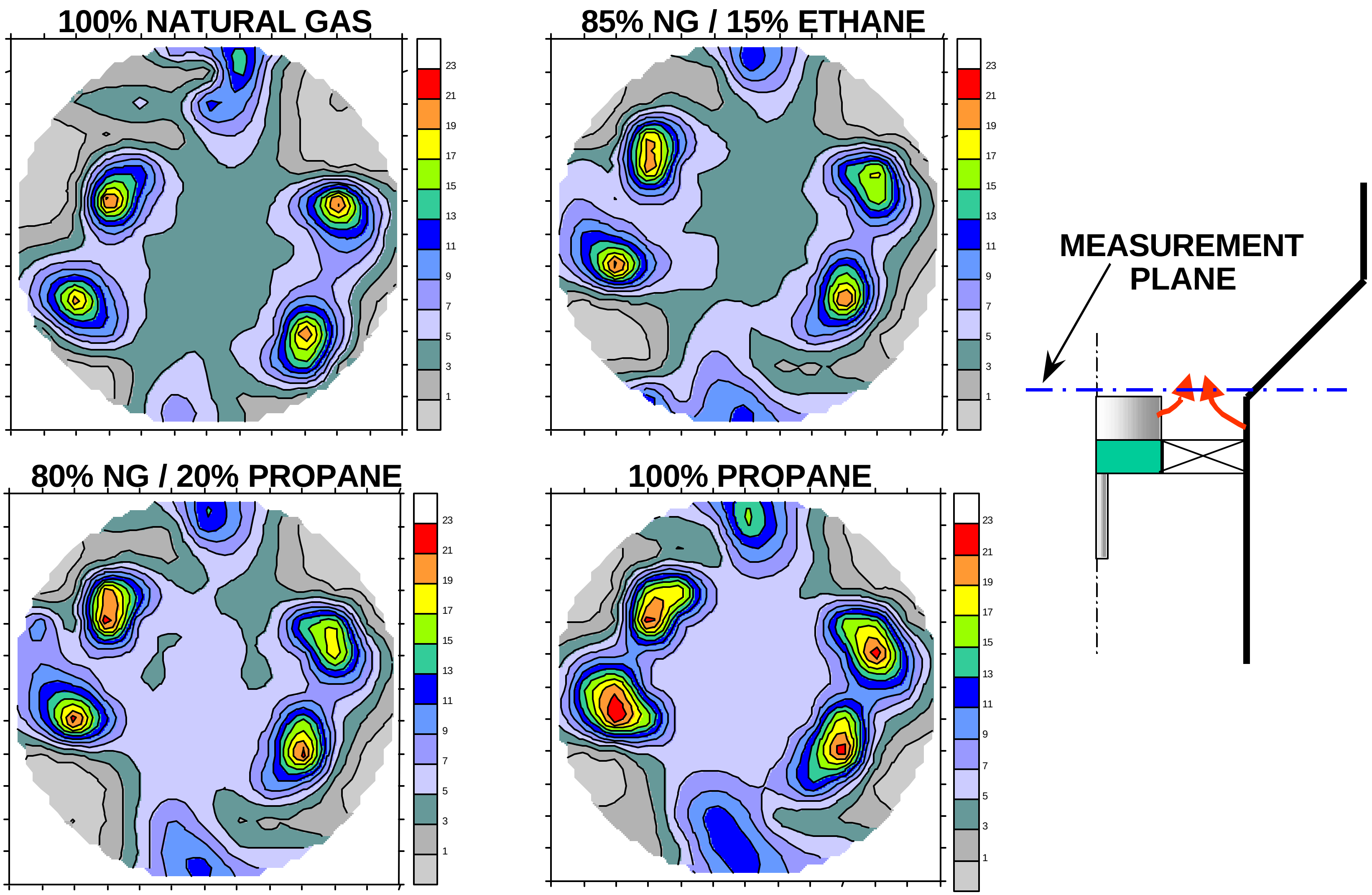
FUEL DISTRIBUTION

- **2 - 4: FIXED φ (0.42) & FUEL SPLIT (80% CENTERBODY)**
- **5 - 7: BEST PERFORMING CASES**



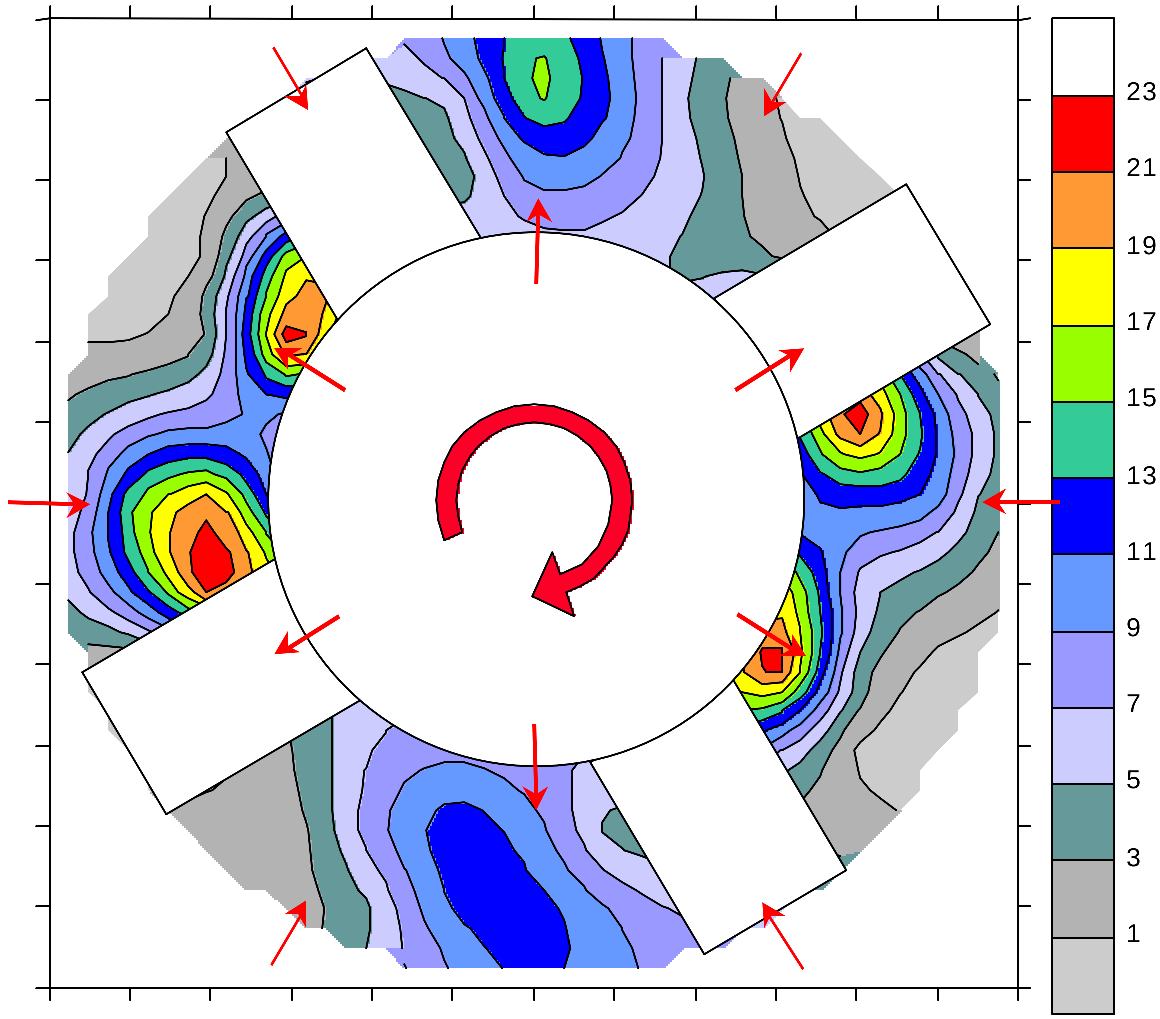
FUEL DISTRIBUTIONS

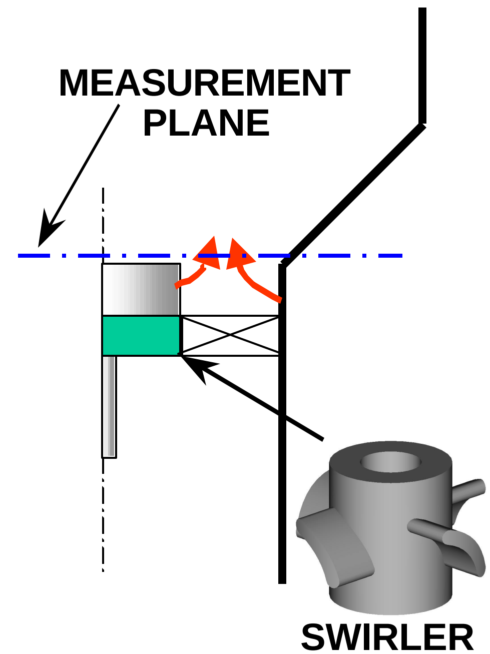
- **FIXED f (0.42) AND FUEL SPLIT (80% CENTERBODY)**



FUEL DISTRIBUTIONS

- **PROPANE AT FIXED f (0.42) AND FUEL SPLIT (80% CENTERBODY)**

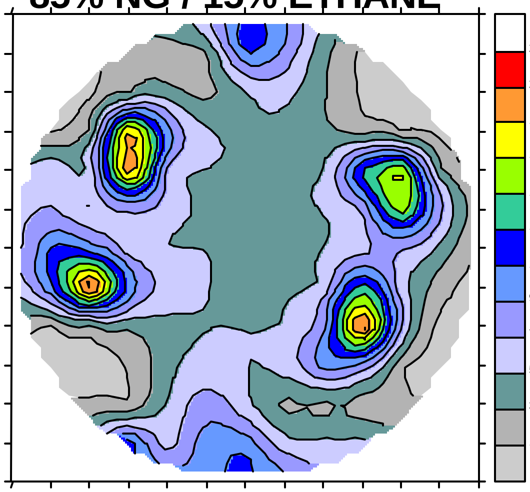




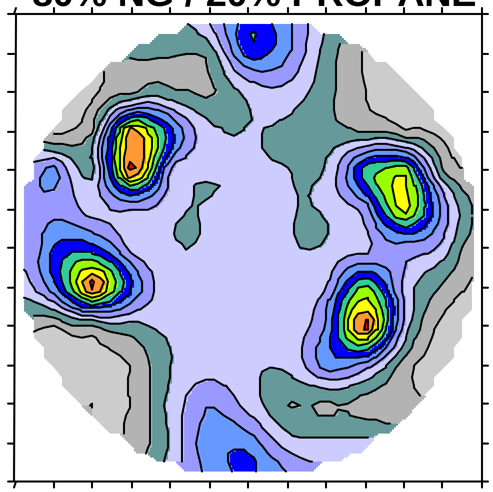
FUEL DISTRIBUTIONS

- **FIXED f (0.42) AND FUEL SPLIT (80% CENTERBODY)**

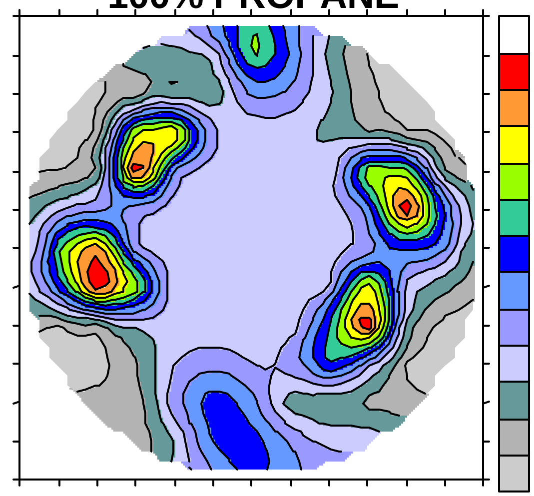
85% NG / 15% ETHANE



80% NG / 20% PROPANE

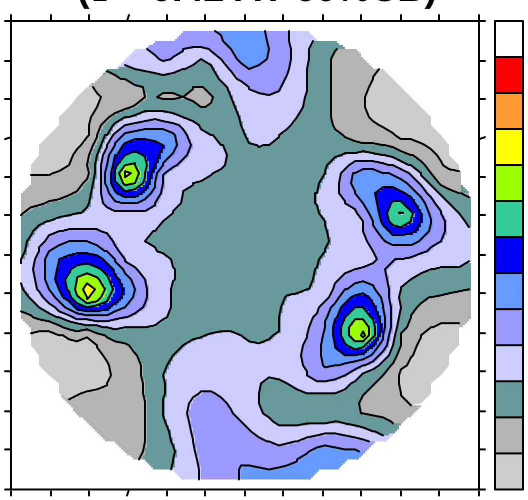


100% PROPANE

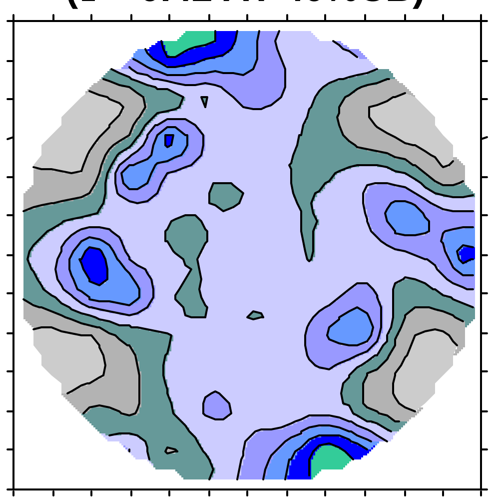


- **BEST PERFORMING CASES**

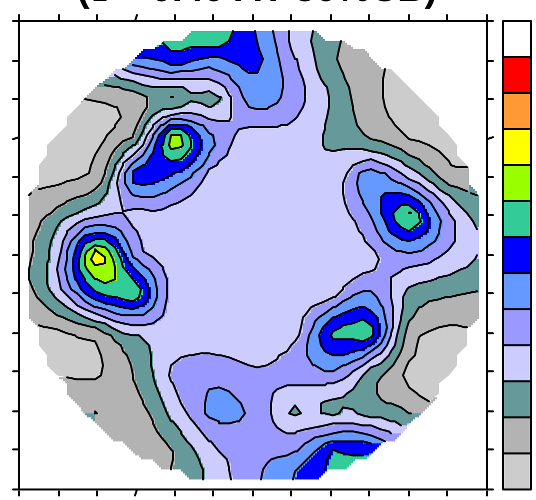
85% NG / 15% ETHANE (f = 0.42 AT 60%CB)



80% NG / 20% PROPANE (f = 0.42 AT 40%CB)



100% PROPANE (f = 0.40 AT 50%CB)



SUMMARY & NEXT STEPS

- **STABILITY LIMITS ARE IMPACTED BY THE FUEL COMPOSITION**
  - **HIGHER HYDROCARBONS ENHANCE STABILITY**
  - **APPEARS TO BE KINETIC GIVEN SIMILARITY IN MIXING**
- **COMBUSTION PERFORMANCE IS IMPACTED BY FUEL COMPOSITION**
  - **FUEL DISTRIBUTION?**
  - **KINETICS?**
- **DIFFERENT FUEL INJECTION STRATEGIES MAY BE UTILIZED TO RETAIN OPTIMAL PERFORMANCE AS THE FUEL COMPOSITION CHANGES**

NEXT STEPS

- **RUN FULLY PREMIXED CASES TO ISOLATE KINETICS**
- **IMPLEMENT INTO GEN-II HARDWARE THAT IS MORE FLEXIBLE AND CAN ACCOMMODATE DUEL FUEL EFFECTS AND FUEL COMPOSITION EFFECTS SIMULTANEOUSLY**
- **ADD HIGHER HYDROCARBONS TO STUDY**
- **TEMPERATURE AND PRESSURE EFFECTS**