Fuel Sensitivity of Gas Emissions, Lean Blowout and Combustion Dynamics for a 9-point LDI Combustor

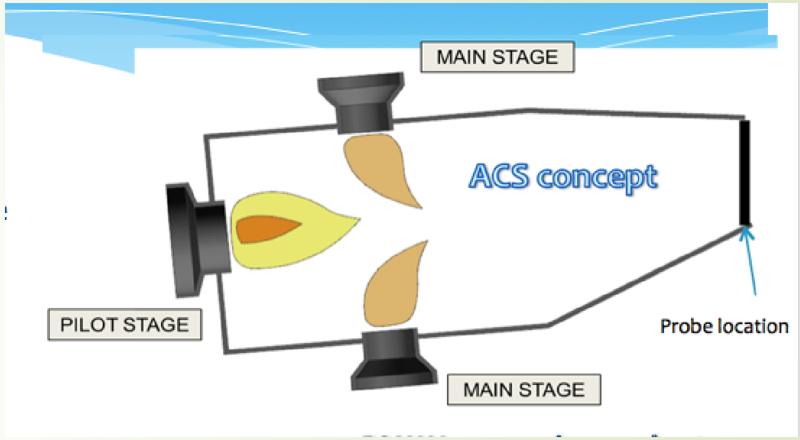
Zhuohui J. He, Derek P. Podboy and Clarence T. Chang

NASA Glenn Research Center, Cleveland, Ohio, 44135

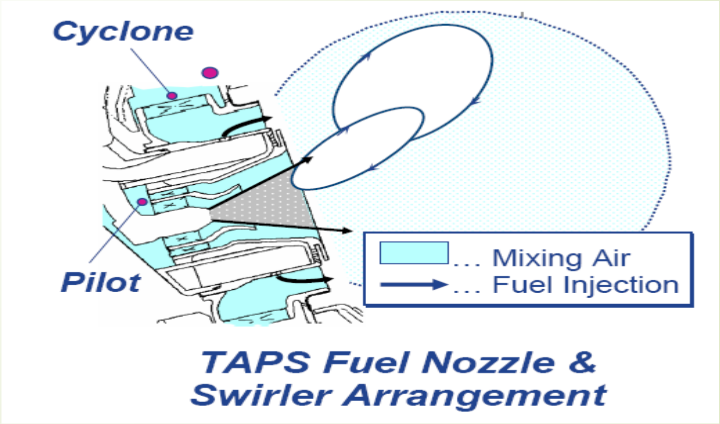
Introduction

- **NASA has been investigated the using synthetic fuel on aircraft combustor for decades.**
- **Advanced Air Transport Technology (AATT) Program**
  - 50%/50% alternative fuel/ jet-a blended
  - 80% NOx emissions reduction of ICAO CAEP 6.
- **Environmentally Responsible Aviation (ERA)**
  - 75% NOx reductions
  - 50%/50% Rentech /Jet-A blended.
- **Alterative fuels tested recently:**
  - hydrotreated tallow (HRJ),
  - direct sugar fermentation (Amyris AMJ-710)
  - Fishcher-Tropsch processes (Rentech).

Pratt & Whitney,
Axially Controlled Stoichiometry (ACS)



General Electric, twin-annular pre-mixing swirler



National Jet Fuels Combustion Program (NJFCP)

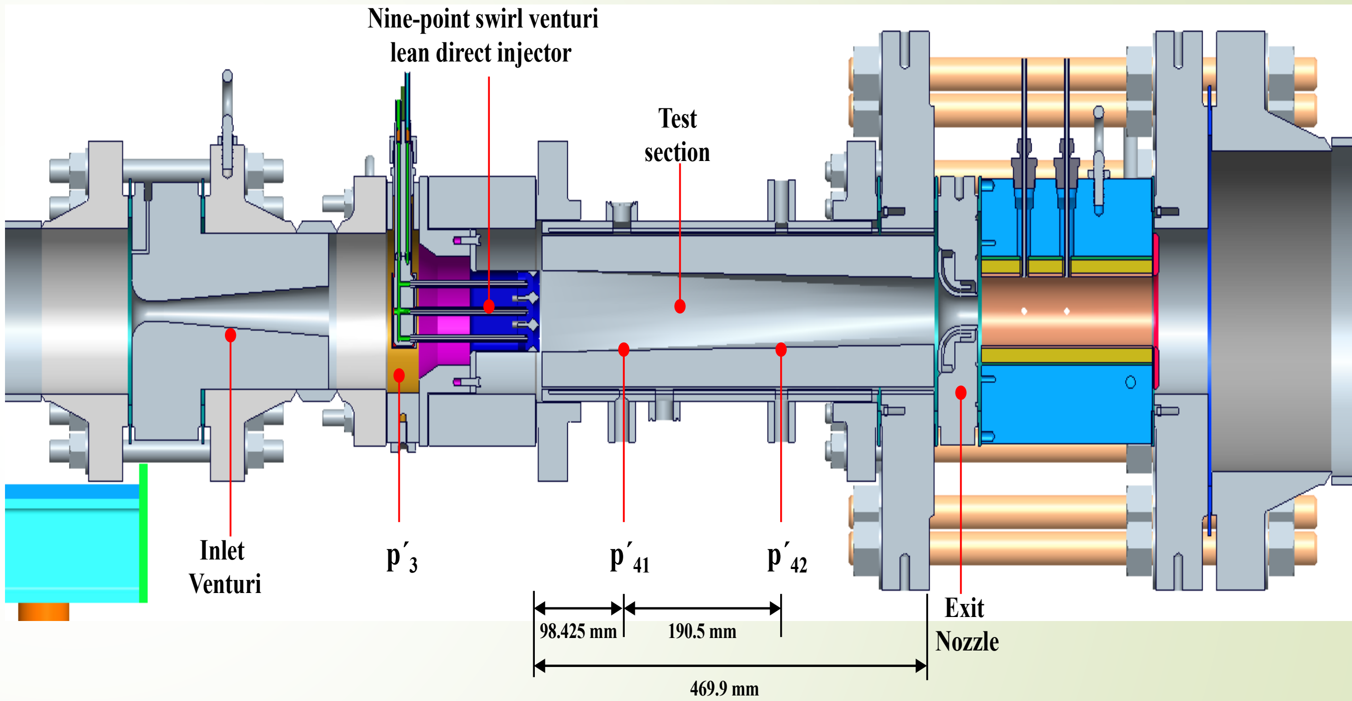
- highly-coordinated, involving several government agencies, universities, industry partners and international collaborations
- focused on the impacts of fuel compositions and physical properties on aviation engine combustor operability
  - lean blowout
  - high altitude ignition
  - cold start
- The fuels under investigation
  - Category A fuels are petroleum base fuels, (JP-8 (A1), JP-A (A2), or JP-5 (A3))
  - Category C fuels are bended fuels, with unconventional properties, composition or distillation curves

OBJECTIVE

- Compare behavior of test fuels C1 and C3 to average Jet A (A2)
- A lean-burn combustor
  - 9-point Lean Direct Injection (LDI)
  - Short fuel-air mixture preparation time
- High pressure and high temperature conditions (T3 = 575 K to 825 K, P3 = 689 to 1723 kPa)
- Gas emissions and combustion dynamics
  - Near Lean blow-out, NO_x emissions, combustion dynamics, ignition.

Experimental Set Up

- NASA Glenn Research Center's CE-5 test facility
- Ceramic liners, rectangular cuboid,
  (7.6 cm X 7.6 cm X 46 cm)
- Inlet air temperature up to 830 K and inlet air pressure up to 2400 kPa or 24 bar.
- Standard gas-analysis procedure, SAE-ARP1256D
- Three dynamic pressure sampling locations

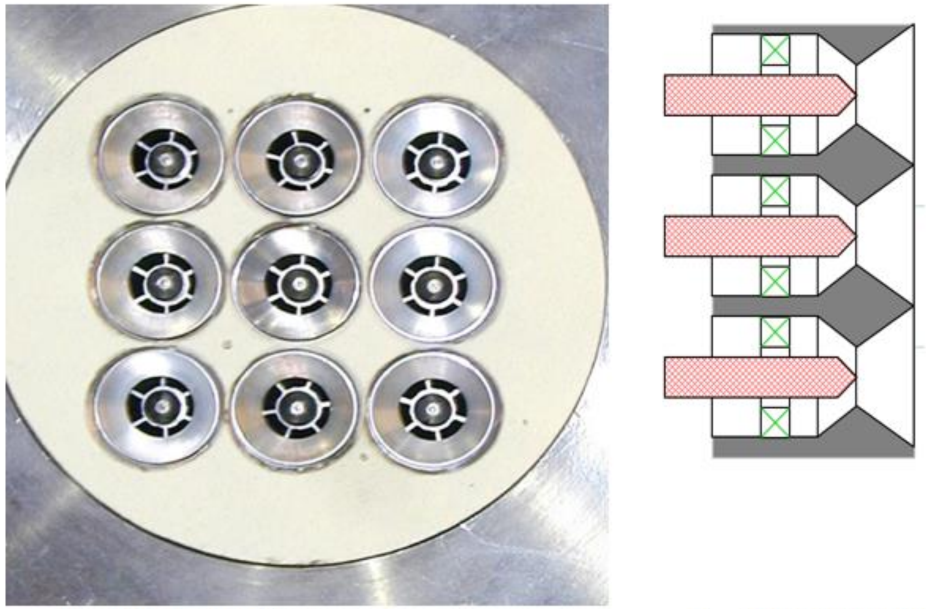


Test Hardware

- Two 9-point Swirl-Venturi Lean Direct Injection (SV-LDI) injector configurations

- A lean burn concept
- Three fuel circuits

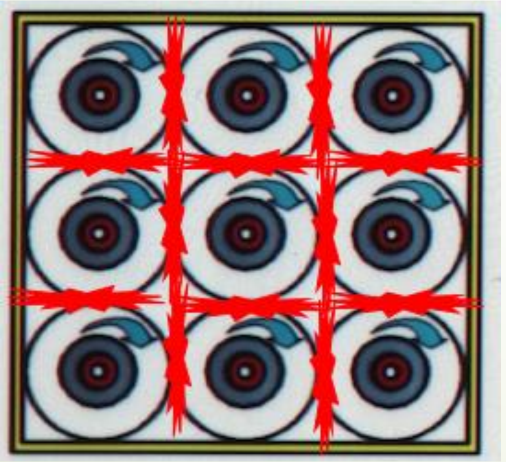
- Local fuel air equivalence ratios were similar among the nine fuel air mixers for most conditions



a) Injector hardware b) Cross-sectional drawing

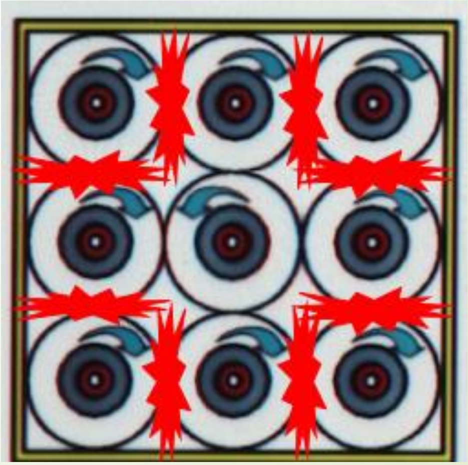
2015 test

- Fuel:
  - random batch of Jet-A, A2, C1,C3.
- Injector configuration:
  - Co-rotating pilot



2016 test

- Fuel:
  - A2 and C1
- Injector configuration,
  - Counter-rotating pilot



Fuels Properties

- A2, (POSF 10325), "average/nominal" Jet-A
- C1, (POSF 11498)
  - high molecular weight duel-component iso-paraffin
  - low cetane number
  - long ignition delay time
  - 80% fuel distillated at a temperature of 35^{o}C lower, faster vaporazation rate.
- C3, (POSF 12341)
  - high viscosity (upper specification limit at -20C)
  - look at the effect of atomization

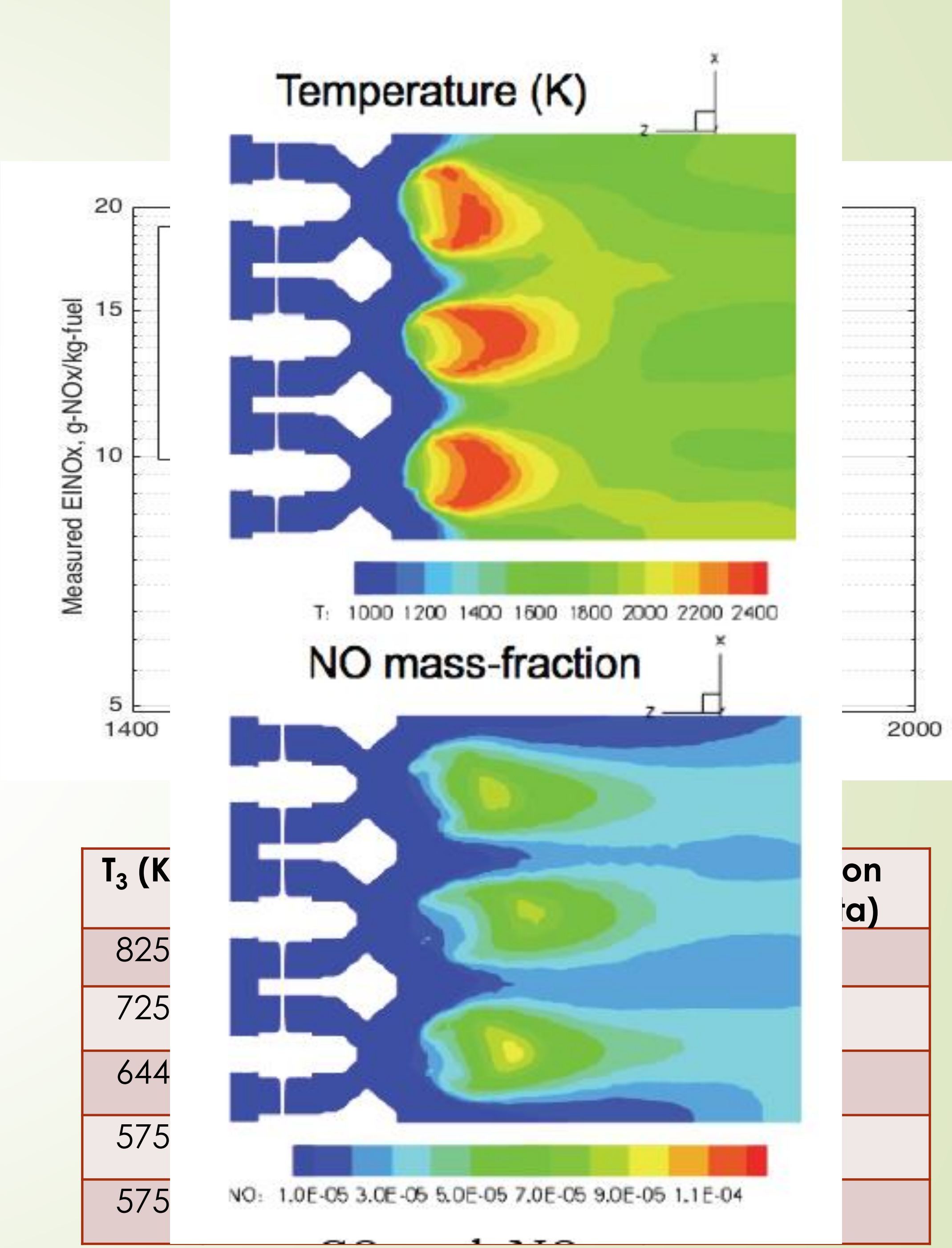
Properties	**A2**	**C1**	**C3**
Overall composition	Petroleum Jet A (w/ average properties)	Gevo ATJ; C12/C16 highly-branched iso-paraffins	64% A-3; 36% Amyris farnesane (C15 iso-paraffin)
Viscosity, -20 C (cSt)	4.5	4.9	8.0
Cetane number	48.3	17.1	47
Distillation (^{o}C), 90%	244	228	245
80%	230	195	243
50%	205	182	230

Results-NO_x emissions

- **A random batch of Jet-A, C3 about the same as A2.**
- **C1 lower NOx emissions**
  - 12% EI lower at T3 of 725 K,
  - 5% EI lower at T3 of 825 K.

- **Possible explanation for Lower NOx with C1**
  - Longer ignition delay time, low cetane number
  - faster vaporization rate.

- **NOx emissions do not appear to correlate with Cetane Number.**
  - Current testing shows similar NOx emissions for C1 (DCN=16) and A2 (DCN=48)
  - Previous HRJ (Cetane Index =69) testing showed similar NOx emissions as Jet-A



Results-ignition

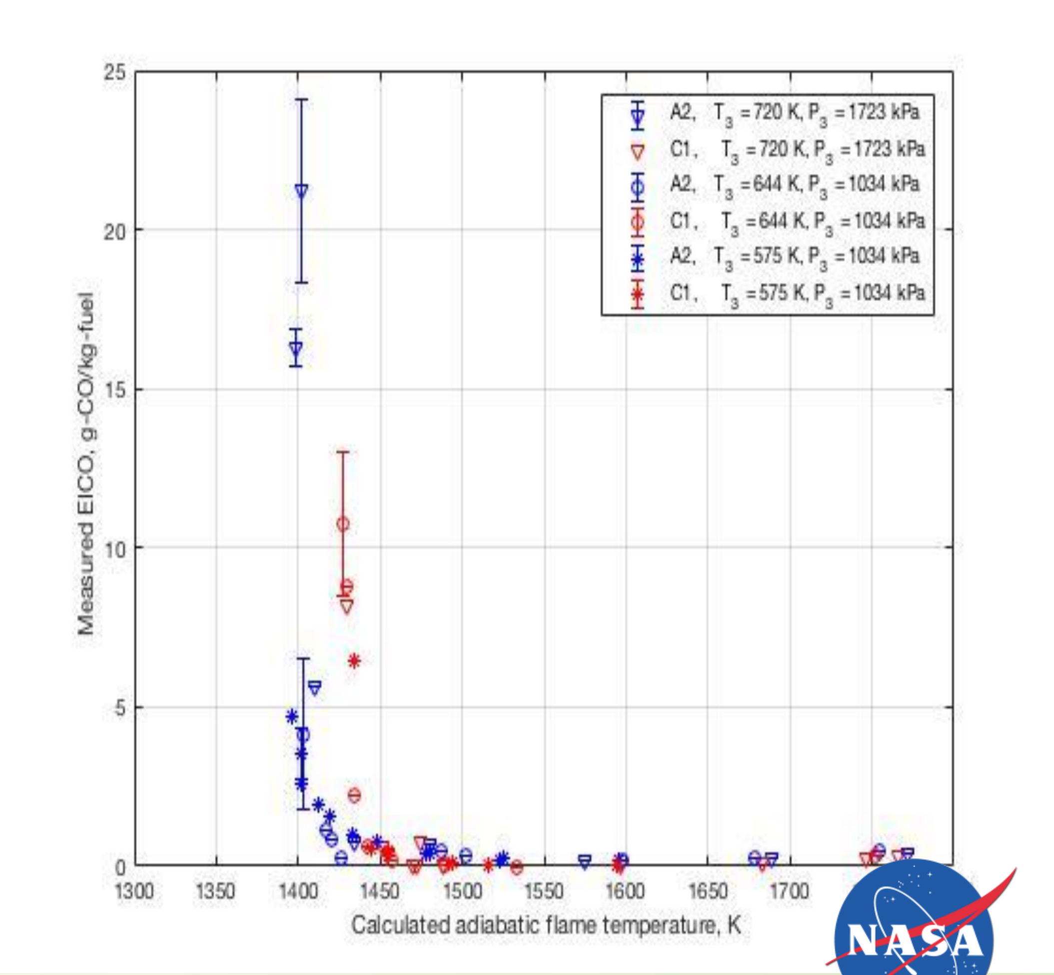
- The C1 fuel was hard to ignite.
- Auto-ignition temperature for A2 is about 700k.
- One successful C1 ignition (P3=1379 kPa, T3=810 K, phi=0.49)
- Also tried fueling the center (pilot) mixer with A2 (instead of C1) at lower T3 and P3 conditions, but no successful ignition.

Fuel used	P_3 (kPa)	T_3 (K)	DP%	Φ (Pilot)	Φ (Main1)	Φ (Main2)	Φ (total)	Successful ignition
C1 only	1723	727	2	0.96	0.37	0.37	0.43	NO
C1 only	1034	727	2	0.96	0.36	0.36	0.42	NO
C1 only	1379	810	3	0.97	0.37	0.37	0.44	NO
C1 only	1379	810	3	0.97	0.43	0.43	0.49	YES
Pilot A2/ Main C1	862	672	2	1.05	0.37	0.37	0.44	NO
Pilot A2/ Main C2	862	672	2	1.67	0.37	0.37	0.51	NO

Results-Near lean blow-out

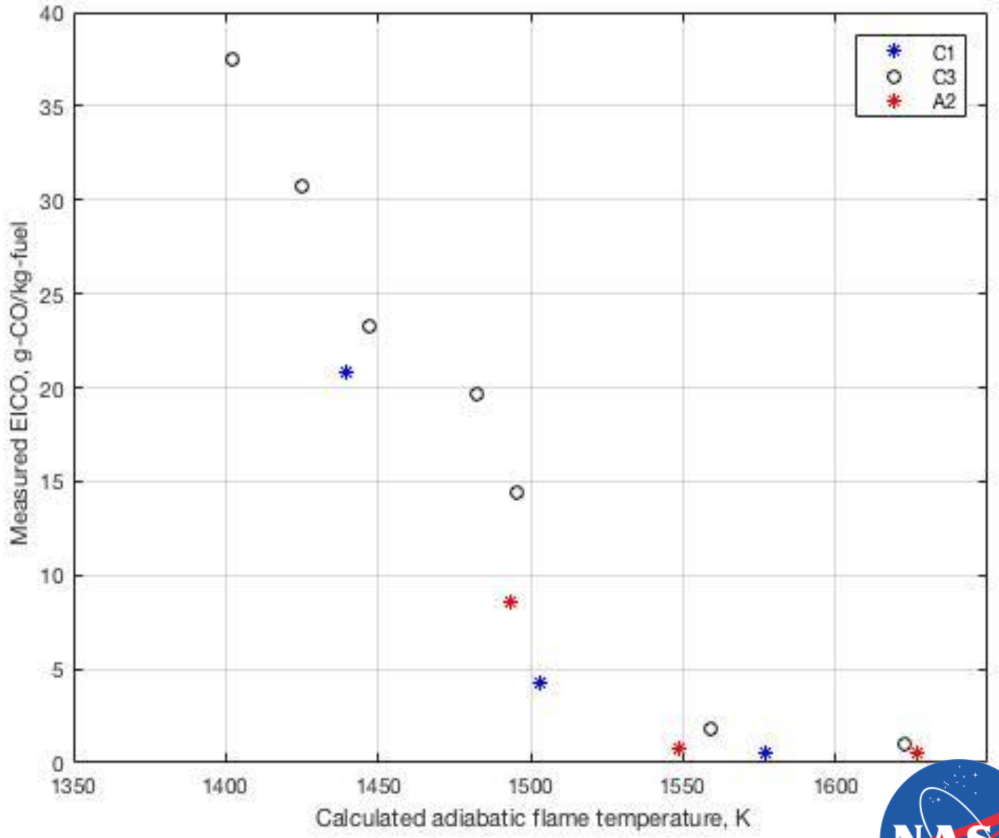
- CO curves for fuel evenly distributed.
- The C1 flame blows out at a calculated adiabatic flame temperature 25 K higher than the A2 fuel.
- Near LBO results are independent of T3, inlet air temperature

2016 test data

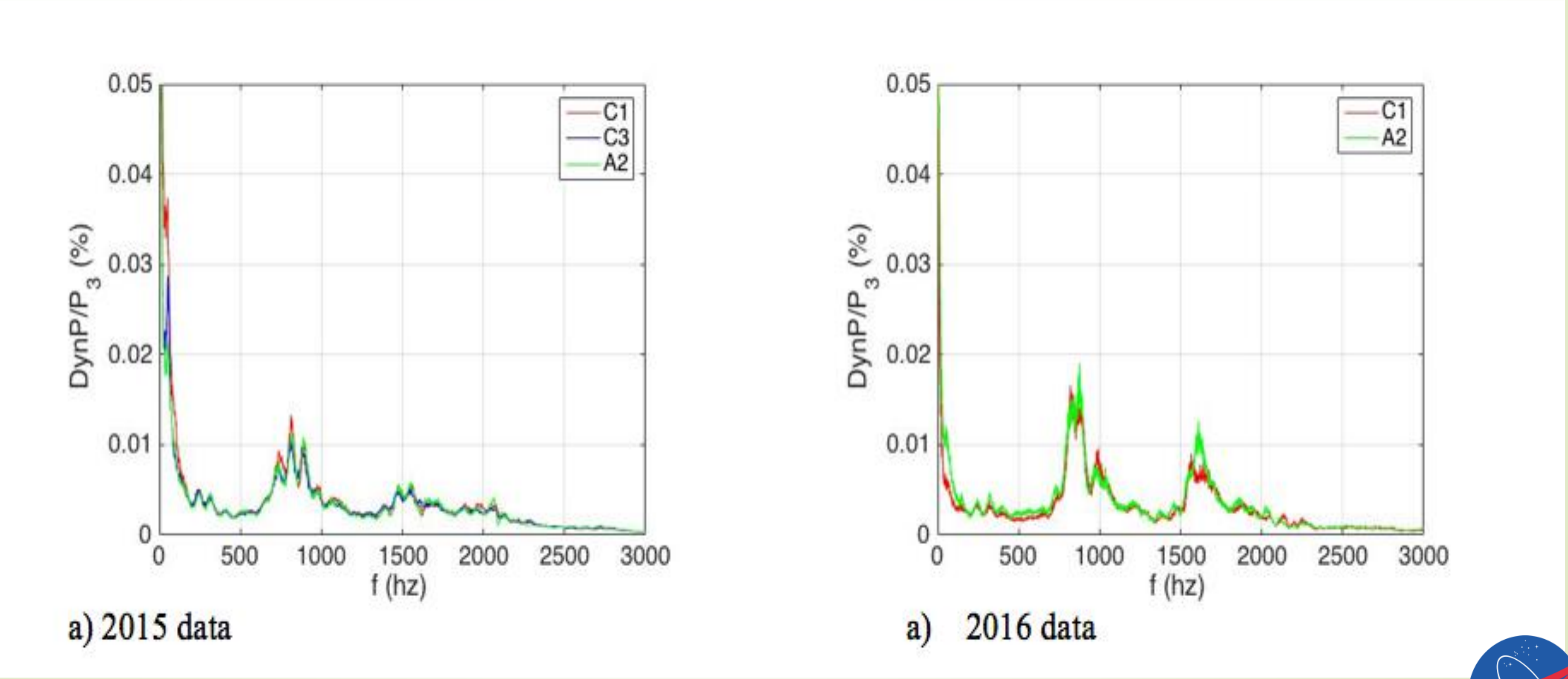


Low power conditions, high PILOT Φ OF 0.68

- CO curves vary with combustor design
- Rich burn or lean burn with relatively higher pilot fuel air ratio tend to stay lite even at lower fuel air ratio and at high CO emissions conditions
- C3 has higher CO emissions than C1 and A2 at similar adiabatic flame temperature.
  - high viscosity property of C3
  - the fuel injector may produce larger fuel drop sizes relative to A2 and C1



Combustion Dynamics



Conclusion

- **Two tests series were completed**
  - Used a 9-point LDI combustor
  - Measured gaseous emissions and combustion dynamics
- **C1**
  - long ignition delay time. faster vaporization rate than A2
  - promotes better fuel air mixing and lower NO_x emissions
  - C1 blows out at a flame temperature 25 K higher than A2
- **C3**
  - high in viscosity. larger size fuel droplets and slower vaporization rate
  - no NO_x emissions differences observed
  - At low power, higher CO emissions observed
- **No combustion dynamics difference observed between the three fuels.**

Acknowledgments

- This work supports the objectives and goals of NASA's Advanced Air Transportation Technology Project funded by the Aeronautics Research Mission Directorate.

Questions and Comments