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Fundamental Combustion Properties of a Fischer-Tropsch Jet Fuel

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Prepared for
Multi Agency Coordination Committee for Combustion Research – Summit on Fuels

September 9, 2008

Outline of Presentation

- Motivation
- Objectives
- Autoignition of S-8 under High Pressure Conditions
- Laminar Flame Speeds of Preheated S-8/Air Mixtures
- Conclusions

Motivation (1)

- Environmental concerns and energy security have led to the development of new aviation fuels based on the Fischer-Tropsch process.
- One such fuel made from natural gas is designated as S-8, intended as a synthetic JP-8.
- S-8 is a hydrocarbon mixture rich in C_7 to C_{18} linear and branched alkanes.
- In collaboration with NASA GRC for physics-based model development.

Motivation (2)

- NASA goals in *Subsonic Fixed Wings*:
  - Develop necessary technologies to enable low emissions combustion systems to be developed for subsonic engine applications.
  - Develop fundamental technologies to assess the feasibility of alternative fuels in subsonic aircraft applications.
  - Develop and validate physics-based models to enable quantitative emissions and performance predictions using combustion modeling.

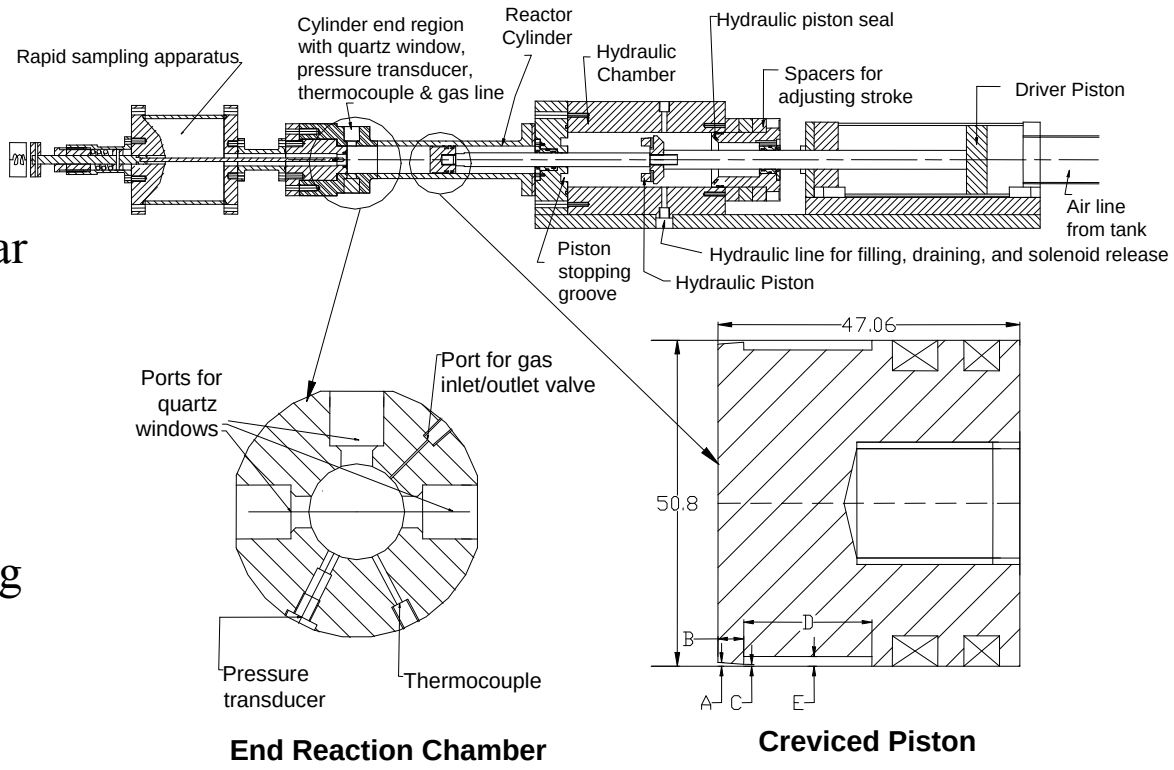
Objectives

- Acquire detailed fundamental database relevant to alternative jet fuel combustion over a wide range of conditions.
  - Obtain extensive experimental data for *autoignition delays* at elevated pressures.
  - Determine extensive experimental data for fundamental flame properties, including *laminar flame speeds*.
- Compare fundamental combustion data of Jet-A, JP-8, and S-8.

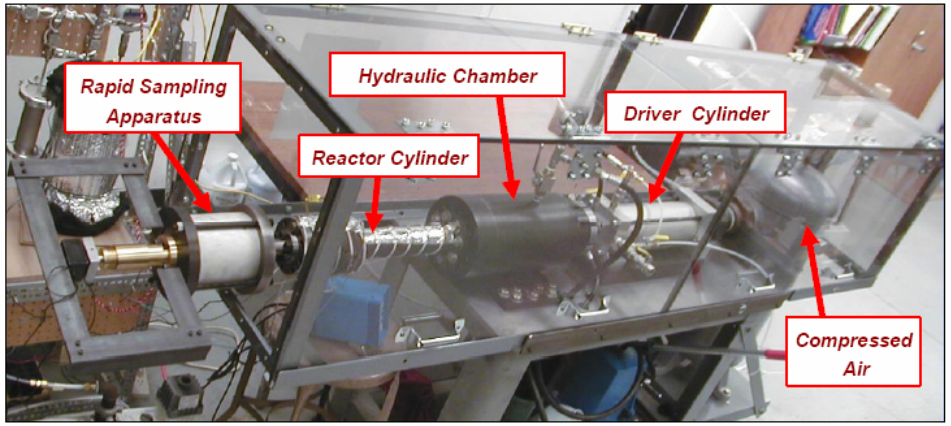
Autoignition of S-8 under High Pressure Conditions

Rapid Compression Machine

- Adjustable stroke and clearance
- Fast compression (< 30 ms)
- Compressed pressure up to 60 bar
- Temperature – 650 to 1100 K
- Elevated pressure condition is sustained up to 100 ms
- Optimized creviced piston for ensuring homogeneity of reacting mixture
- Optically accessible
- GC/MS and a fast sampling apparatus for species measurement
- Direct measurement of ignition delay
- Study of low-to-Intermediate temperature chemistry



End Reaction Chamber **Creviced Piston**



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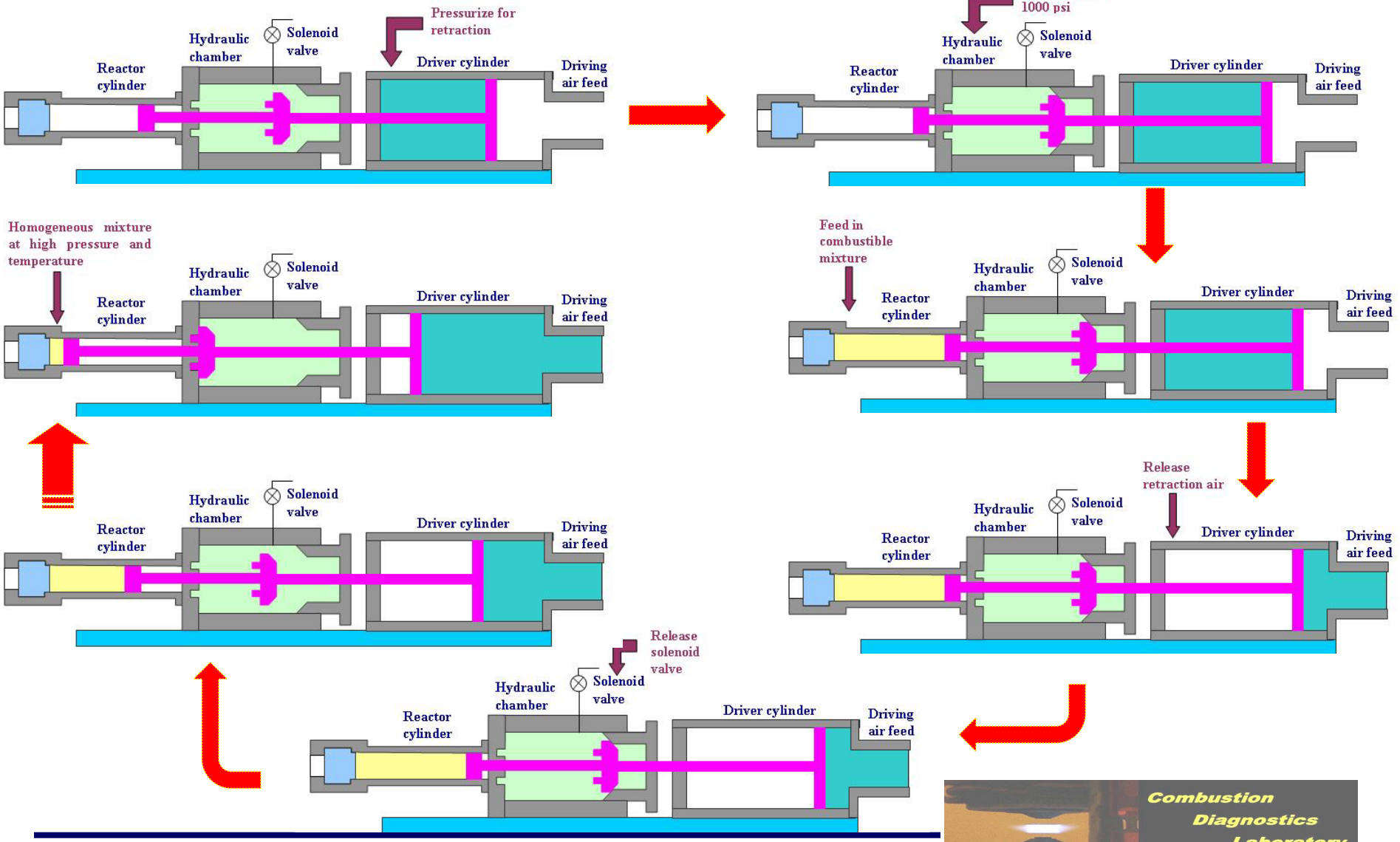
RCM Operation



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Test Matrix

Mass Proportion								
S-8	**O_2**	**N_2**	**Ar**	**O/F**	**ϕ (est.)**	**7 bar**	**15 bar**	**30 bar**
5.00	33.21	61.79	0.00	19.00	0.51		data available	
7.14	32.46	60.40	0.00	13.00	0.75			
5.00	22.14	72.86	0.00	19.00	0.77	to be presented		
7.14	21.64	71.22	0.00	13.00	1.12			
5.00	11.07	83.93	0.00	19.00	1.53		data available	
7.14	10.82	82.03	0.00	13.00	2.24			
1.16	9.50	31.25	58.09	84.85	0.42	data available		

S-8, designated POSF4734, was supplied by Tim Edwards.

S-8 Surrogate

Component	*Name*	*Composition, Mole Fraction*
1	methylcyclohexane	0.0293
2	2,5-dimethyl heptane	0.0562
3	n-undecane	0.1438
4	2,9-dimethyldecane	0.1161
5	2,3-dimethyl undecane	0.0767
6	n-dodecane	0.0386
7	3-methyl undecane	0.1531
8	n-tridecane	0.1368
9	2,7,10-trimethyldodecane	0.1050
10	n-tetradecane	0.1444

T.J. Bruno, The Properties of S-8, MIPR-F4FBEY6237G001 Contract Report, 2006.

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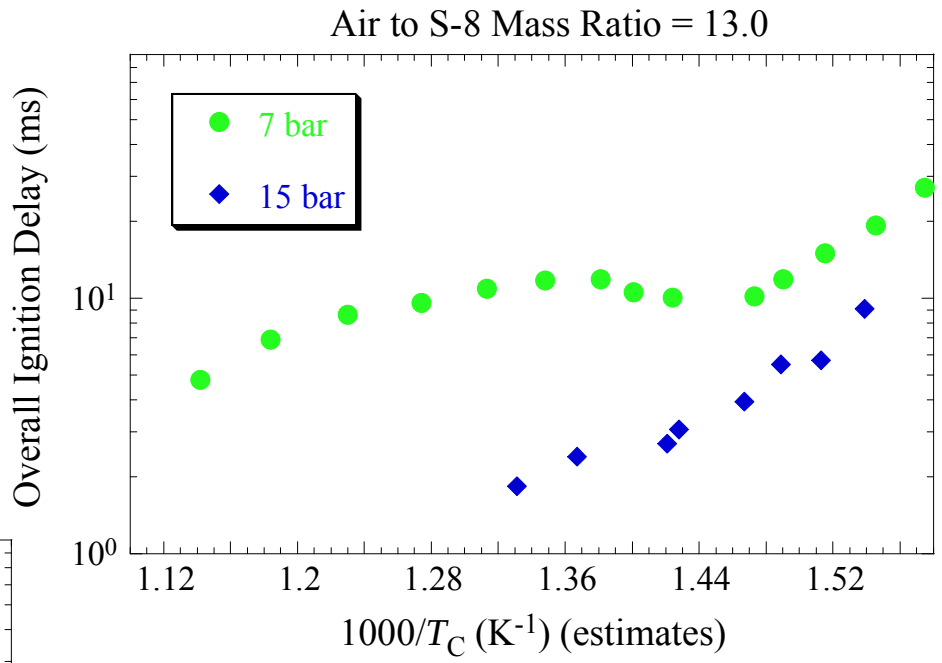
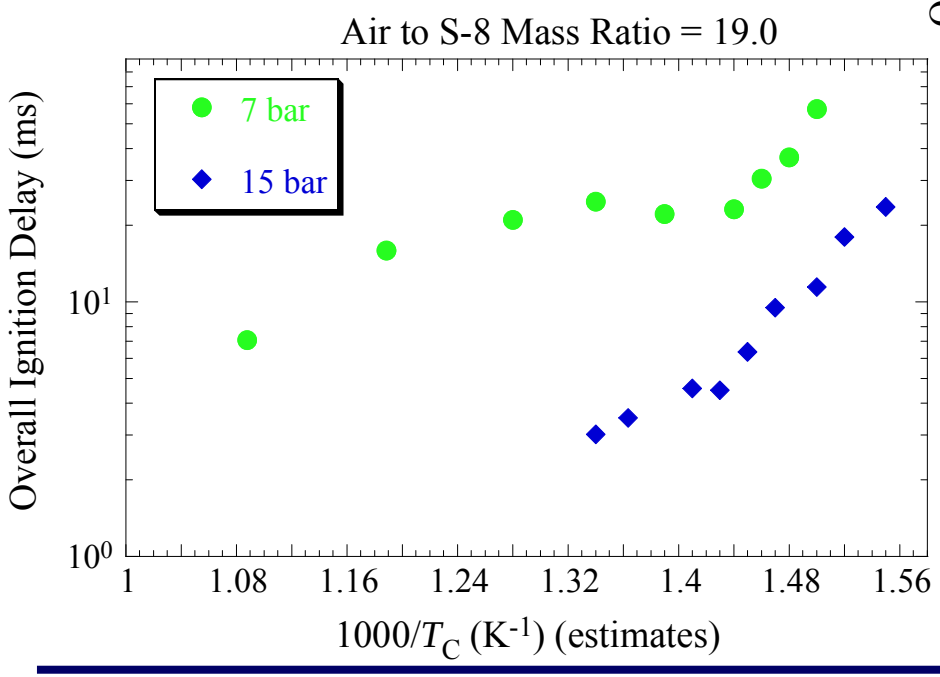
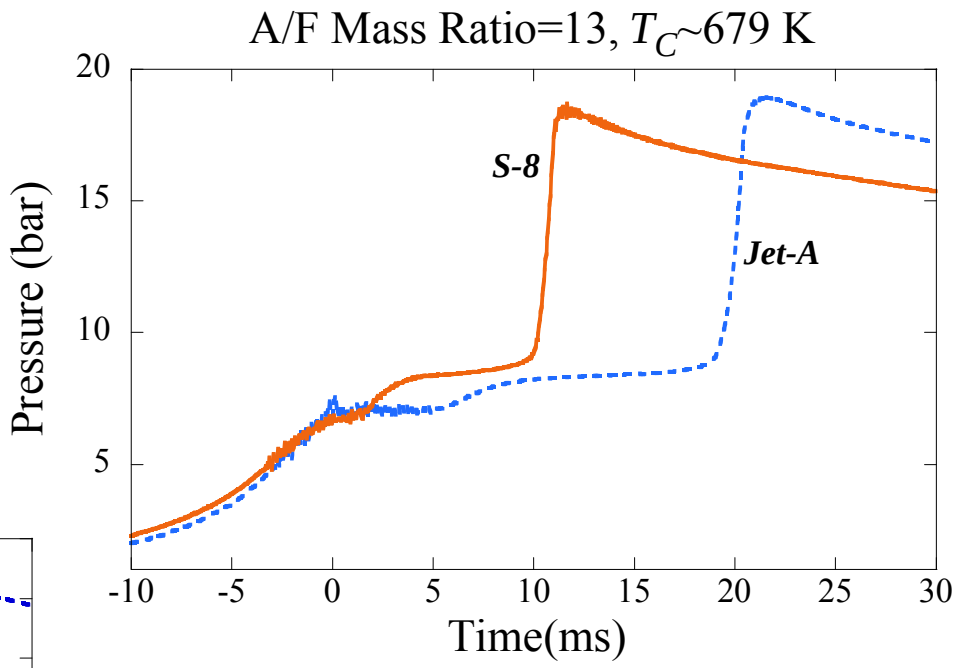
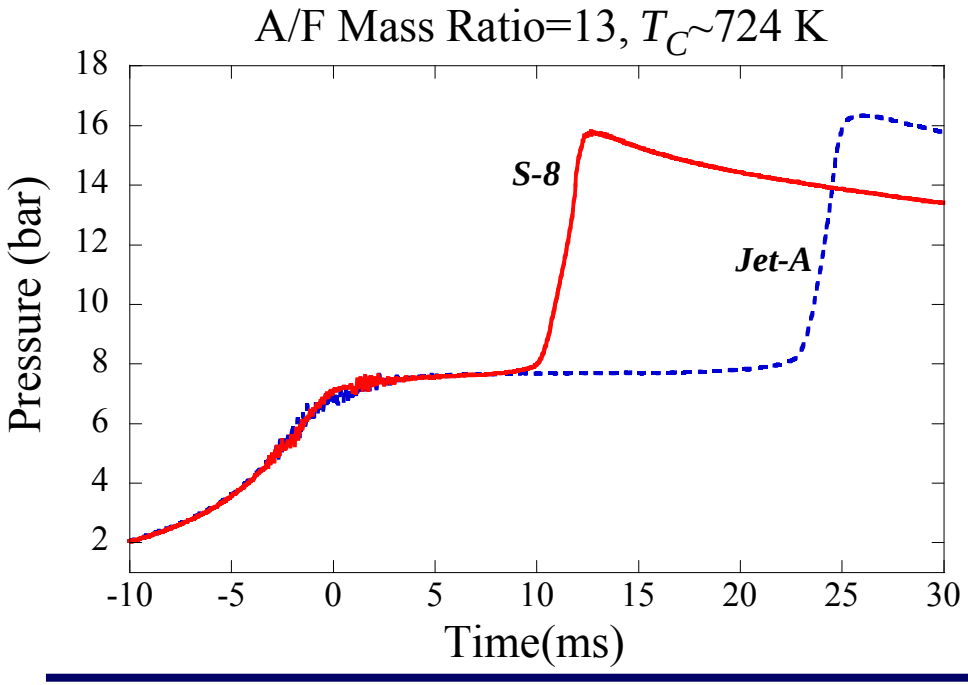
Effect of Pressure





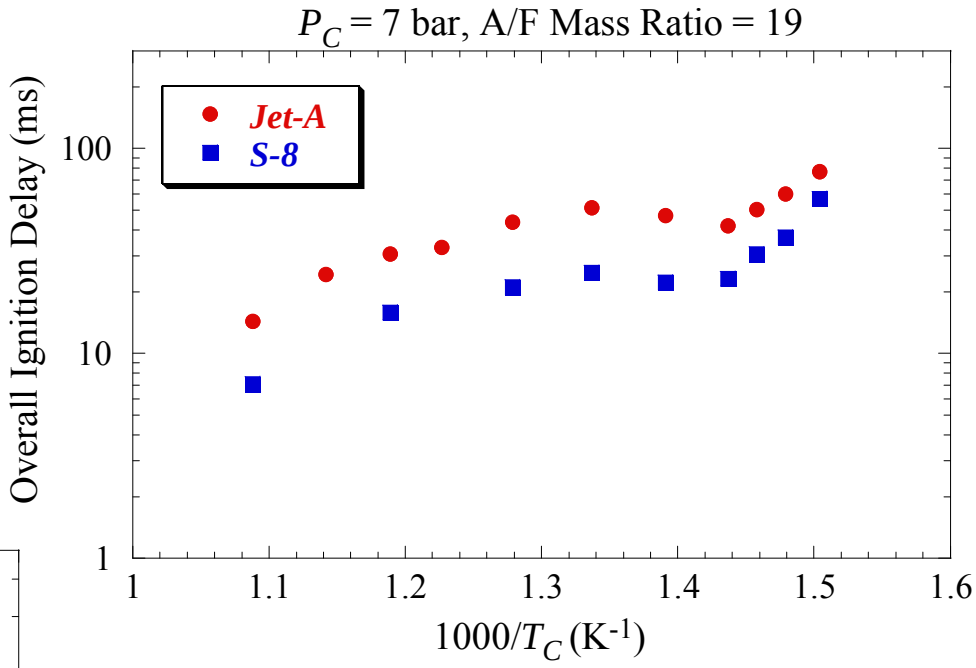
S-8 versus Jet-A (1)

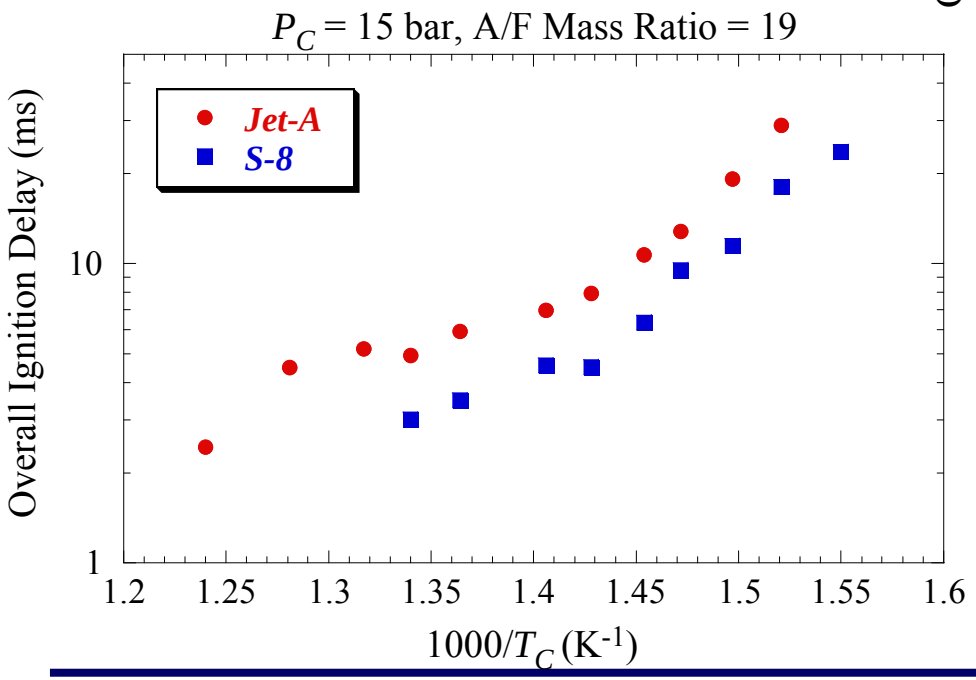




- Identical initial conditions and CR for S-8 and Jet-A.
- T_C calculated for Jet-A.

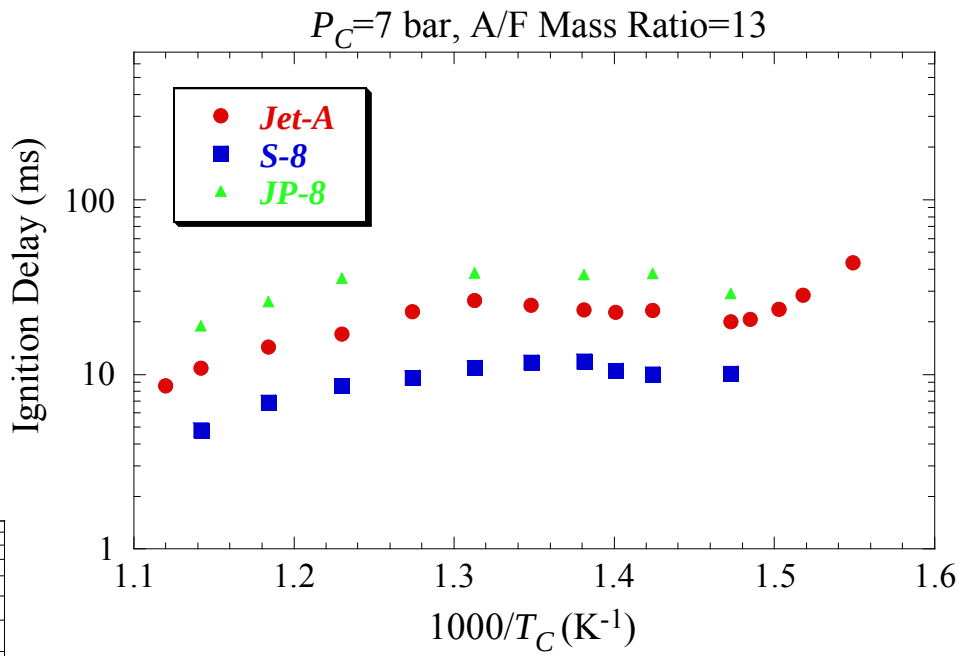
S-8 versus Jet-A (2)

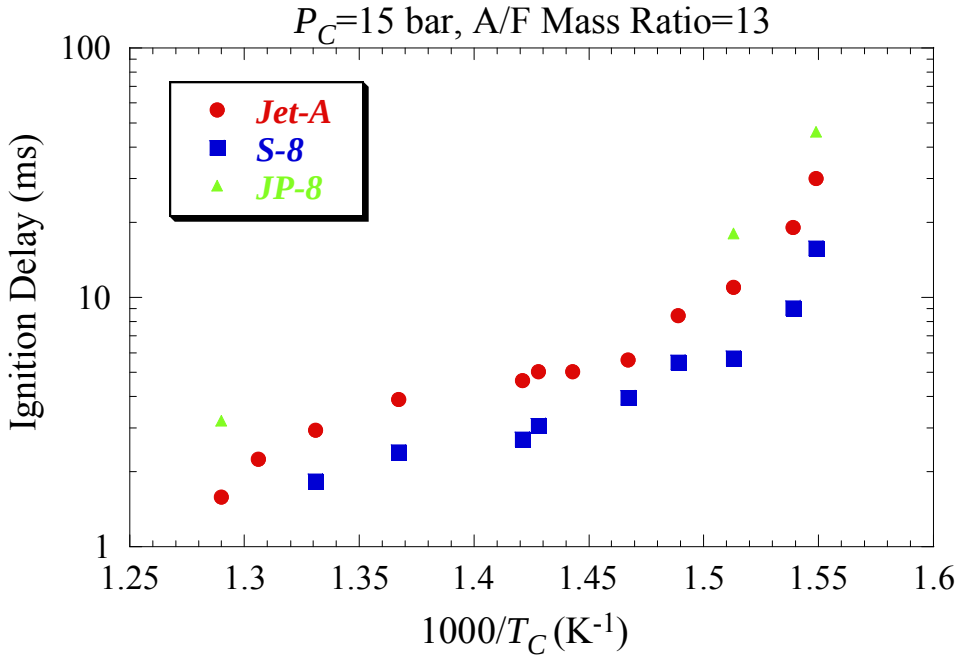




- Identical initial conditions and CR for S-8 and Jet-A.
- T_C calculated for Jet-A.

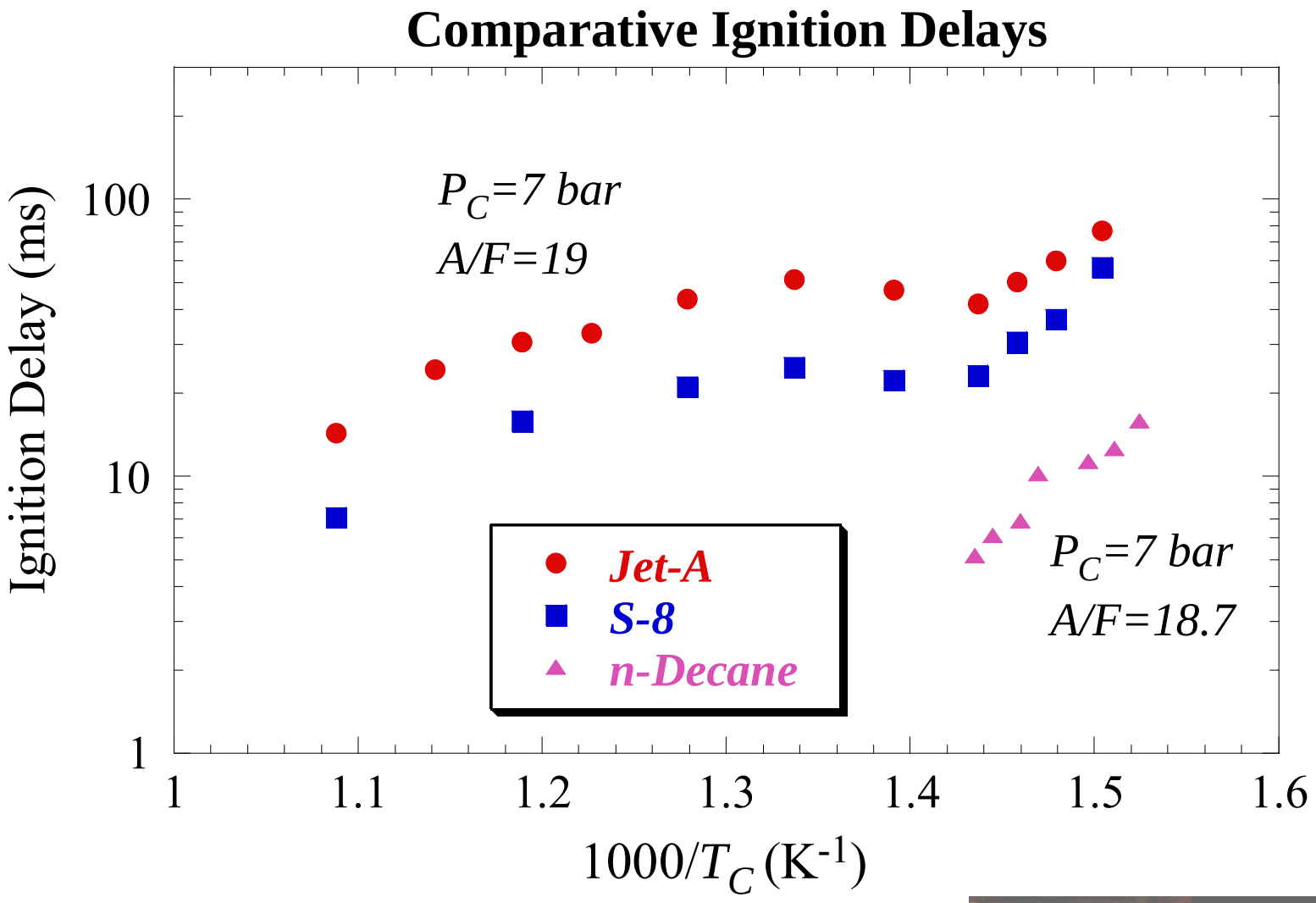
Jet Fuels Comparison





- Identical initial conditions and CR.
- T_C calculated for Jet-A.

Autoignition Comparison



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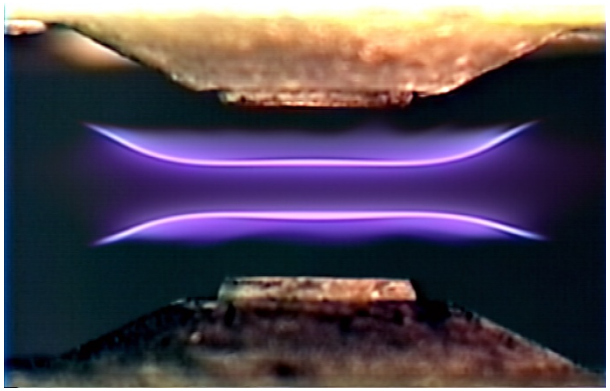
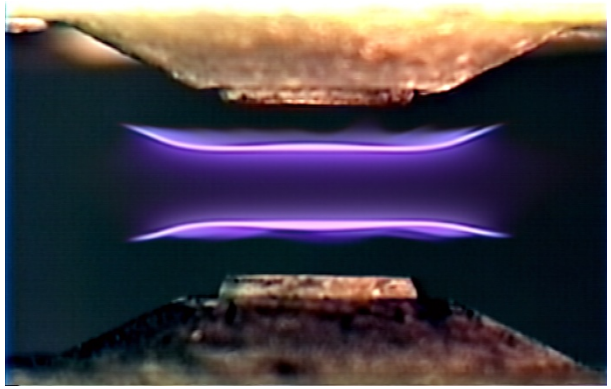
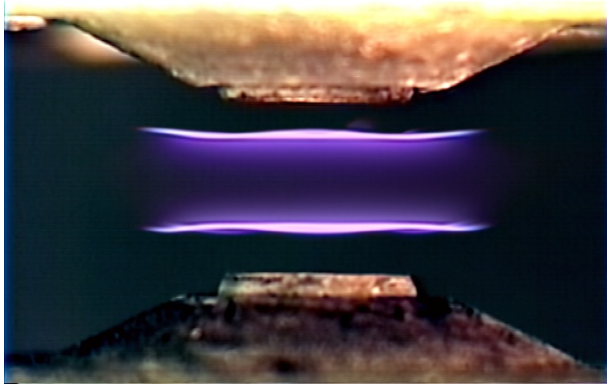
Laminar Flame Speeds of Preheated S-8/Air Mixtures

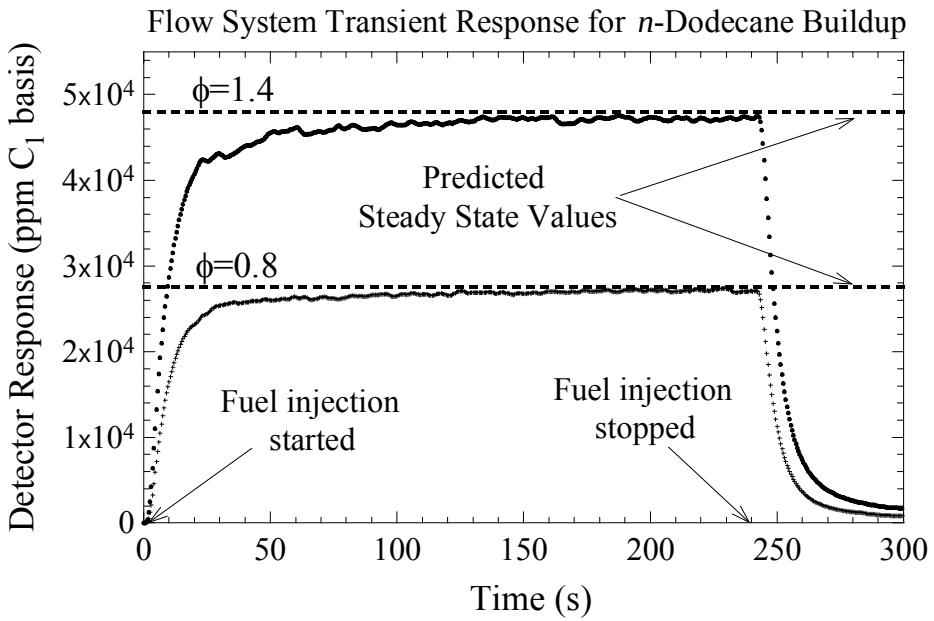
Counterflow Twin Flames

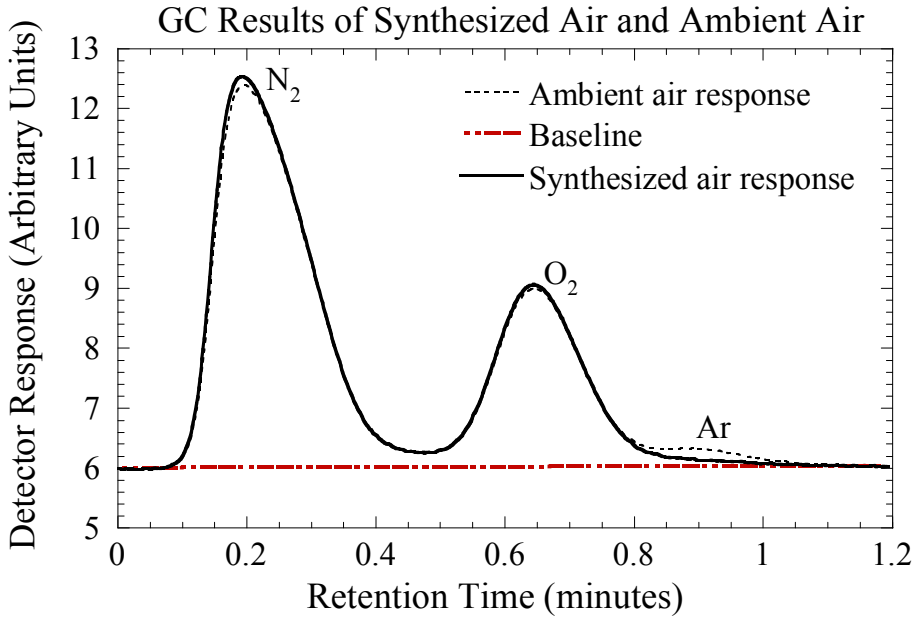




Decreasing Stretch Rate ⇒ *laminar flame speed*

extinction stretch rate ⇐ Increasing Stretch Rate

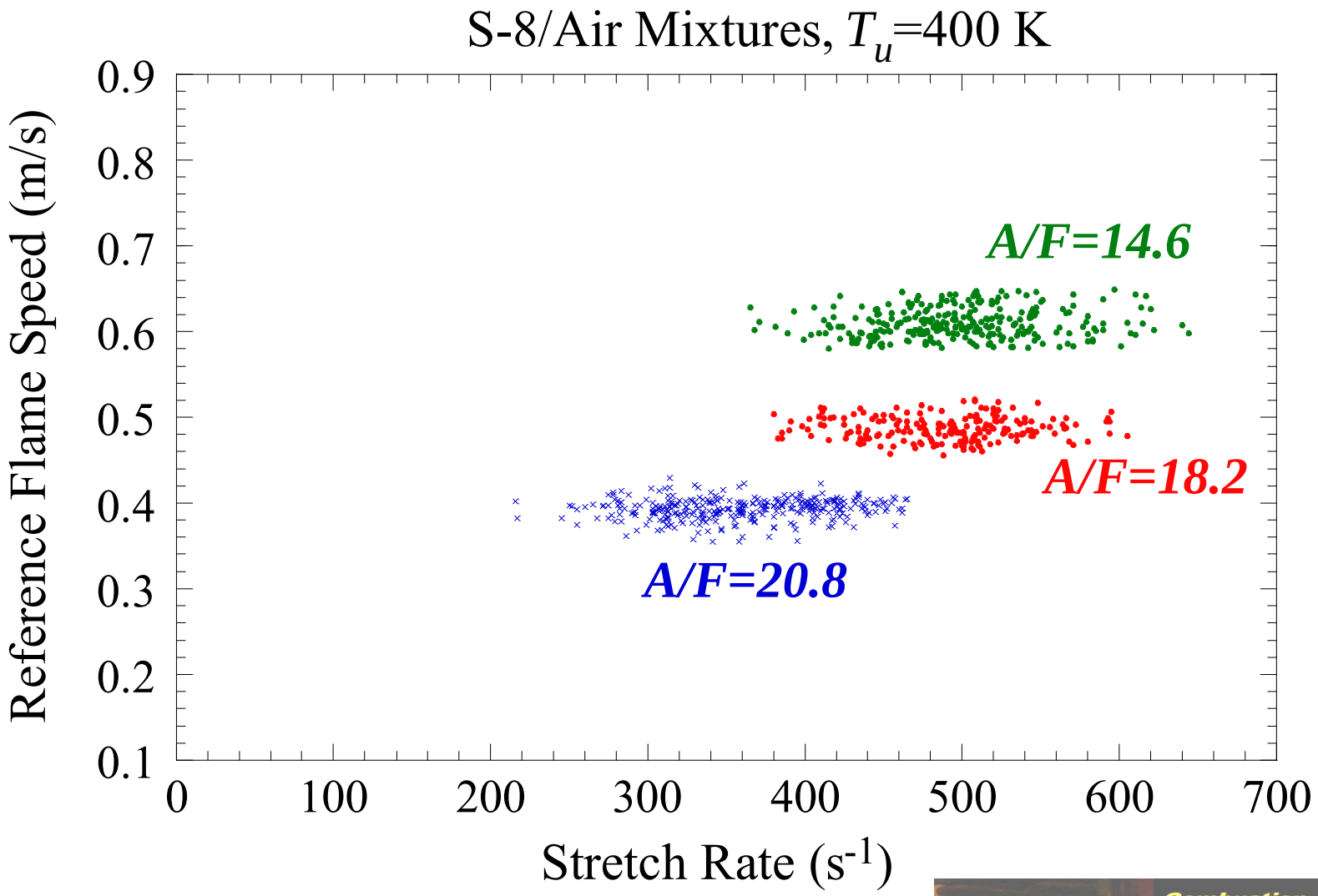
Mixture Composition Check



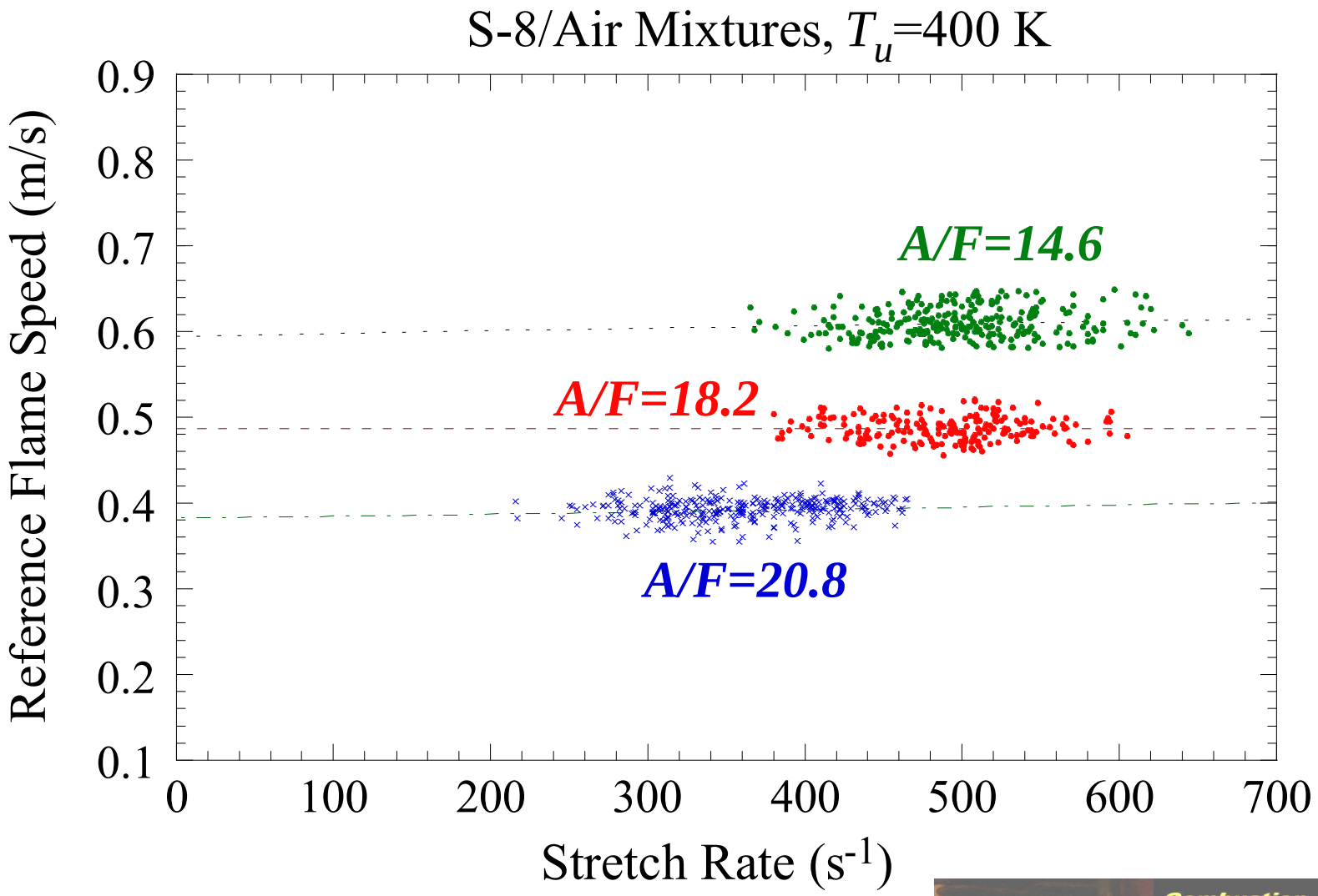


- Mean HFID response after a three-minute duration is 98.7% and 98.2 % of the expected steady state values for equivalence ratios of 0.8 and 1.4, respectively.
- Synthesized air composition is in the desired molar proportion of N_2:O_2 = 3.76:1.

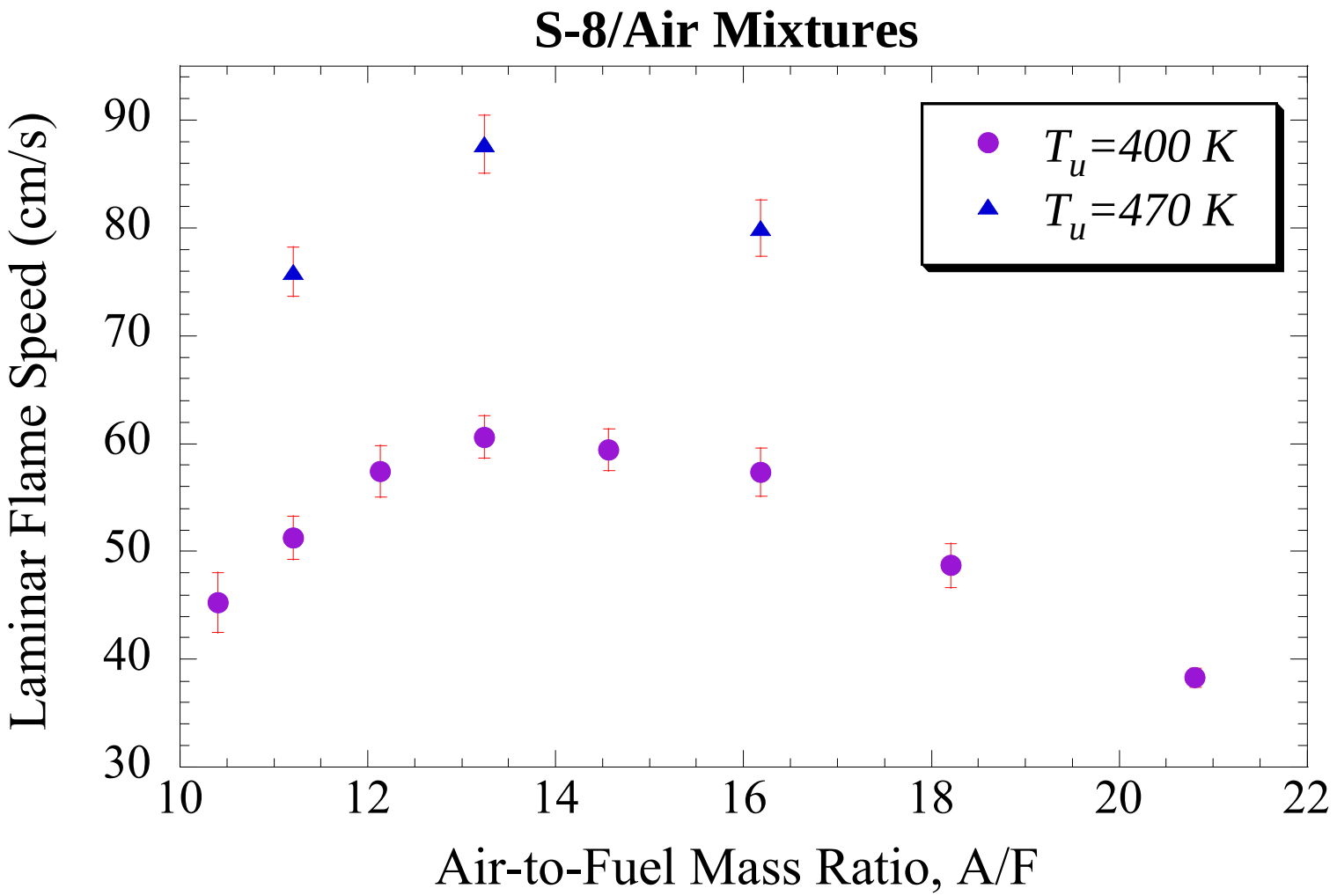
"Raw" Data


S-8/Air Mixtures, T_u=400 K
Reference Flame Speed (m/s)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100
200
300
400
500
600
700
Stretch Rate (s^{-1})
A/F=14.6
A/F=18.2
A/F=20.8

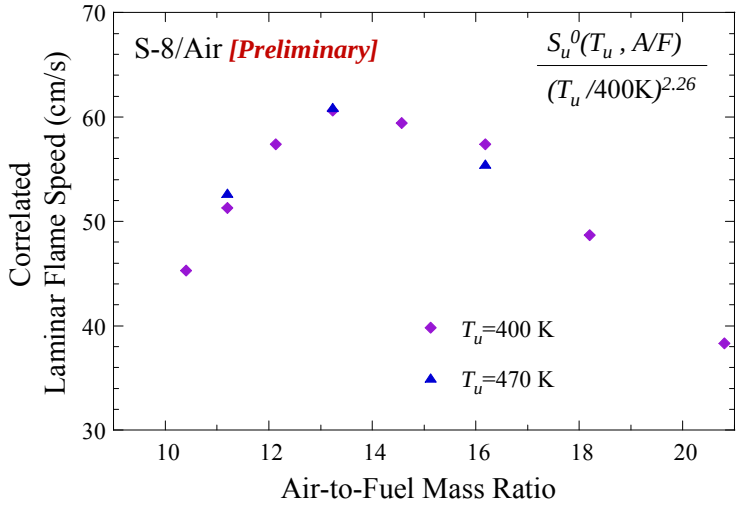
Linear Extrapolation

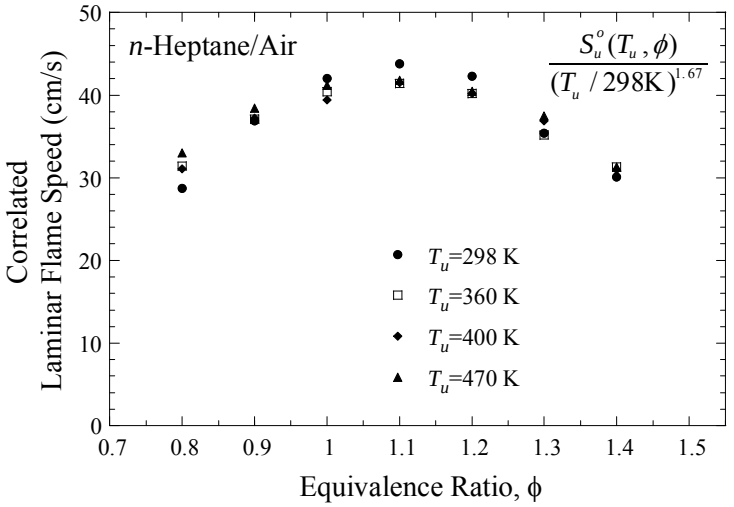


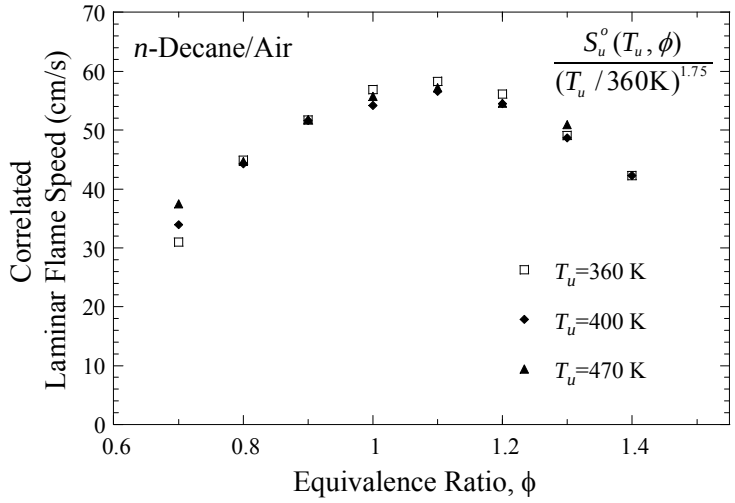
Laminar Flame Speeds of S-8

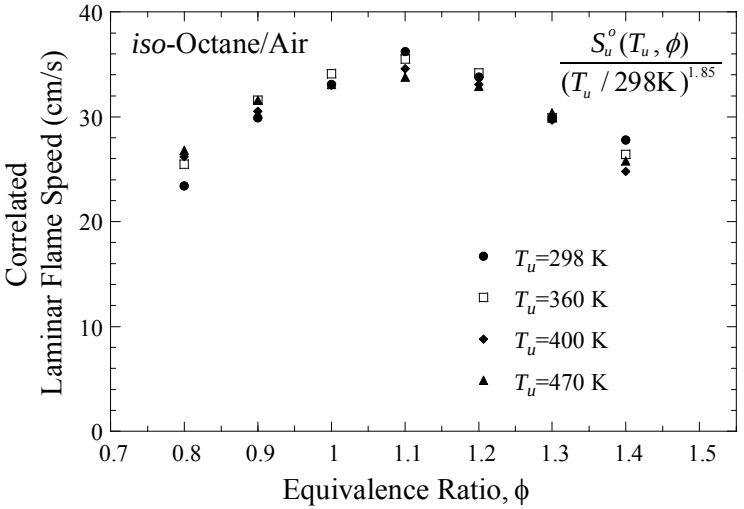


Laminar Flame Speeds of Preheated Fuel/Air Mixtures









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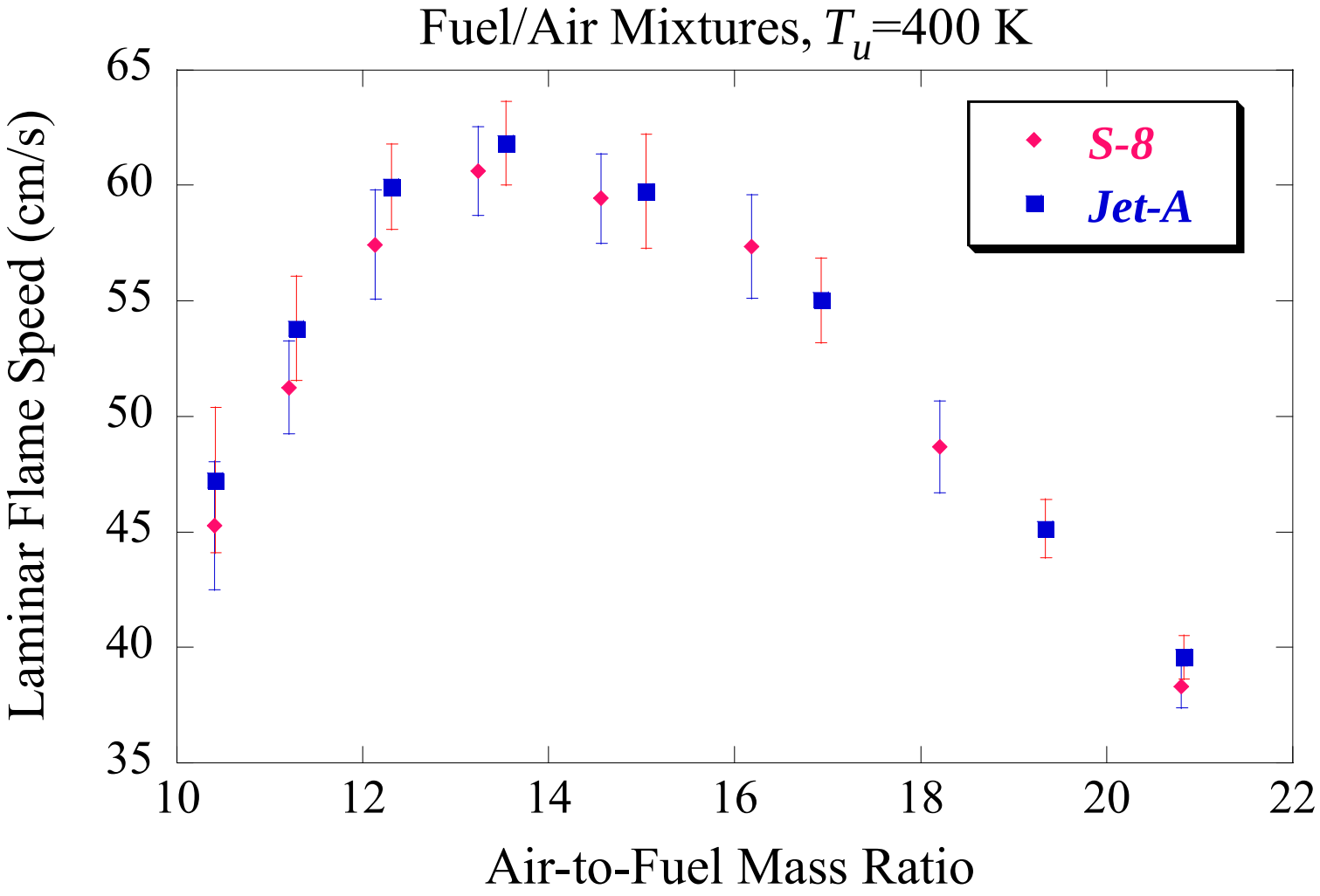
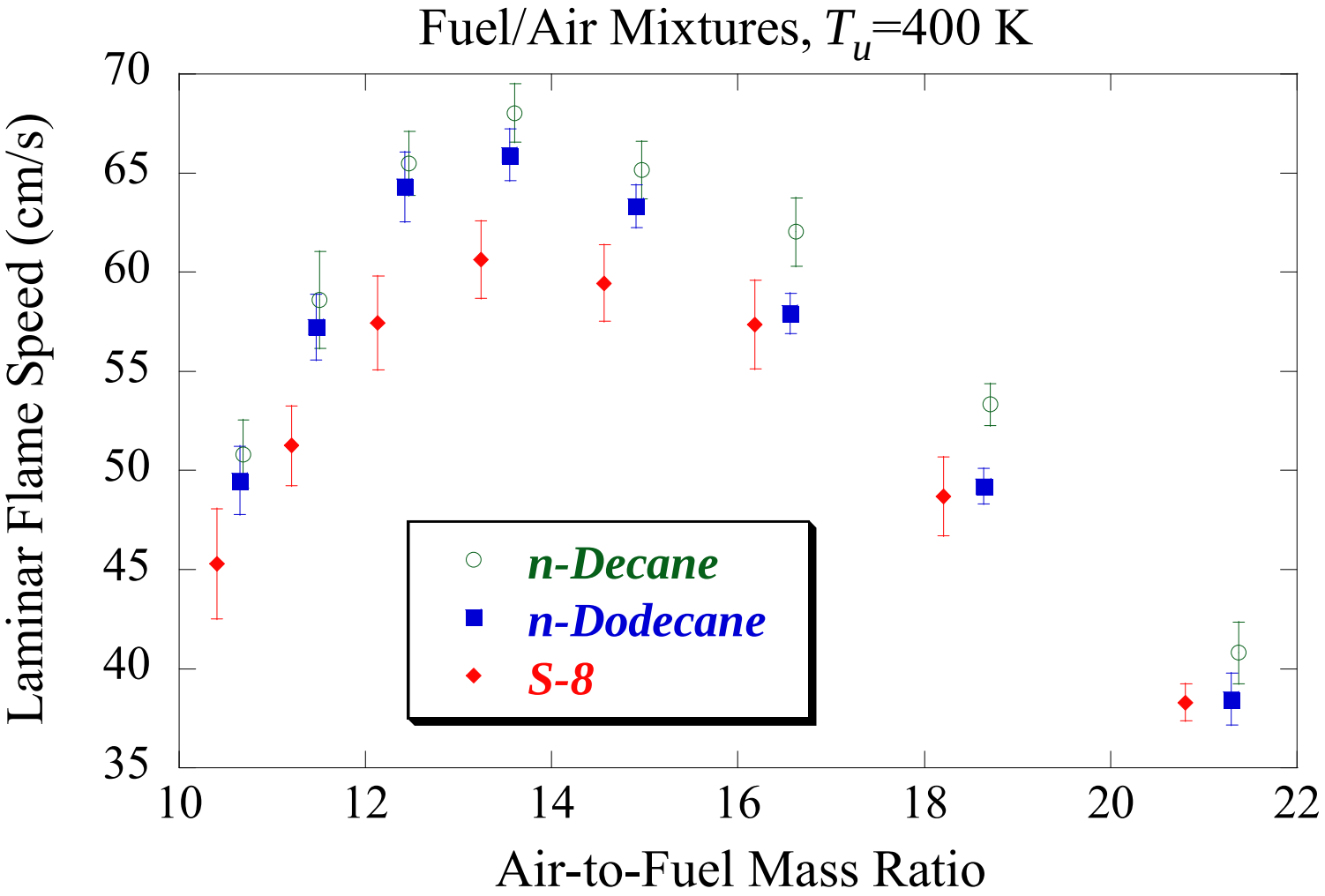
Laminar Flame Speeds of Jet Fuels



Laminar Flame Speed Comparison



Conclusions

- Under identical initial conditions and compression ratio:
  - S-8 exhibits shorter first-stage ignition delay, higher first-stage pressure rise, and shorter second-stage ignition delay than Jet-A.
  - Overall pressure rises are similar for conventional and alternative jet fuels.
  - Ignition propensity is consistent with Cetane number.
- Dependence of laminar flame speed on mixture preheat temperature (T_u) in the form of $(T_u/T_0)^n$, with $n \approx 2$ for the conditions investigated.
- Coordinate with AFOSR-MURI and DOD/DOE/EPA-SERDP teams for specific surrogate composition.