Fuel Tank Flammability

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The 4th Triennial Int'l Aircraft Fire and Cabin Safety Research Conference
Lisbon, Portugal
November 15 – 18, 2004

Background/Agenda

- In addition to LOC testing and in-flight flammability measurements, the FAA has several fuel tank flammability tests ongoing
- We will discuss
  - Effects of fresh fuel leakage into a nearly empty, heated tank
  - Theoretical flammability limits as a function of MIE, flashpoint and O_2 Content
  - Combustion sphere testing

Flammability Effects of Fresh Fuel Leakage Into a Nearly Empty, Heated Tank

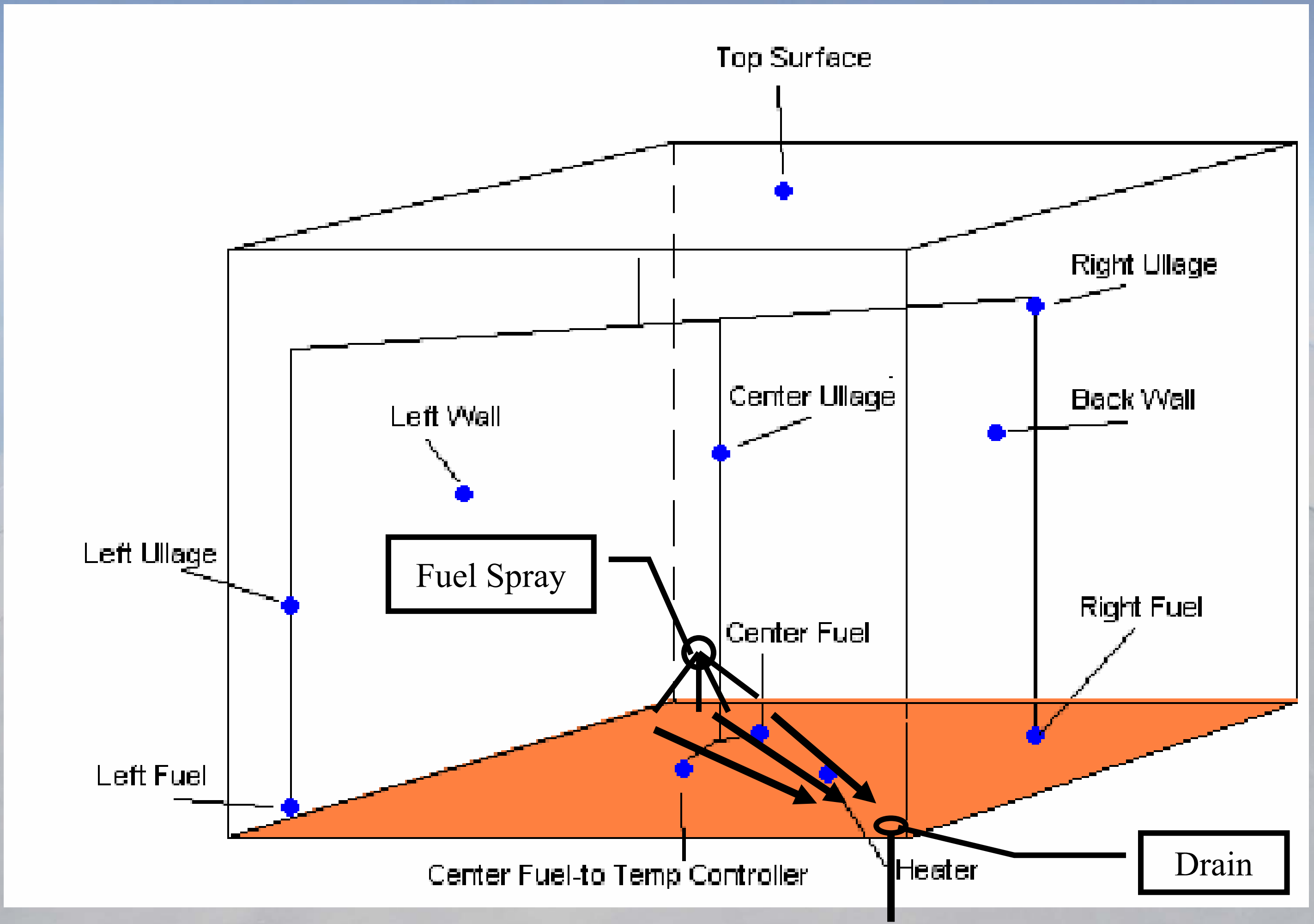
Objectives

- Previous tests have shown that in order to see a significant decrease in flammability, the mass loading of the tank must be driven down to 0.25 kg/m^3 or less.
- If it were feasible to do this though, would fuel leaking in from other tanks be counterproductive to the flammability reduction.

Apparatus

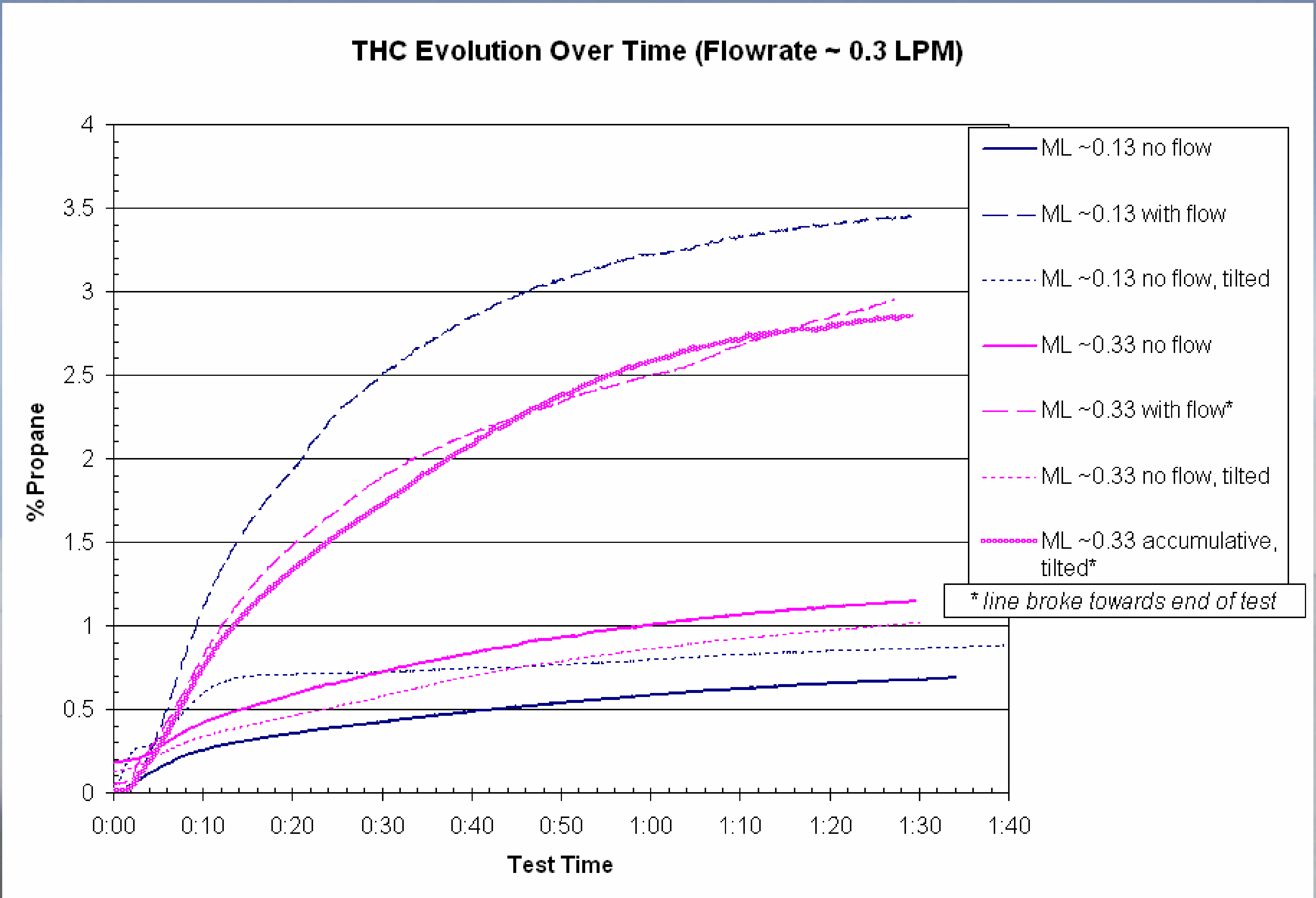
- Utilizing same tank as was used in the fuel condensation modeling work.
- Peristaltic pump used to pump fresh fuel into tank such that it sprays in at far side and traverses the entire bottom of the tank.
- Fuel inside of tank is continuously drained at approximately the same rate that fresh fuel is entering (~0.3 LPM).
- Bottom heater temperature is maintained at 180ºF for approximately 1.5 hours.

Apparatus



Top Surface
Right Ullage
Center Ullage
Back Wall
Left Wall
Left Ullage
Fuel Spray
Center Fuel
Right Fuel
Left Fuel
Drain
Center Fuel-to Temp Controller
Heater

Results


THC Evolution Over Time (Flowrate ~ 0.3 LPM)
% Propane
Test Time
0
0.5
1
1.5
2
2.5
3
3.5
4
0:00
0:10
0:20
0:30
0:40
0:50
1:00
1:10
1:20
1:30
1:40
ML ~0.13 no flow
ML ~0.13 with flow
ML ~0.13 no flow, tilted
ML ~0.33 no flow
ML ~0.33 with flow*
ML ~0.33 no flow, tilted
ML ~0.33 accumulative, tilted*
* line broke towards end of test

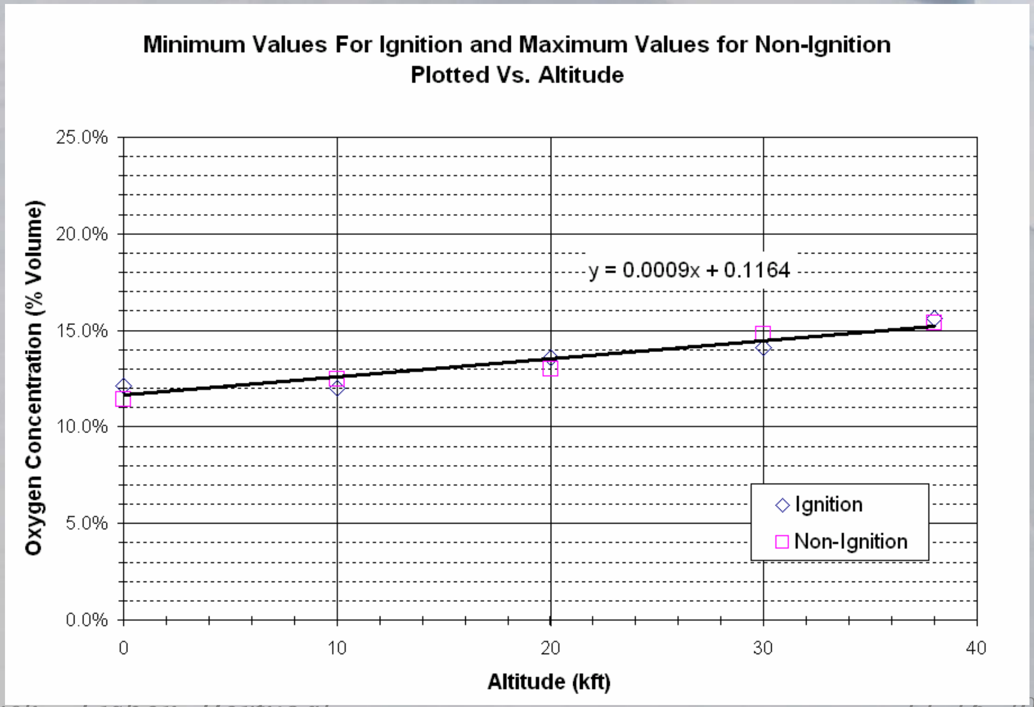
Conclusion

- Flow of fresh fuel across the heated bottom surface of a tank negate the effects of a low fuel load by increasing THC (flammability) by a factor of 2.5 - 4.

Theoretical Flammability Limits as a Function of MIE, FP & O_2 Content

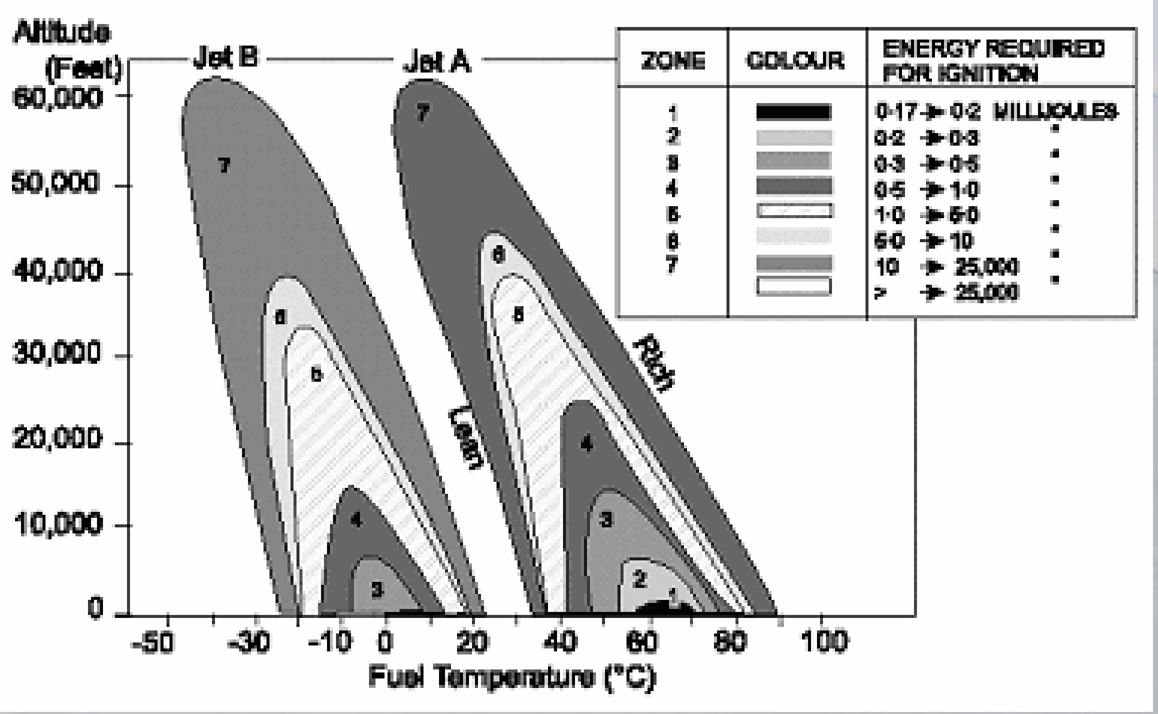
Background

- Present thinking in fuel tank inerting is that above x% O_2, the tank is at risk throughout the entire flammability envelope, below x% O_2 it is inert.



Background

- Previous work has shown how flammability limits vary as a function of ignition energy.

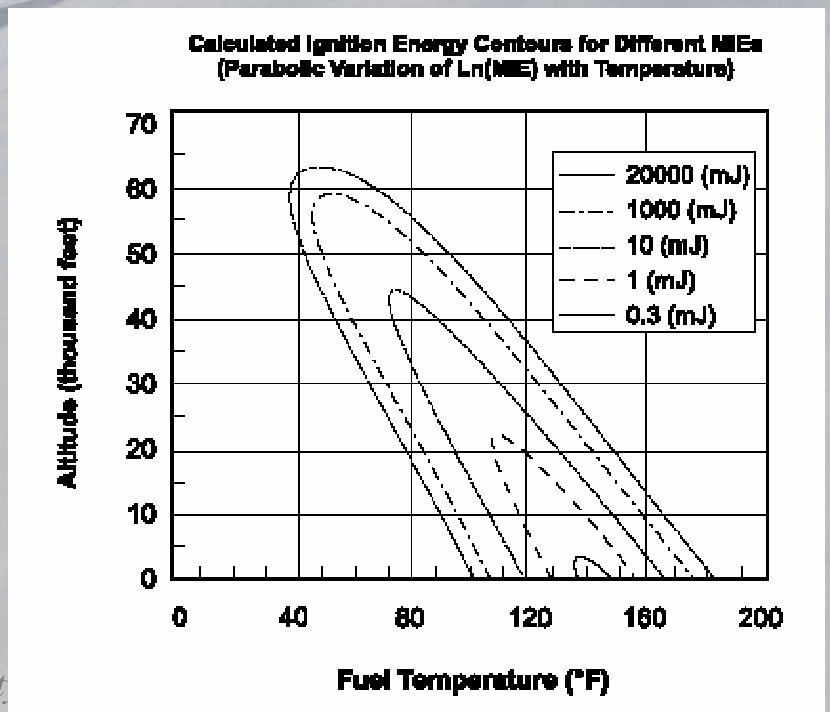


Background

- It follows intuitively that flammability limits will shift in a similar manner as inert gas is added to the fuel tank.
- Thus, if your fuel tank is only partially inerted, the flammability exposure time has still been reduced by a significant amount.
- How can this be quantified, validated and built into the flammability model?

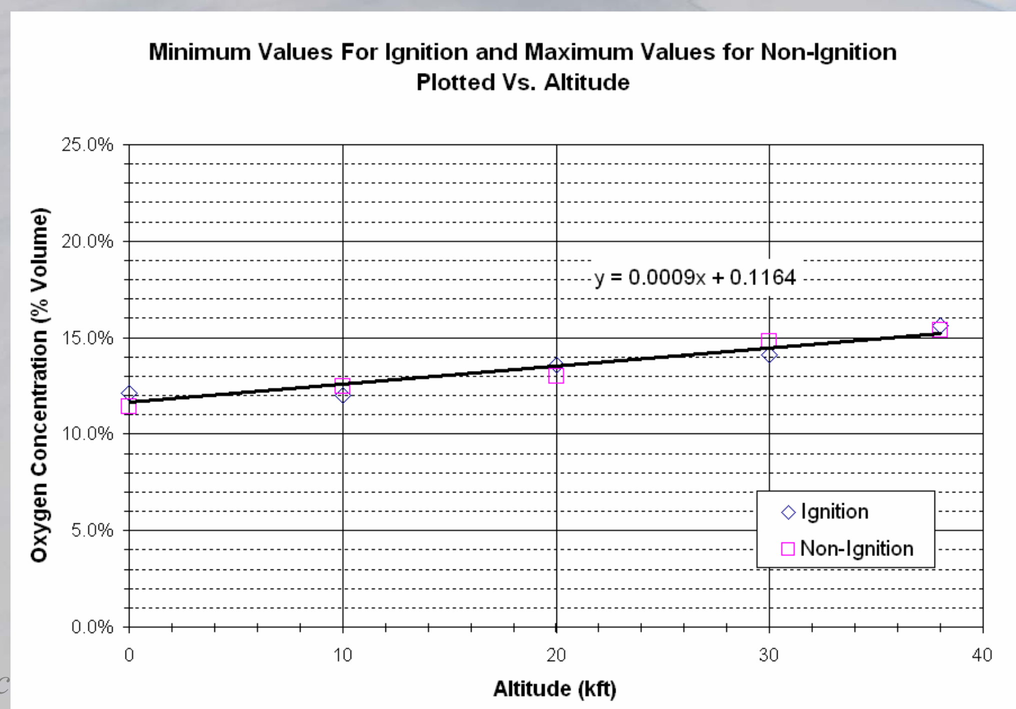
Computed Flammability Limits as a Function of O_2

- Similar methodology as that in DOT/FAA/AR-98/26 to compute flammability limits as a function of MIE.



Computed Flammability Limits as a Function of O_2

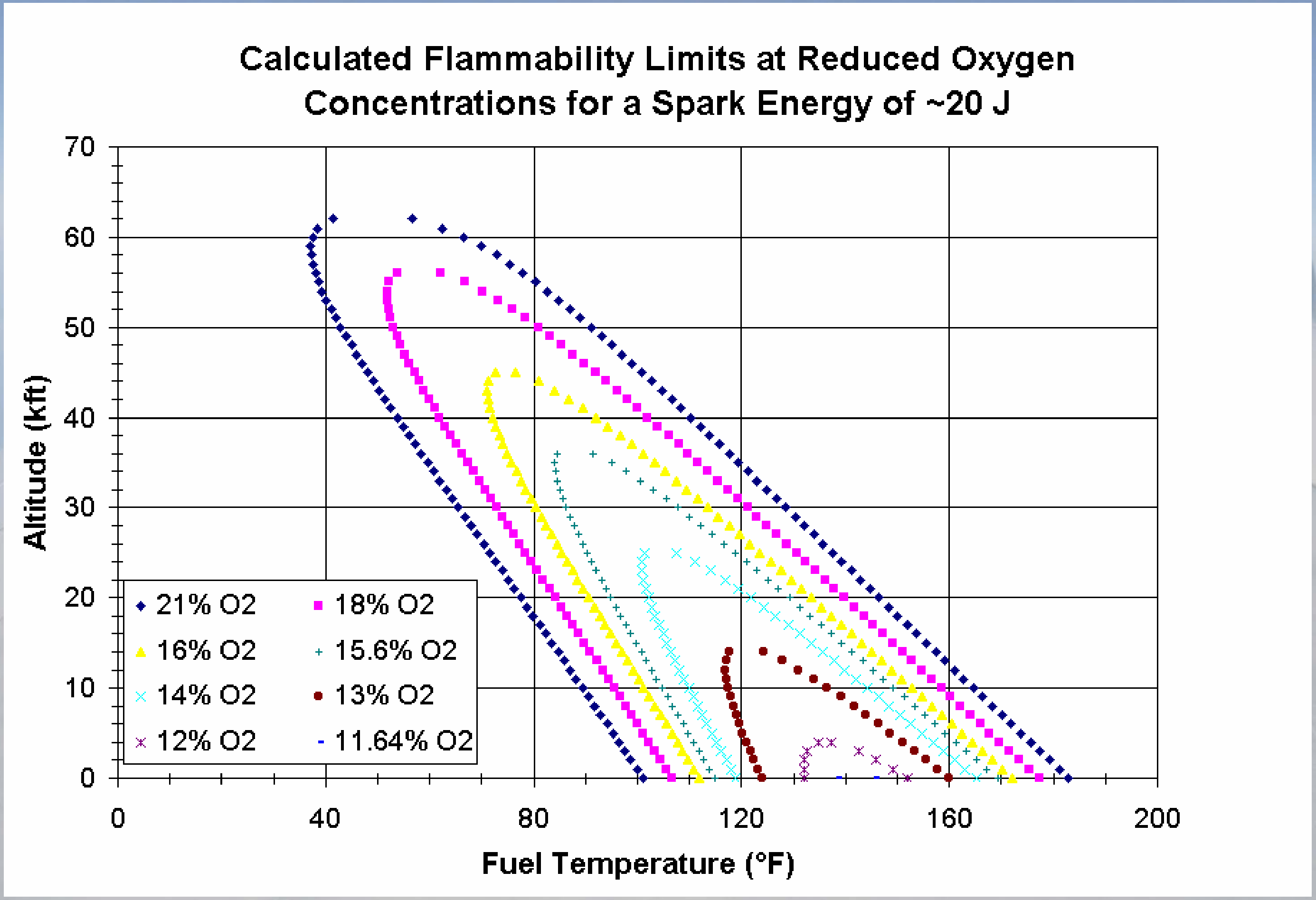
- Correlation of the variation of LOC with altitude.
  - Previously determined with a large (~20 J) spark source.



Computed Flammability Limits as a Function of O_2

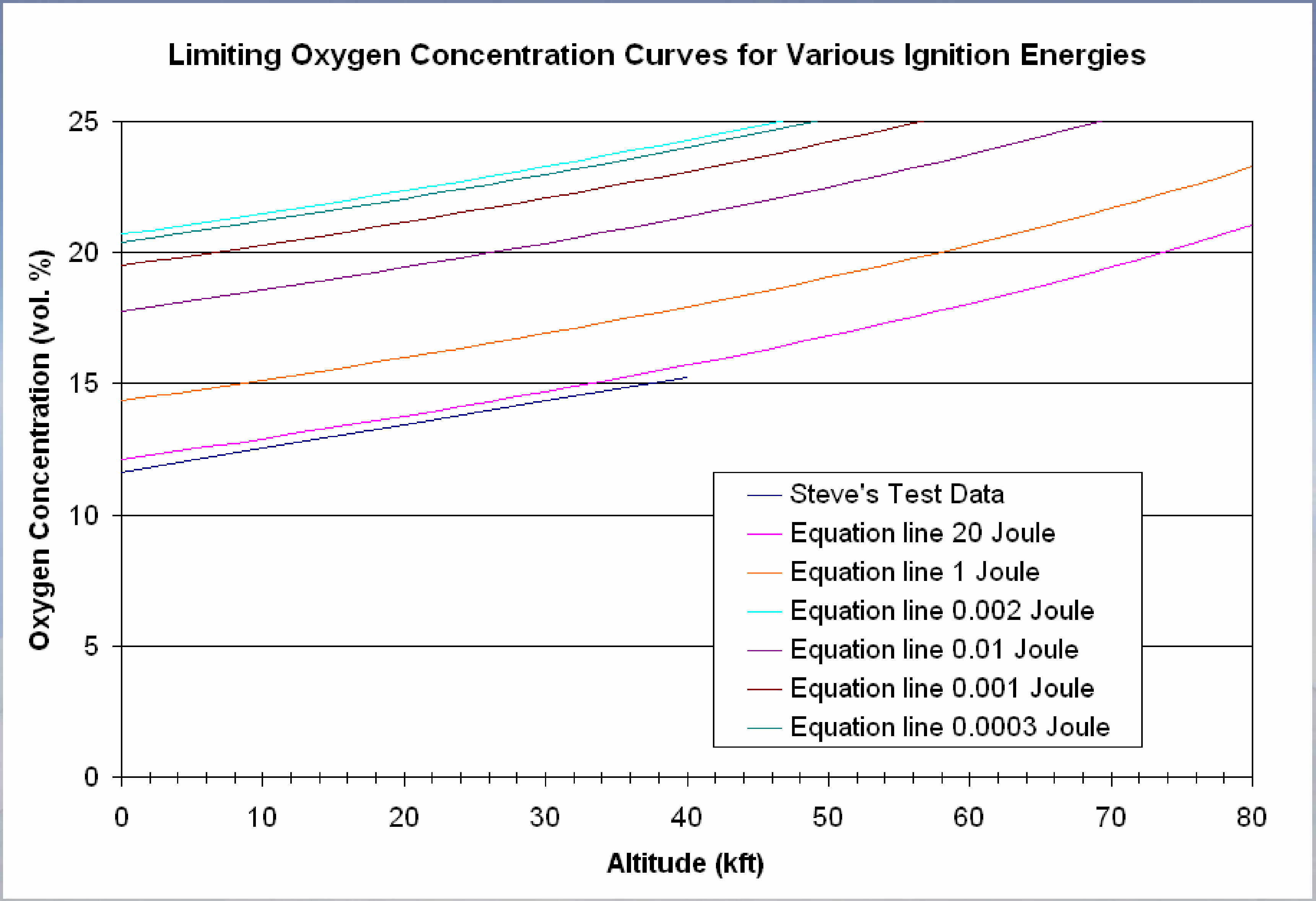
- $T_{Fuel} = T_{min} \pm \sqrt{\dfrac{Ln(O_2) - Ln(O_{2min})}{a}}$, where
  - T_{min} is the minimum of the parabola given by $T_{min} = T_{fp} + 22 - 1.5Z$.
  - a is a constant, determined by matching the curve as best as possible to the calculated 21% O_2 curve for the given ignition energy.

Resultant Curves for a 20 J Calculation



Flammability Limits as a Function of MIE, O_2 and FP

- Combining this with the parabolic MIE calculations and LOC curves for various ignition energies, results in flammability limits which vary as a function of ignition energy, O_2 concentration and flashpoint.
  - The sum of this work was put together into a working MS Excel model by Ivor Thomas


Limiting Oxygen Concentration Curves for Various Ignition Energies
Oxygen Concentration (vol. %)
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
Altitude (kft)
Steve's Test Data
Equation line 20 Joule
Equation line 1 Joule
Equation line 0.002 Joule
Equation line 0.01 Joule
Equation line 0.001 Joule
Equation line 0.0003 Joule

Click Here

Conclusions

- By a set of simple calculations, one can obtain varying flammability limits as a function of ignition energy, O_2 concentration and flashpoint.
- Once validated, this data can be used in the flammability model to show reduction in fleet wide fuel tank flammability as a function of the amount of inert gas added to the tank.
- Tests to validate these calculations are planned at the technical center.

Combustion Sphere Testing

Background

- Our current method for ignition testing of Jet-A fuel vapors is extremely time consuming (up to as long as 2 hours per test).
- If a gaseous mixture was available to simulate the flammability properties of Jet A, it would allow us to perform more tests quicker.
- Availability of said mixture would also have applicability to other issues (e.g. explosion proof testing, etc.)

Past Simulants - Hexane

	LFL	UFL	Stoich.	AIT (F)
Hexane	0.033	0.22	0.065	437
JP-8/Jet A	0.032	0.24	0.068	~420

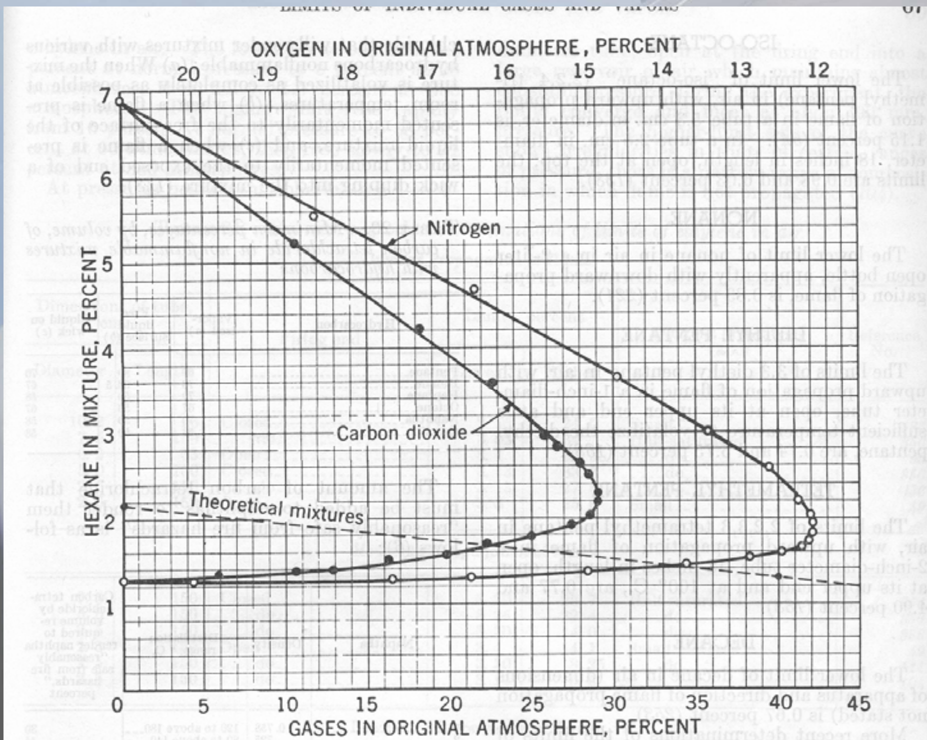


FIGURE 38.—Limits of Flammability of Hexane in Mixtures of Air and Nitrogen, and of Air and Carbon Dioxide.

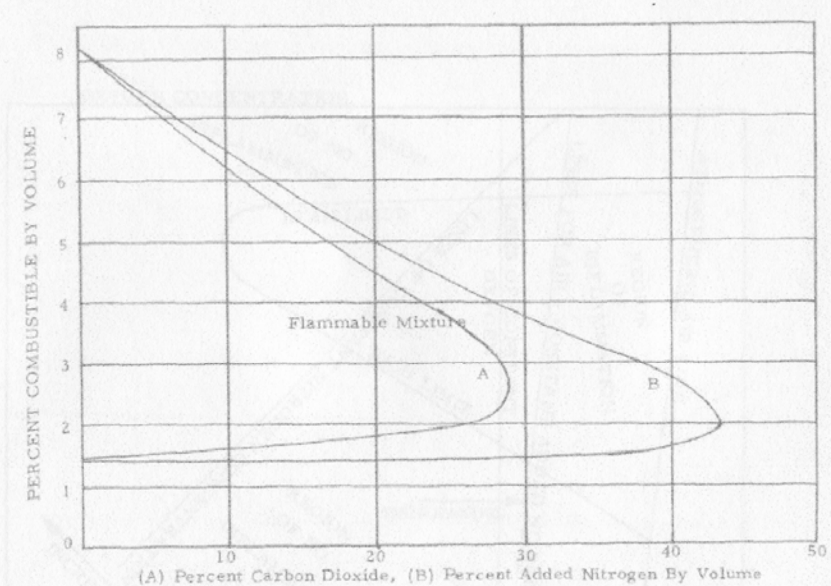
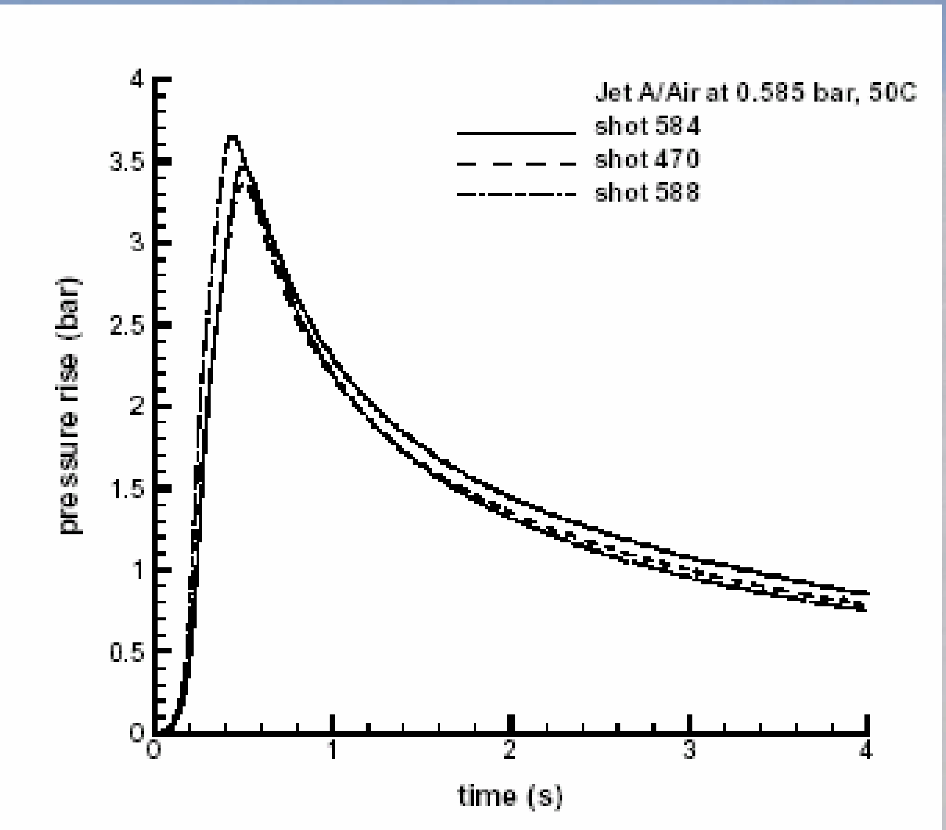


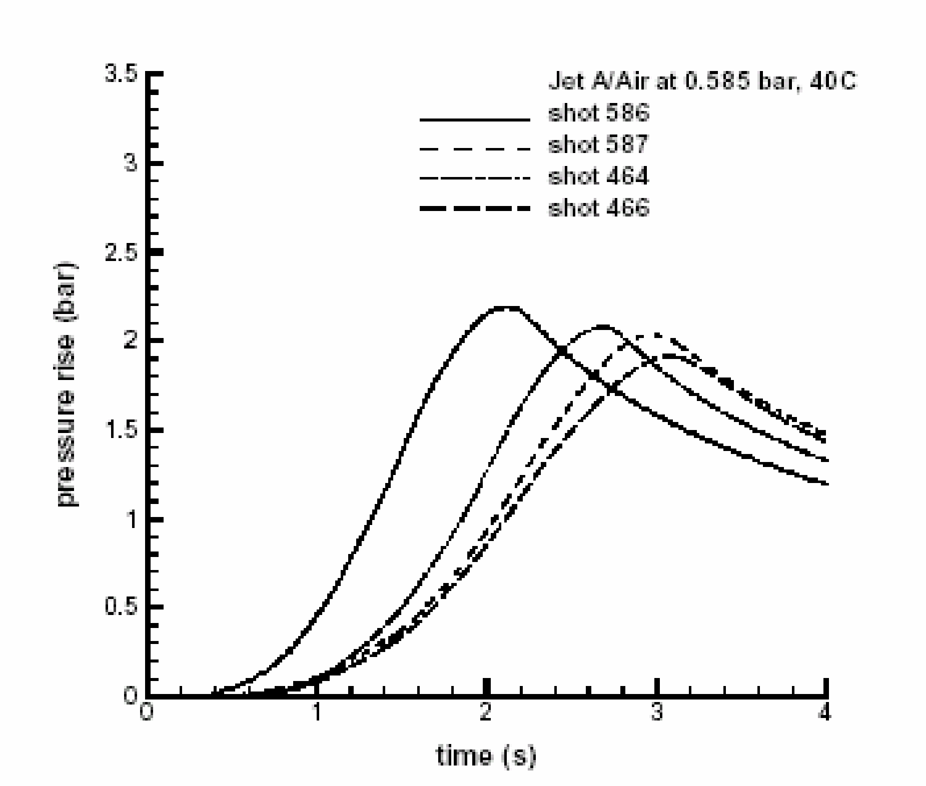
FIG. 2 CONCENTRATION LIMITS OF FLAMMABILITY FOR (A) AVIATION JET FUEL GRADE JP-4 VAPOR-AIR-CO_2 MIXTURES, AND (B) AVIATION JET FUEL GRADE JP-4 VAPOR-AIR-N_2 MIXTURES AT ATMOSPHERIC PRESSURE AND 75°F

Past Simulants – Caltech Mixture

- NTSB Docket No. SA-516, Exhibit No. 20O
- Volumetric Ratio of H_2:C_3H_8 of 5:1
- Examined the effect of fuel concentration, vessel size and ignition source on pressure history.

Past Simulants – Caltech Mixture

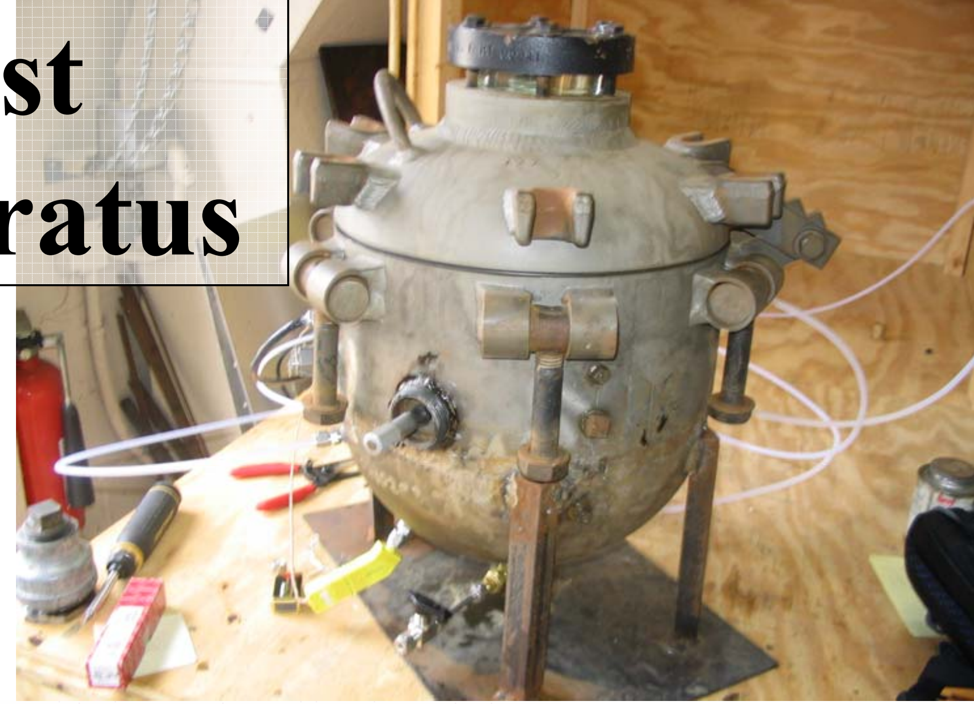


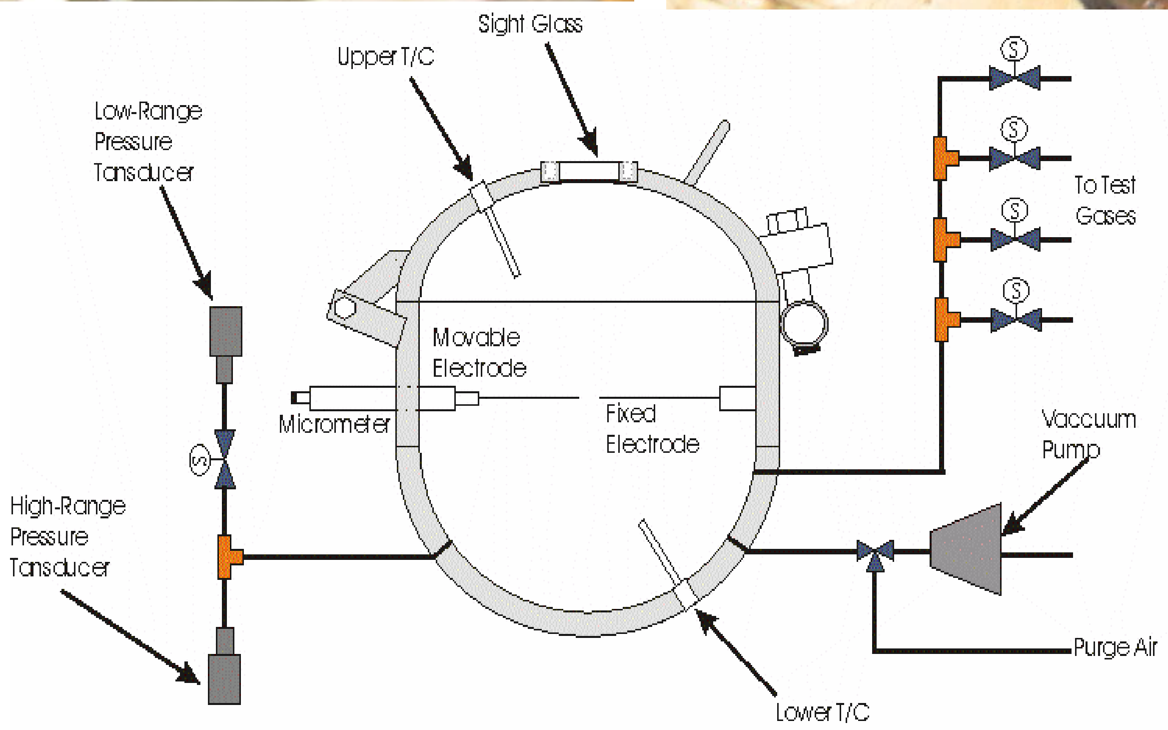


Test Apparatus

- 20 L combustion vessel constructed with an adjustable spark gap and the ability to utilize various spark/arc sources.
- Tests conducted in a manner similar to the procedures given in ASTM flammability standards (e.g. E582, E2079, etc).

Test Apparatus

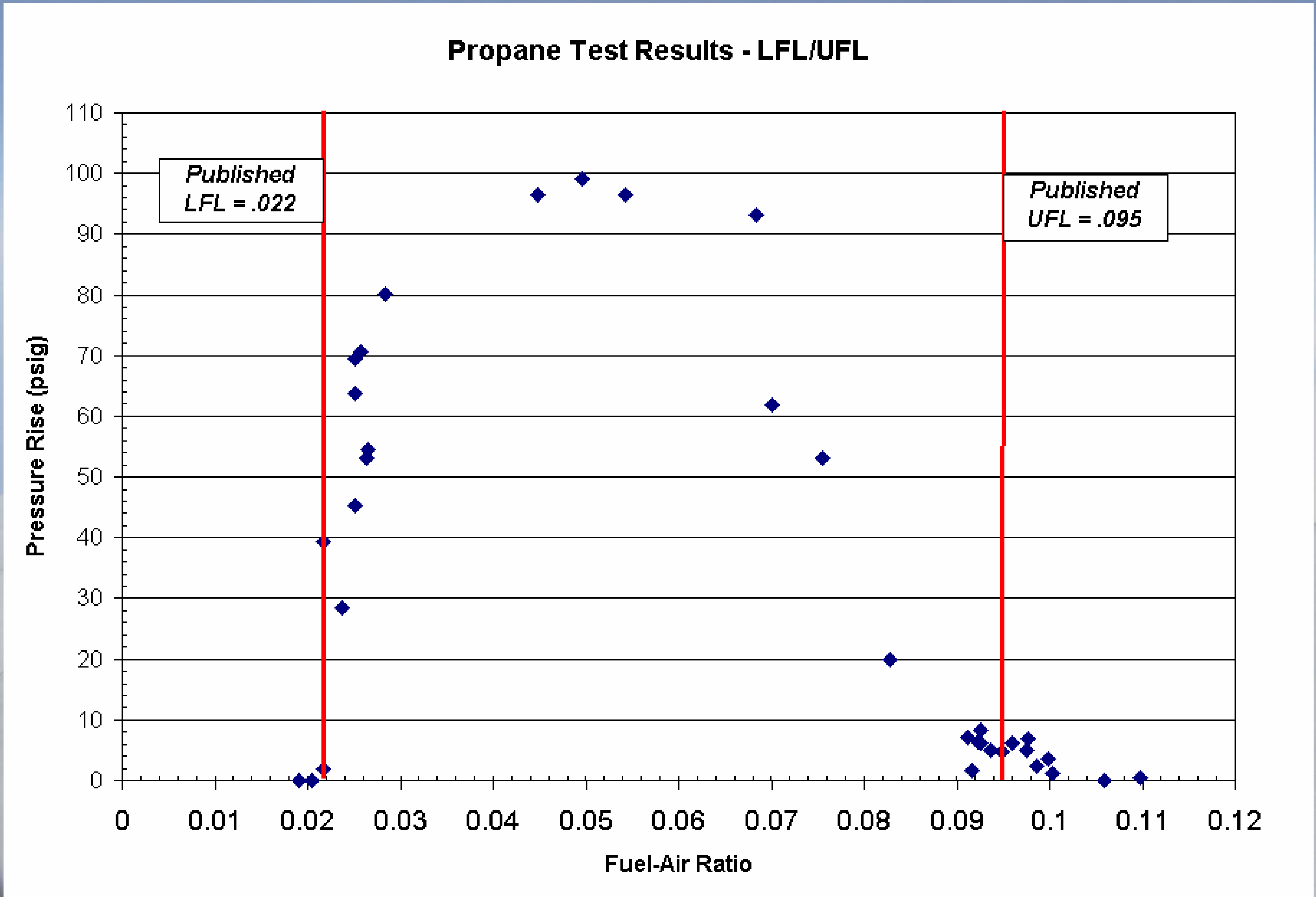




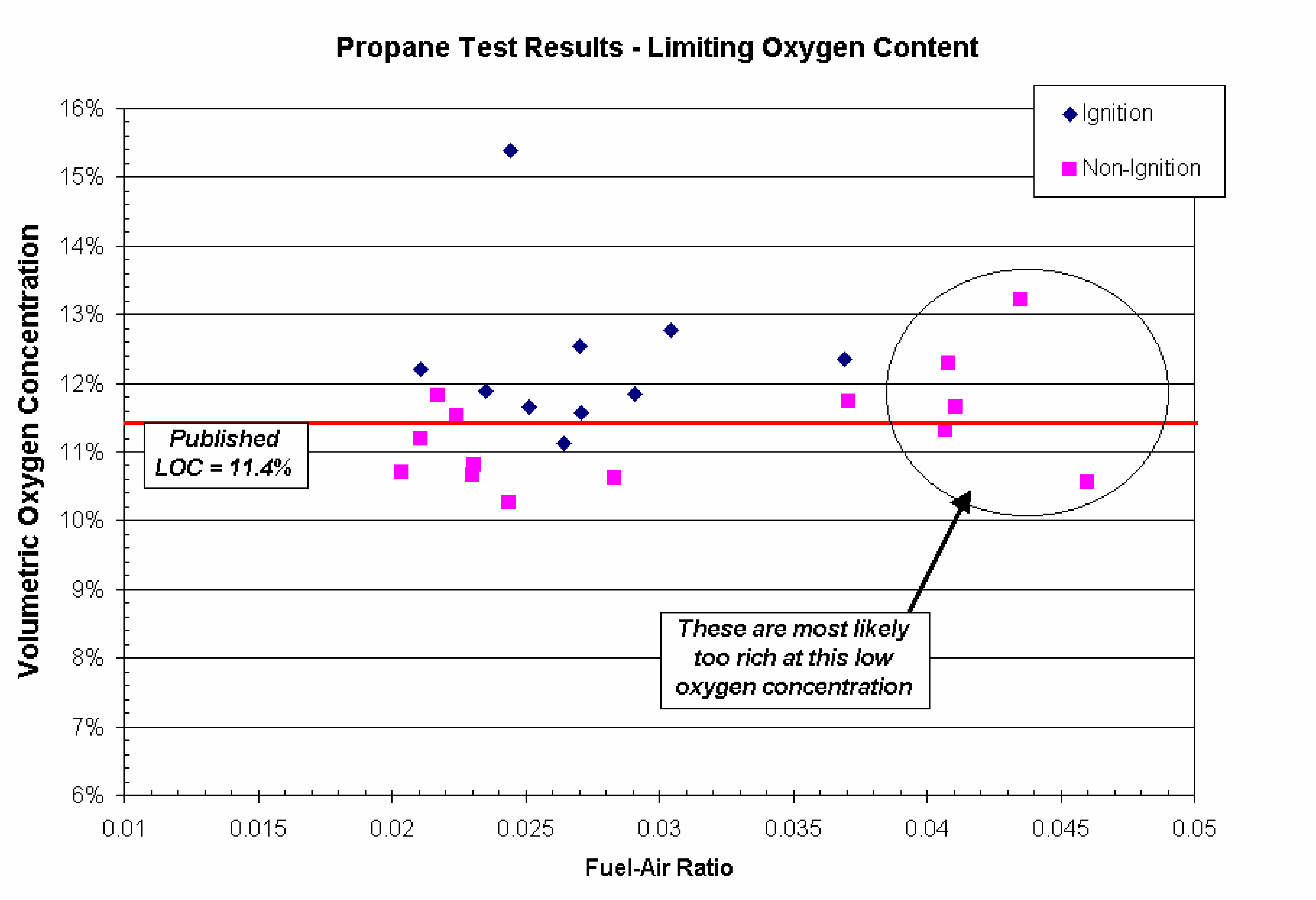
Test Plan

- Propane testing completed
  - Validation of LFL, UFL and LOC to ensure test article provides accurate results
- Testing with Hexane to be initiated shortly
  - Determination of LOC at reduced pressures

Propane Test Results



Propane Test Results



Future Testing

- Next phase of testing to be conducted with hexane both at sea level and reduced pressures
- Will compare results to the Jet A test results previously acquired to determine its validity as a simulant at reduced pressures
- Once a suitable simulant is determined (hexane or otherwise), the goal is to generate full flammability curve data at various pressures, O_2 concentrations and ignition energies