Detection of Oxygen release from simulated Aviation Fuel using a Quenched-Luminescence Sensing Technique

Adam P. Harris
Faculty of Applied Science
University of the West of England

University of the West of England

5th Triennial International Aircraft Fire And Cabin Safety Research Conference, Atlantic City, New Jersey, October 29-1 November 2007

AIRBUS

Outline

- Background
- Development of Sensor & Apparatus
- Testing Performed
- Results
- Summary
- Further Work
- References

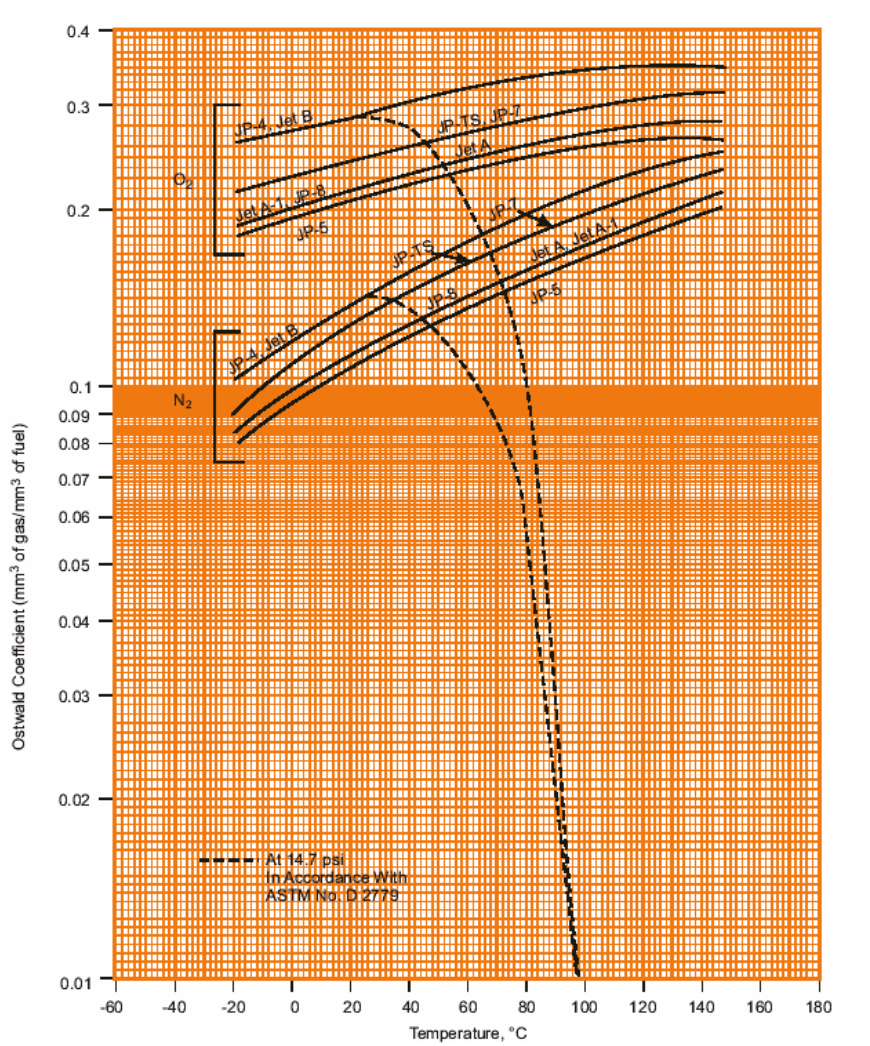
Background

- Requirement to understand how air evolves from aviation turbine fuels.
- Improve design of fuel management systems (air evolution model for CFD).
- Rate of air release is affected by:
  - Decrease in atmospheric pressure – high altitudes
  - Rate of change of atmospheric pressure
  - Degree of fuel agitation
- Air release is oxygen rich (up to 35% by vol.) – Fuel tank flammability considerations.
- Methodology needed to measure air/O_2 release from aviation fuel under simulated fuel tank conditions.
- Collaborative study launched between Airbus UK and UWE (Faculty of Applied Science)

University of the West of England
BRISTOL

AIRBUS

Background



Solubility of atmospheric gases in aviation fuels is affected by:

- Pressure (Henry's Law)
- Temperature
- Fuel Type
- Gas Type

Ostwald Coefficient is vol. gas dissolved in vol. of solvent at equilibrium conditions

- Measured at the conditions of solution
- Independent of pressure

University of the West of England
BRISTOL

AIRBUS

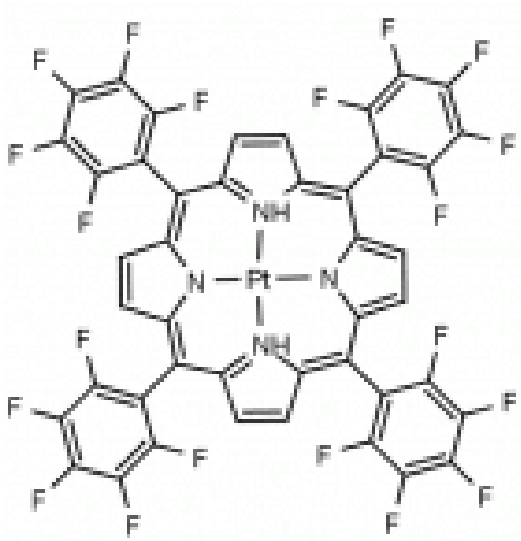
Sensor Development

Detection Principle

- Dissolved O_2 in fuel can be detected by observing the phosphorescence of luminophores dissolved in fuel.
- Phosphorescence is promoted by irradiating the luminophore/fuel solution with UV light.
- O_2 efficiently ‘quenches’ phosphorescence of certain luminophores allowing concentration and pressure of O_2 dissolved within fuel to be determined.
- Method selected to give:
  - In-situ sample measurement
  - Rapid analysis time
  - Reduction in error – no need to extract samples and process offline (previous Gas-Chromatography approaches)
  - Very sensitive - low concentrations of dissolved O_2 (ppm by weight) detectable

Sensor Development

- A Pt Porphyrin luminophore was selected:



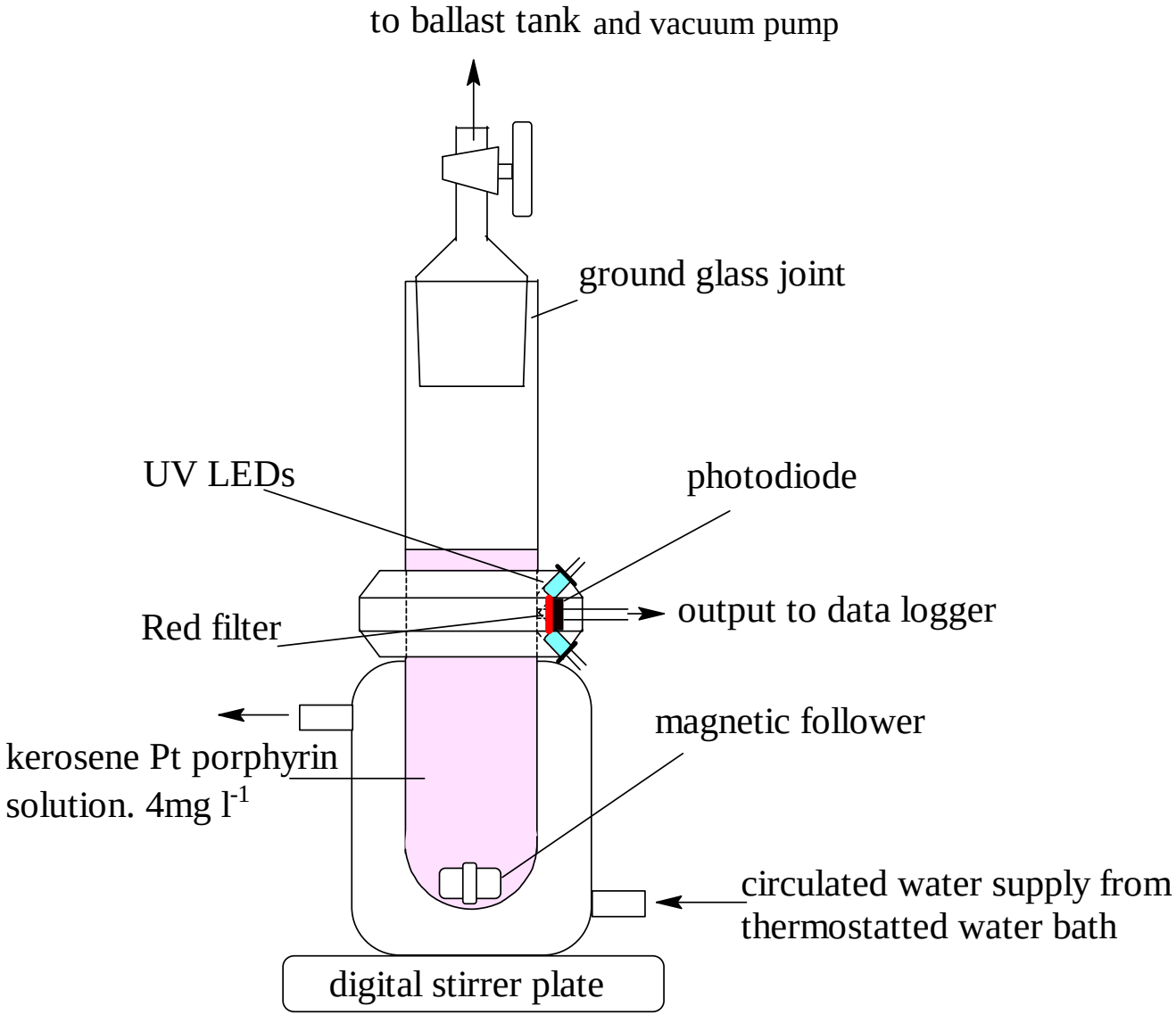
Pt(II) meso-Tetra(pentafluorophenyl)porphine

- The luminophore was selected as it exhibits known phosphorescence in pressure sensitive paint formulations.
- Can be readily dissolved in kerosene and exhibit phosphorescence.
- Previous attempts to dissolve the luminophore in Jet A-1 affected phosphorescence behaviour (additives in fuel?).

University of the West of England
BRISTOL

AIRBUS

Apparatus



University of the West of England BRISTOL

AIRBUS

Testing Performed

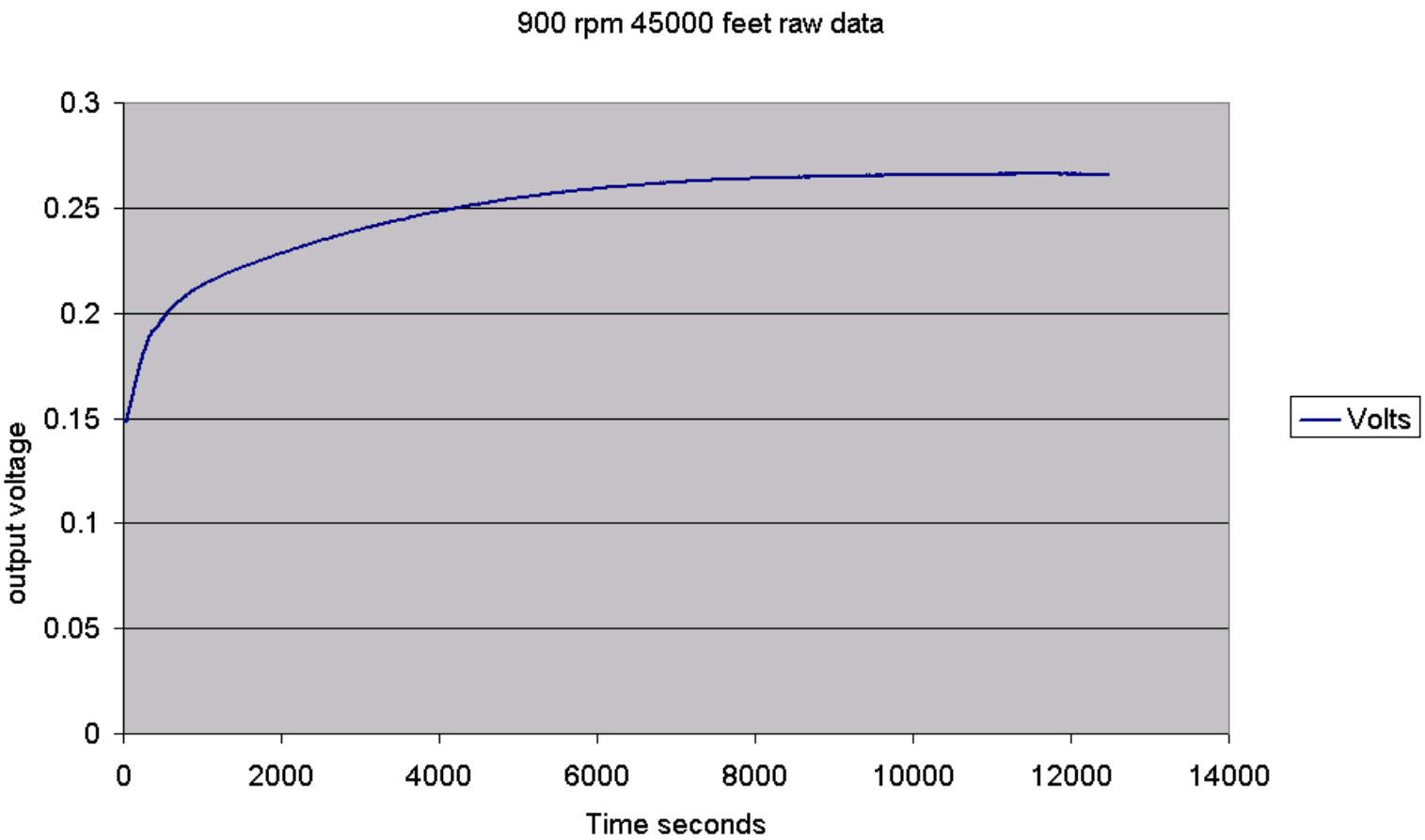
Environmental Conditions

- Pressure above fuel surface mimics range of fuel tank ullage pressures in flight.
- Agitation of fuel to mimic operation of fuel pumps and fuel movements within systems and tanks.
- Tests were conducted under isothermal conditions

Pressure Altitude (KFt)	Fuel Agitation (rpm)	Temperature(°C)
5 – 45Kft (5Kft intervals)	1100	20
5 – 45Kft (5Kft intervals)	1000	20
5 – 45Kft (5Kft intervals)	900	20
5 – 45Kft (5Kft intervals)	700	20
5 – 45Kft (5Kft intervals)	500	20

Results

- Photodiode output voltage as a function of time

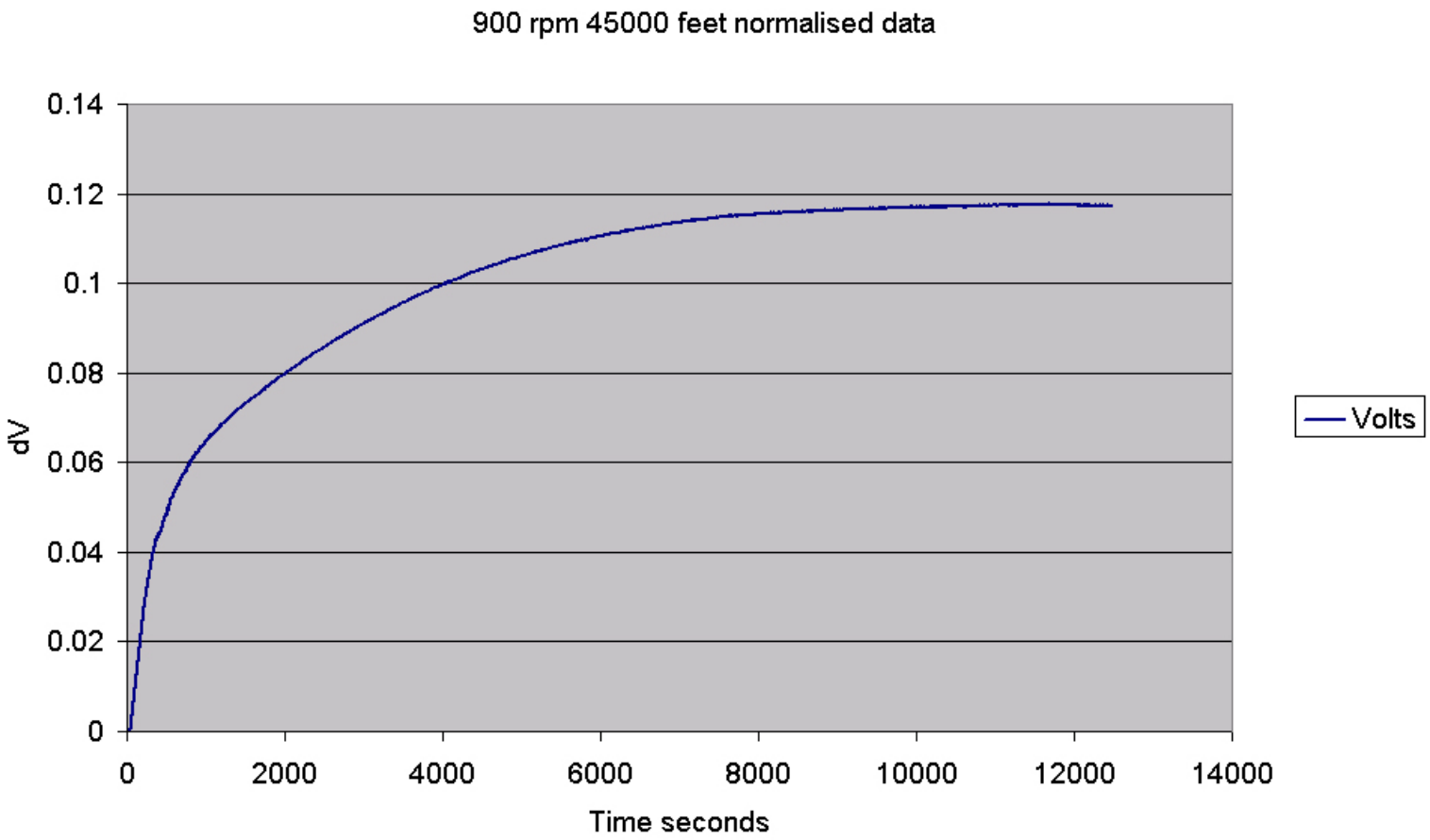


University of the West of England
BRISTOL

AIRBUS

Results

- Normalised Photodiode output voltage as a function of time

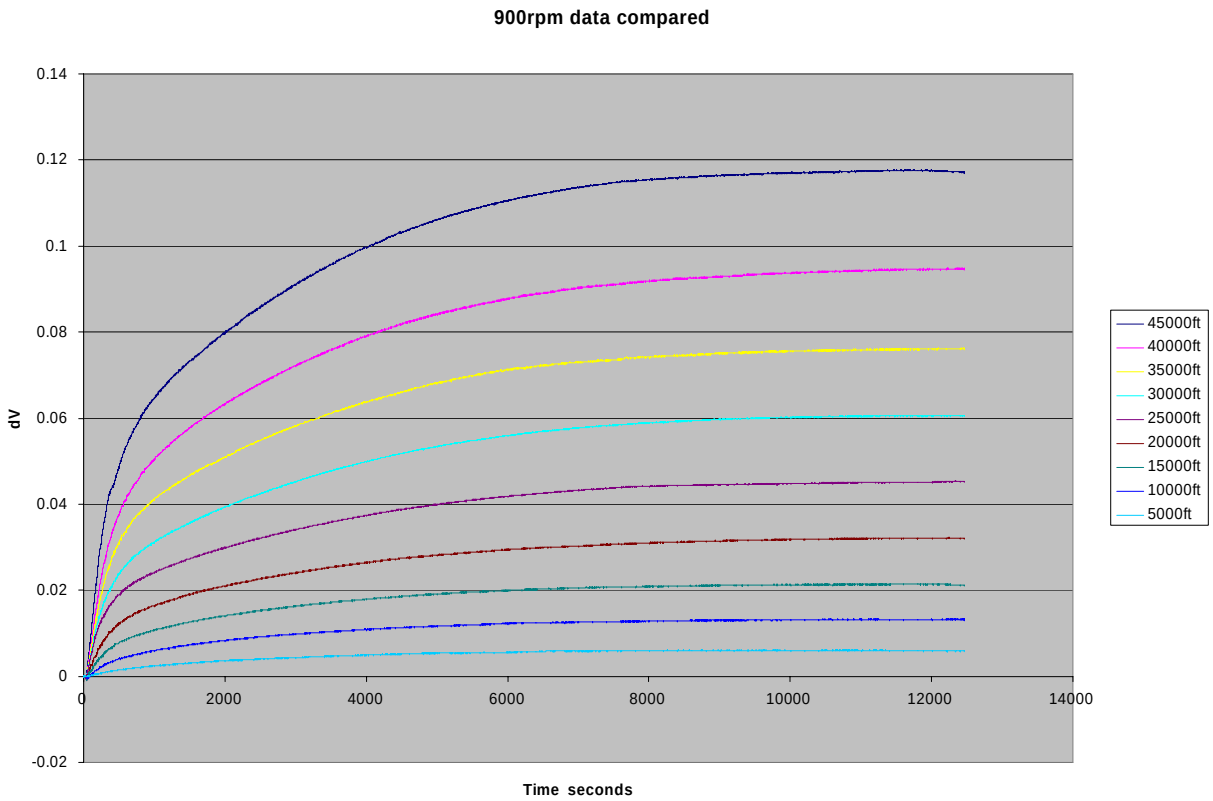


University of the West of England
BRISTOL

AIRBUS

Results

- Raw data is normalised to an effective zero baseline giving dV photodiode values as a function of time.
- Normalisation of data repeated for pressure-altitudes between 5000 and 45000 ft at 5000 ft intervals.



University of the West of England
BRISTOL

AIRBUS

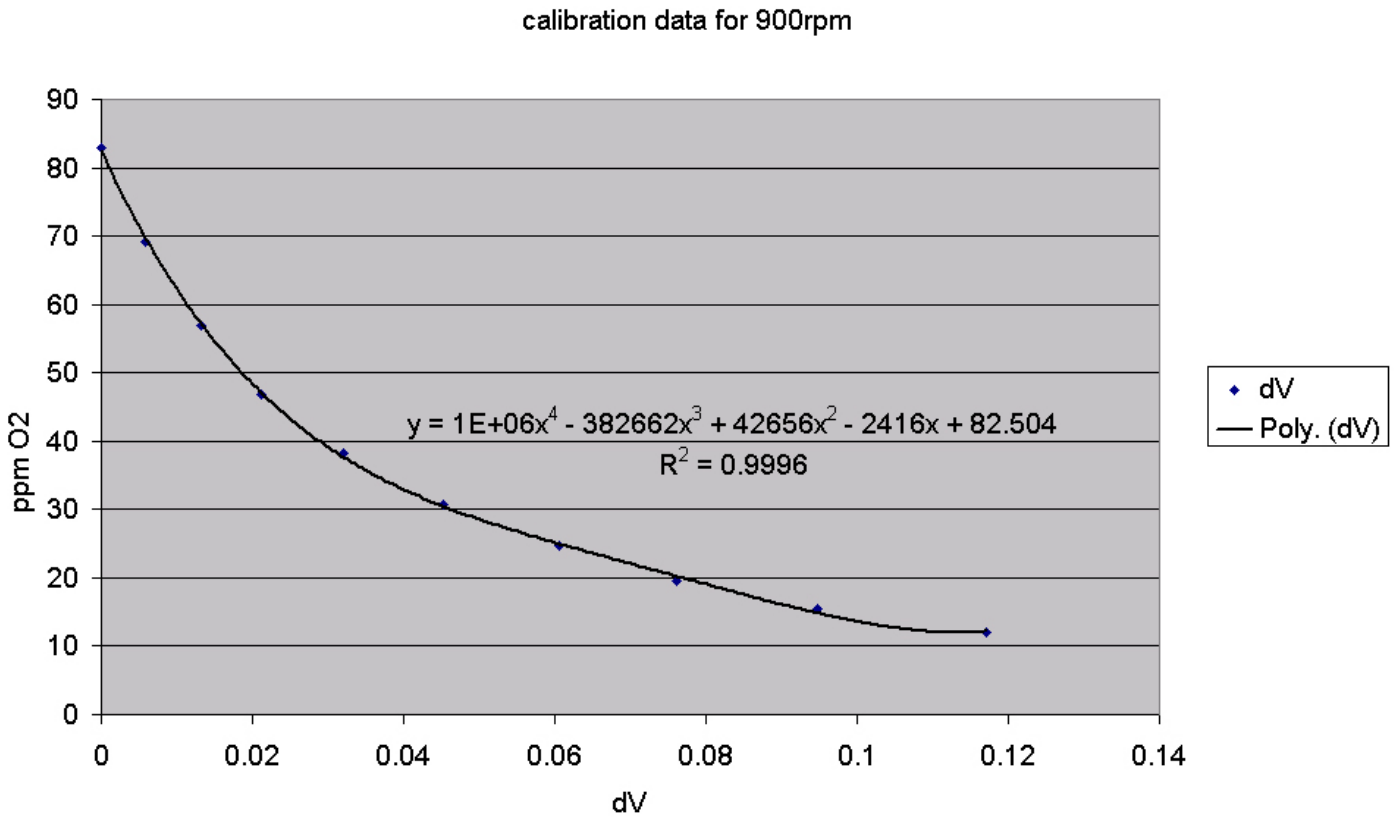
Results

- dV values converted to dissolved O_2 concentrations (by weight) using Ostwald coefficient - gas solubility calculation (ASTM D2779)
  - Example of data from 900 rpm agitation experiment:

Altitude (ft)	Calculated ppm O_2 (ASTMD2779)	dV (volts) for Altitude
0	83	0
5000	69.1	0.005895069
10000	57	0.013230844
15000	46.8	0.021174436
20000	38.2	0.032129142
25000	30.8	0.045312937
30000	24.7	0.060543984
35000	19.6	0.076133618
40000	15.4	0.09469749
45000	12.1	0.117184202

Results

- Calculated O_2 concentration as a function of dV (volts) for each pressure-altitude gives calibration curve
- Calibration curve generated for each agitation level

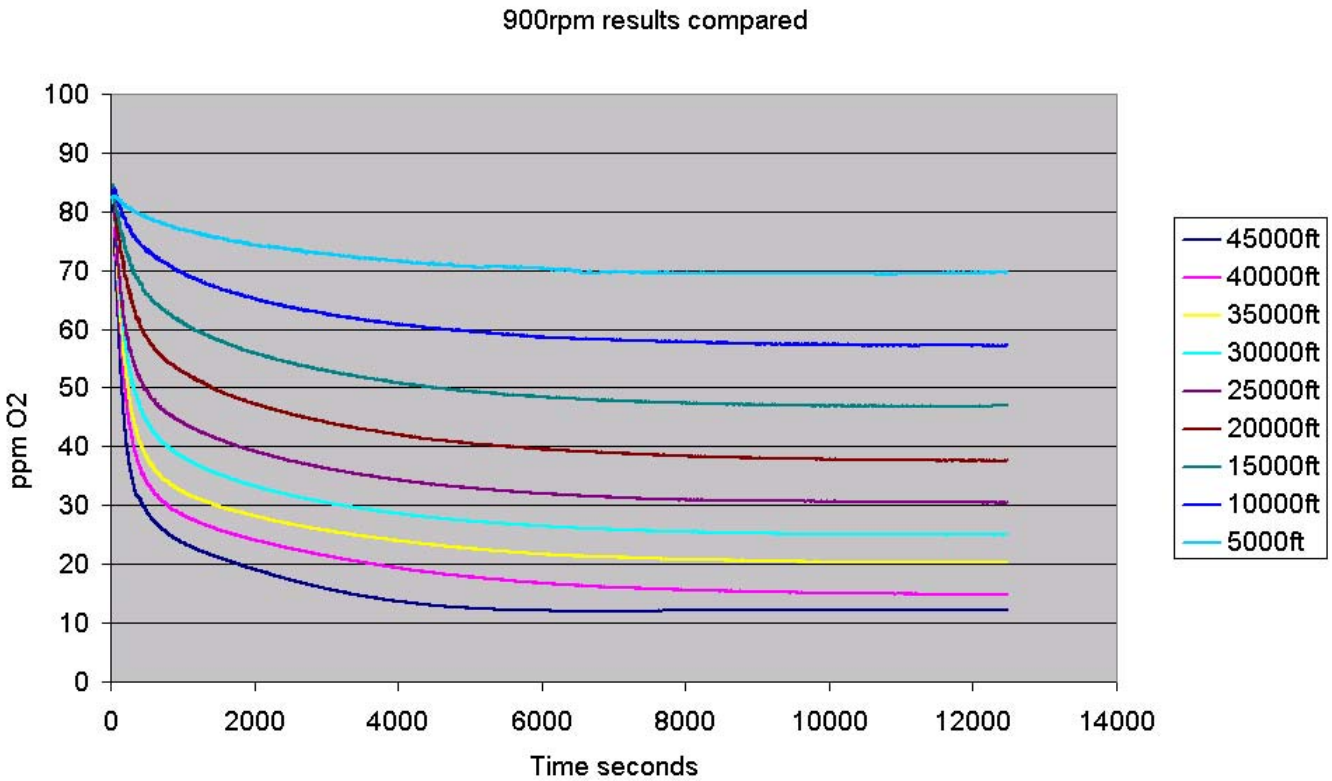


University of the West of England
BRISTOL

AIRBUS

Results

- Calibration curves enable conversion of dV values into dissolved O_2 concentration in kerosene (ppm by weight)
- Increasing altitude for a given agitation level promotes increase in rate of O_2 evolution

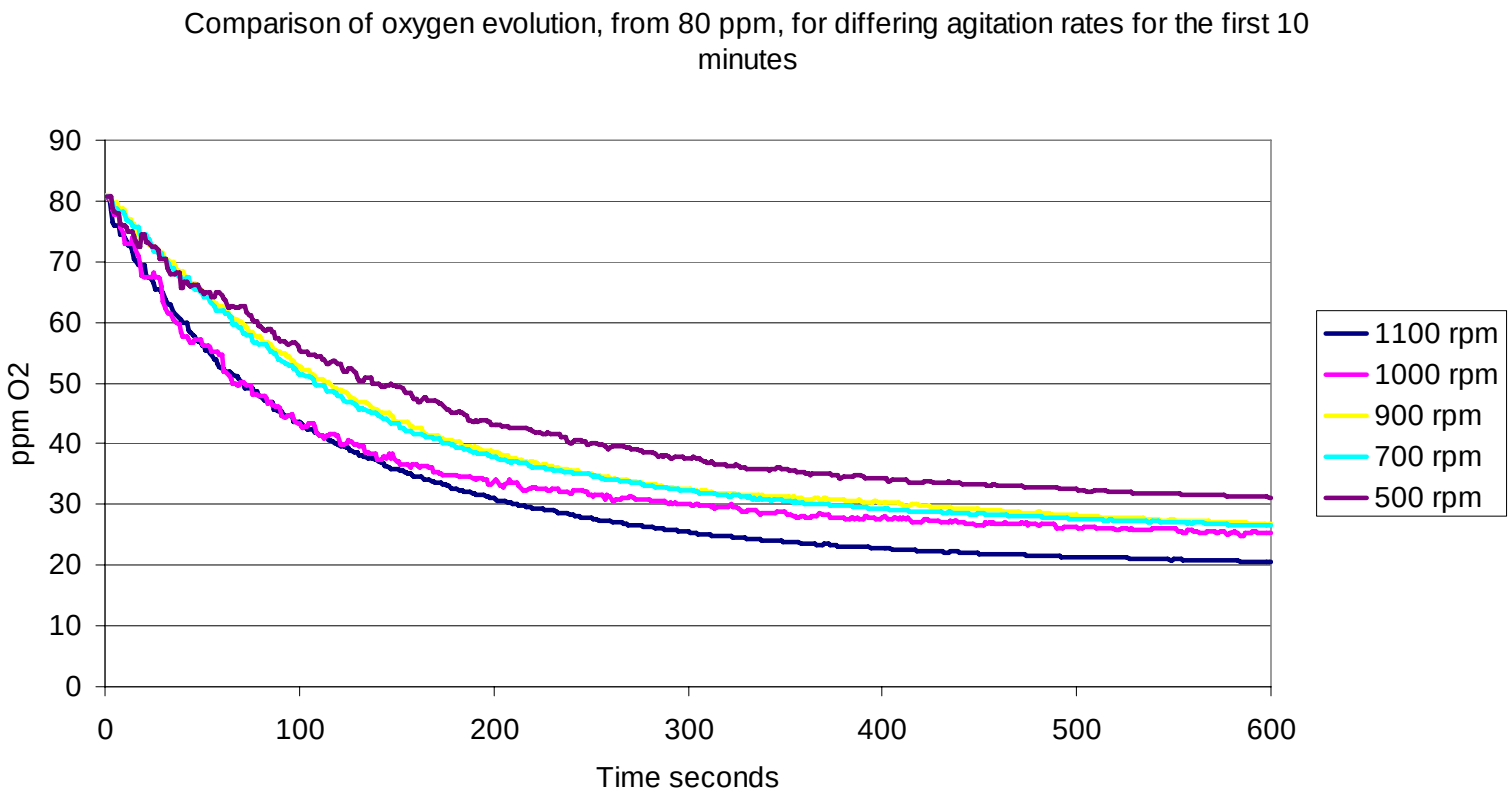


University of the West of England
BRISTOL

AIRBUS

Results

- The effect of fuel agitation on oxygen release at a pressure- altitude of 45000 ft
- Increasing fuel agitation promotes increase in rate and magnitude of O_2 evolution

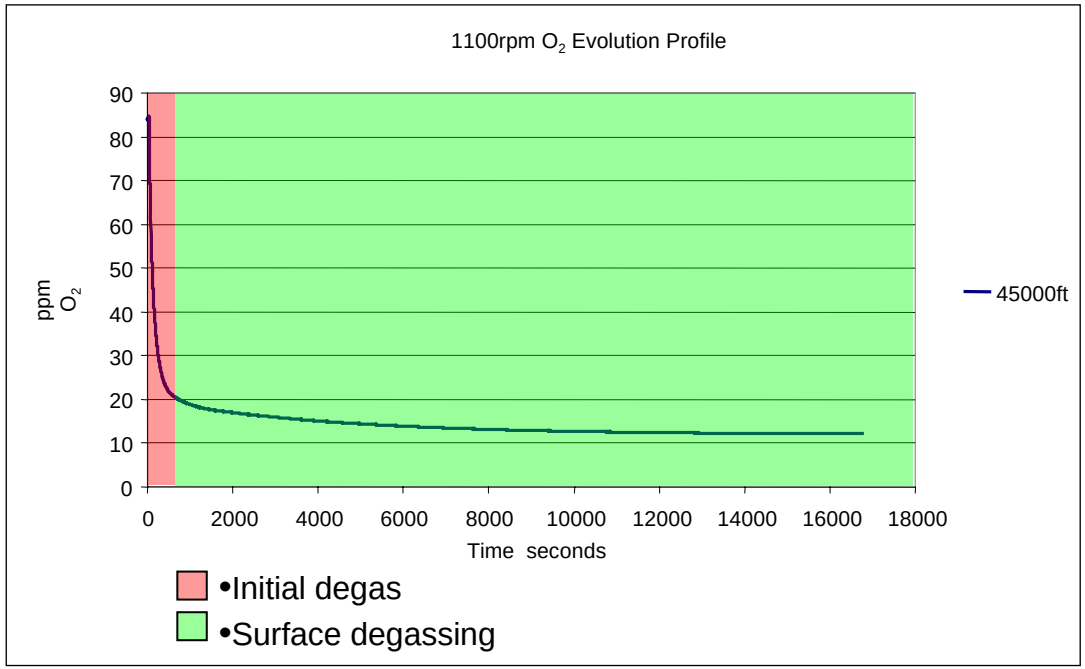


University of the West of England
BRISTOL

AIRBUS

Results

O_2 'Degassing' Hypothesis



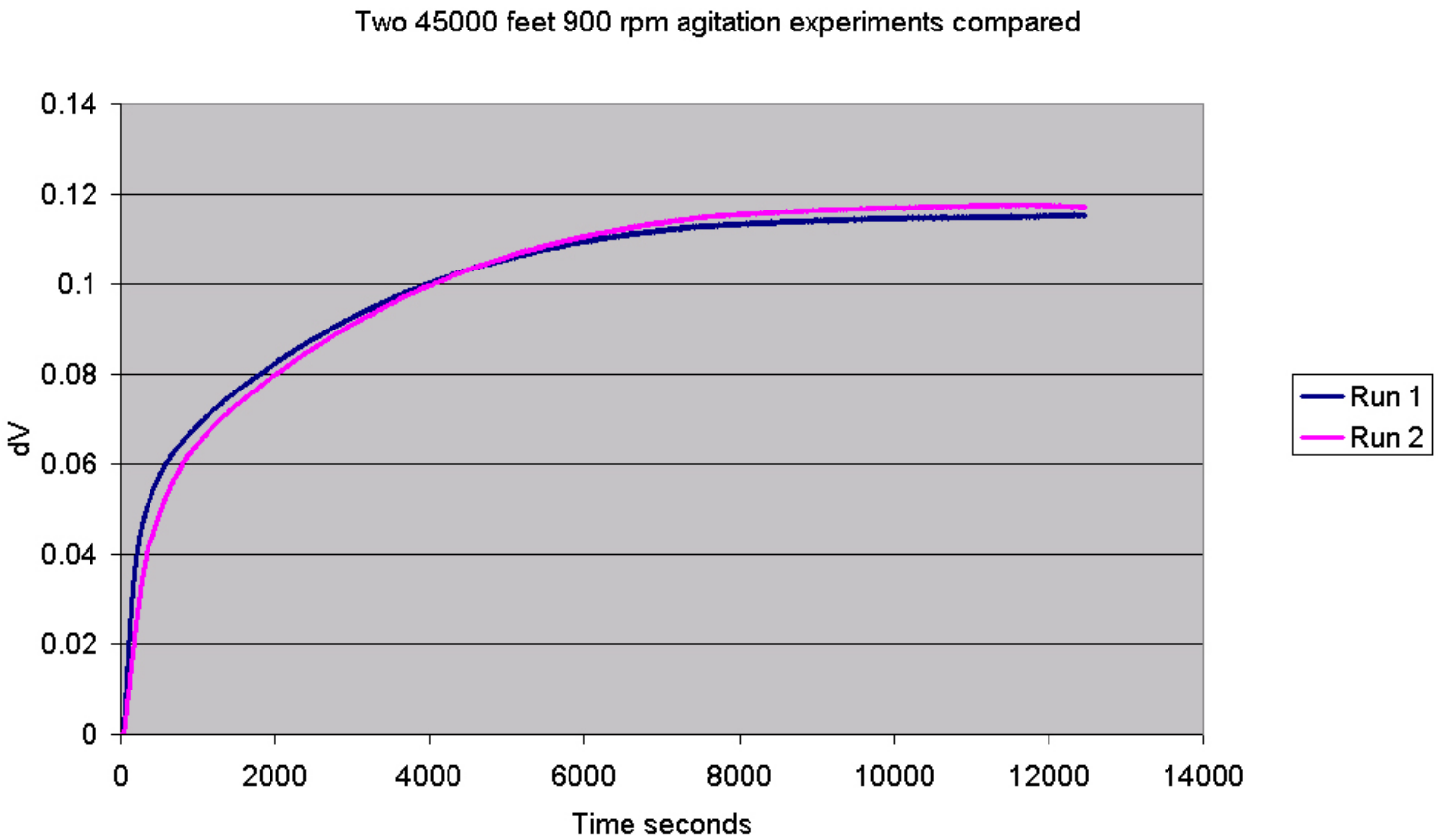
- ~85% of oxygen evolution occurs within first 10 minutes of experimentation
- Two distinct rates of degassing are observed:
  - Initial gradient (red portion) possibly due to observed bubble formation promoted by kerosene agitation
  - Second gradient (green portion) observed possibly due to steady state surface degassing (*no visible bubbles observed under continued agitation*)

University of the West of England
BRISTOL

AIRBUS

Results

- Experimental repeatability



University of the West of England
BRISTOL

AIRBUS

Summary

- Dissolved O_2 concentrations in kerosene (by weight) readily detectable down to 10 (ppm) with developed methodology
- Oxygen gas evolution profiles of kerosene under fuel agitated and altitude simulated conditions have been recorded
- Increasing fuel agitation and reducing pressure above kerosene fuel is seen to increase the rate of oxygen gas evolution
- Two separate modes of degassing are hypothesised i) degassing due to bubble evolution ii) due to steady state surface degassing

Further Work

- Examine O_2 evolution from kerosene over a range of temperatures (-40°C to +55 °C)
- Investigate performance and repeatability of developed methodology at fuel temperatures consistent with fuel tanks in flight
- Benchmark accuracy and repeatability of method with other O_2 chemical sensors based on ‘phosphorescence quenching’ methodology
- Fitting of mathematical model(s) to gathered data and perform empirical sensitivity analysis

References

1) Investigation into the Variation of Oxygen Content in the Gas Space above Kerosene Fuel when Subjected to Reduced Pressures, H.W.G Wyeth, Royal Aircraft Establishment, February 1958.
2) Principles of Fluorescence Spectroscopy, Third Edition, J R Lakowicz, September 2006.
3) An Analysis of Air in Jet Fuel: Phase 2 Study, N.M. Ratcliffe et al, University of the West of England, November 2006.