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# High Pressure LO<sub>x</sub>/H<sub>2</sub> Rocket Engine Combustion



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# Abstract

Increasing liquid rocket engine performance margins for re-usability and escalating payload demands requires a detailed understanding of injection and reaction of transcritical and supercritical propellants. Full scale static firing of modern day liquid rocket engines for research and development purposes is prohibitively expensive. A sub-scale combustor has been developed for fundamental liquid rocket engine research. The combustor is fitted with quartz glass windows for optical accessibility and is capable of multiple re-starts for extended periods with representative propellant temperatures, injector flow rates and combustion pressures.

A parametric study based on propellant injection conditions has been performed with a single shear coaxially injected liquid rocket engine combustor. Steady state operation has been closely examined with the thrust chamber operating at sub critical, near critical, and supercritical pressure levels with respect to the thermodynamic critical pressure of oxygen. High speed optical diagnostics have been applied to the near injector field including spontaneous OH chemiluminescence to visualise the combustion zone and shadowgraph imaging to observe the propellant flowfield.

The propellant injection velocity ratio ( $R_v$ ) and reduced pressure ( $P_r$ ) have been identified to have a significant effect on thrust chamber operation. Interchanging injector geometries and

regulating propellant flow-rates at constant oxidiser to fuel ratio ( $R_{OF}$ ) has enabled examination of the local and global influence of  $R_v$  and  $P_r$  on combustion over a range of conditions. Two hydrogen injection temperature ranges have been successfully investigated at a constant liquid oxygen injection temperature.

Analysis of measurement system data indicates a significant difference exists between thrust chamber operation at pressures below, near and above the thermodynamic critical pressure of oxygen. The combustion efficiency ( $\eta$ ) and the peak-to-peak dynamic pressure data analysis ( $P_{p-p}$ ) consistently highlight dissimilarities between sub- and supercritical pressure regimes. An inherent unsteadiness at reduced pressure levels less than unity is frequently observed through examination of the near injector flow-field and combustion zone images. The liquid oxygen core typically exhibits an increase in local surface perturbations and flow oscillations at reduced pressure levels less than unity ( $P_r < 1$ ) which coincides with observations construed from the measurement data.

A range of combustor start-up transients have also been analysed. The point of ignition has been captured using high speed diagnostics with different injection conditions. The start-up process is characterised and described in detail for each of the conditions examined.

Low frequency (LF) combustion instability has been witnessed at subcritical pressure levels. Investigations indicate that unstable combustion triggered at  $P_r < 1$  could not be replicated at a  $P_r$  equal to, or greater than unity under near identical injection conditions. In fact, unstable combustion could not be triggered whatsoever with LOx/H<sub>2</sub> propellants at near or supercritical pressure irrespective of operating conditions. Such findings illustrate that operating near or above the critical pressure of propellants (oxygen) results in inherently stable combustion process over a broad range of operating conditions.

# Table of Contents

<b>Abstract</b>	<b>i</b>
<b>Statement of Originality</b>	<b>iii</b>
<b>Acknowledgements</b>	<b>v</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Objective	2
1.2 Scope	3
<b>2 Literature Review</b>	<b>5</b>
<b>2.1 Launch Vehicles and Rocket Propulsion Systems</b>	<b>5</b>
2.1.1 Rockets and Launch Vehicles .....	5
2.1.2 Types of Propulsion .....	6
2.1.3 Liquid Propellant Rocket Engines (LPRE's) .....	7
2.1.4 Liquid Oxygen .....	9
2.1.5 Hydrogen .....	9
2.1.6 LOx/LH2 Bi-Propellant System .....	10
<b>2.2 Propellant Injection and Combustion</b>	<b>12</b>
2.2.1 Liquid Rocket Engine Injectors .....	12
2.2.2 Coaxial Injection .....	13
2.2.3 Coaxial Injection and Combustion Research .....	16
<b>2.3 High Pressure Injection and Combustion</b>	<b>18</b>
2.3.1 Supercritical Phenomena .....	18

2.3.2	High Pressure Injection Studies .....	19
2.3.3	Supercritical Modelling .....	28
2.3.4	High Pressure Experimental Combustion Studies .....	31
2.3.5	Summary .....	33
2.3.6	Gaps in Existing Knowledge .....	35
2.3.7	Experimental Characterisation of High Pressure Combustion .....	37
<b>3</b>	<b>Experimental Approach</b>	<b>39</b>
3.1	<b>Introduction</b>	<b>39</b>
3.1.1	DLR Institute of Space Propulsion .....	39
3.2	<b>The P8 Test Facility</b>	<b>40</b>
3.2.1	Test Operating Sequence .....	42
3.2.2	Test Campaigns .....	43
3.3	<b>Hardware</b>	<b>43</b>
3.3.1	Combustion Chamber C .....	43
3.3.2	Single Shear Coaxial Injector Element .....	45
3.4	<b>Thrust Chamber Measurement System</b>	<b>47</b>
3.4.1	Temperature Measurement Errors .....	48
3.4.2	LOx Mass Flow Meter Errors .....	48
3.5	<b>Optical Diagnostics</b>	<b>50</b>
3.5.1	Spectral Emission Imaging .....	50
3.5.2	Shadowgraph Photography .....	51
3.5.3	Coherent Anti-Stokes Raman Spectroscopy (CARS) .....	51
3.6	<b>Initial Experimental Setup VIS2001</b>	<b>53</b>

3.6.1	Aims .....	53
3.6.2	Operating Conditions .....	53
3.6.3	Simultaneous Flame and Flow field Visualisation Setup .....	55
3.6.4	Temperature Probing Optical Setup .....	57
<b>3.7</b>	<b>Evolved Optical Diagnostic Setup</b>	<b>60</b>
3.7.1	Proposed Operating Conditions and Test Matrix .....	61
3.7.2	Steady State Combustion Optical Diagnostics Setup .....	62
3.7.3	Ignition Transients Optical Setup .....	64
3.7.4	Flame Emission Spectral Measurements .....	65
3.7.5	Precautionary Measures .....	66
<b>4</b>	<b>Analysis Techniques</b>	<b>69</b>
<b>4.1</b>	<b>Image and Data Processing</b>	<b>69</b>
4.1.1	Data Processing .....	69
4.1.2	Image Processing .....	70
<b>4.2</b>	<b>Initial Test Campaign Analysis Techniques</b>	<b>70</b>
4.2.1	Time Averaged OH Emission Images .....	71
4.2.2	Tomographic Reconstruction Method Utilising Abel's Transform .....	72
<b>4.3</b>	<b>Combustor Response</b>	<b>75</b>
4.3.1	Propellant Mixture Sound Speed .....	75
4.3.2	Combustion Chamber Acoustic Modes .....	76
4.3.3	Spectral Analysis .....	77
4.3.4	CARS Spectra Fitting .....	79
<b>4.4</b>	<b>Additional Image Processing Techniques</b>	<b>79</b>

4.4.1	Shadowgraph Image Temporal Averaging .....	80
4.4.2	Time Resolved Radial and Axial Flame Emission Intensity Tracking	80
4.4.3	Centre of Emission Intensity .....	82
4.4.4	Flame Front Tracking .....	83
4.4.5	Mean OH Emission Intensity .....	84
4.4.6	Relative Mean Flame OH Emission Intensity .....	84
4.4.7	Batch Crop and Re-Position .....	85
<b>4.5</b>	<b>Calculating Precise Propellant Injection Conditions</b>	<b>87</b>
4.5.1	Thermodynamic Properties of Oxygen .....	88
4.5.2	Thermodynamic Properties of Hydrogen .....	90
4.5.3	H <sub>2</sub> -Injector Flow Rate Data Correction .....	91
4.5.4	LO <sub>x</sub> -Injector Flow Rate Data Correction .....	93
<b>4.6</b>	<b>Summary</b>	<b>94</b>
<b>5</b>	<b>Preliminary Visualisation Results</b>	<b>95</b>
<b>5.1</b>	<b>Flame and Flow Visualisation</b>	<b>95</b>
5.1.1	Simultaneous Flame and Flowfield Visualisation .....	95
5.1.2	Time Averaged OH Emission Images .....	97
<b>5.2</b>	<b>Discussion</b>	<b>99</b>
5.2.1	Flame and Flowfield Characterisation .....	99
5.2.2	Combustor Response .....	102
5.2.3	Hydrogen Film Cooling .....	103
5.2.4	Temperature Field .....	104
5.2.5	Statistical Confidence .....	108

5.2.6	Local Mixture Ratio Approximation .....	109
5.2.7	Conclusions and Discussion from Initial Experiments .....	112
<b>6</b>	<b>Start-up Transients and Ignition</b>	<b>115</b>
<b>6.1</b>	<b>Ignition in Liquid Rocket Engines</b>	<b>115</b>
6.1.1	Gaseous O <sub>2</sub> /H <sub>2</sub> Torch Igniter .....	116
6.1.2	Propellant Flow Rate Correction During Ignition .....	118
6.1.3	Ignition Test Series - General Observations .....	119
<b>6.2</b>	<b>Characterisation of Smooth Start-up - Ignition Test Case 1</b>	<b>121</b>
6.2.1	The Start-up Process .....	121
6.2.2	Flame Stability in the Near Injector Field .....	121
6.2.3	Dynamic Pressure Data .....	124
6.2.4	Low Frequency Injection Coupled Ignition Instability .....	125
6.2.5	Dynamic Pressure Fluctuation .....	126
6.2.6	Flamefront Analysis .....	128
6.2.7	Relative Flame Emission Intensity .....	130
6.2.8	Centroid of Emission Intensity .....	131
6.2.9	Near Injector Centroid of Emission Intensity .....	135
6.2.10	Summary of Smooth Start-up - Test Case 1 .....	138
<b>6.3</b>	<b>Stable Start-up - Ignition Test Case 2</b>	<b>140</b>
<b>6.4</b>	<b>Stable Start-up - Ignition Test Case 3</b>	<b>143</b>
<b>6.5</b>	<b>Flame Emission Spectra During Ignition</b>	<b>145</b>
<b>6.6</b>	<b>Discussion</b>	<b>147</b>
6.6.1	LPRE Start-up Transients .....	147



6.6.2	Thrust Chamber Start-up, Ignition and Flame Stability .....	148
6.6.3	Flame Emission Spectra .....	150
6.6.4	Critical Pressure .....	151
<b>7</b>	<b>Steady State Combustion</b>	<b>153</b>
7.1	Test Matrix and Operating Conditions	153
7.2	Steady State Operation	157
7.2.1	Combustion Response .....	157
7.2.2	Propellant Injection Velocity Ratio vs. Momentum Flux Ratio .....	159
7.2.3	Combustion Efficiency .....	160
7.2.4	Flow-field Observations .....	162
7.3	Steady State Combustion Zone	165
7.3.1	Flame Emission Spectral Measurements .....	165
7.3.2	Combustion Zone Visualisation .....	168
7.3.3	Time Averaged and De-convoluted OH Emission Images .....	168
7.3.4	Mean OH Emission Intensity .....	171
7.3.5	Influence of H <sub>2</sub> Injection Temperature .....	173
7.3.6	Near Injector Flame Emission Intensity Tracking .....	175
7.3.7	Centroid of Flame Emission .....	177
7.3.8	Summary .....	179
<b>8</b>	<b>Combustion Instability</b>	<b>183</b>
8.1	Introduction	183
8.1.1	Characterisation of Unstable Combustion Modes .....	184
8.1.2	Low Frequency (LF) Combustion Instability .....	185

8.1.3	Experimental LF Combustion Instability Observations .....	185
8.1.4	Investigating the Stability Threshold .....	187
8.1.5	Chamber Pressure Ramping .....	189
8.1.6	Flame and Flow Field During Combustion Instability .....	191
<b>9</b>	<b>Conclusions</b>	<b>195</b>
9.1	<b>Coaxially Injected Liquid Rocket Engine Thrust Chambers</b>	<b>195</b>
9.2	<b>Experimental Test Campaigns</b>	<b>196</b>
9.3	<b>Preliminary Testing</b>	<b>197</b>
9.3.1	Background .....	197
9.3.2	General Observations .....	197
9.4	<b>Combustor Start-up Phenomena</b>	<b>199</b>
9.4.1	Background .....	199
9.4.2	Thrust Chamber Start-up and Ignition .....	199
9.4.3	General Ignition Observations .....	200
9.5	<b>Steady State Combustion</b>	<b>203</b>
9.5.1	Background .....	203
9.5.2	Subcritical Pressure Operation .....	203
9.5.3	Near Critical and Supercritical Pressure Operation .....	204
9.5.4	Influence of Propellant Injection Temperature .....	205
9.5.5	Summary .....	205
9.6	<b>LF Instability</b>	<b>206</b>
9.6.1	Background .....	206
9.6.2	LF Instability Visualisation .....	206

9.6.3	Reduced Pressure Effects .....	206
9.6.4	Summary .....	207
<b>9.7</b>	<b>Future Work</b>	<b>208</b>
<b>References</b>		<b>209</b>
<b>Appendix</b>		<b>221</b>
<b>A.</b>	<b>Coefficients for EMG Curves</b>	<b>221</b>
<b>B.</b>	<b>Publications Originating from this Thesis</b>	<b>222</b>