SATISFYING THE LNG INDUSTRY’S REQUIREMENTS FOR AGILE OPERATION ON HIGH C2+ AND INERT CONTENT GAS FUELS IN ROLLS-ROYCE AERODERIVATIVE INDUSTRIAL GAS TURBINES

by

Brian J Nolan / Rolls-Royce Canada
Background

- Steady growth in the LNG market since 1960’s.
- 1/600th the volume of natural gas in the gaseous state.
- Production tends towards intermittent (e.g. by ship) rather than continuous.
- Plant design frequently results in an envelope of high C2+ and high inert gas for use in the gas turbines.
- Rolls-Royce Energy launched analysis and testing to validate whole engine functionality for the envelope of gas mixtures.
Key Drivers for Aero derivative Usage

- Power Density
- Availability and Reliability
- Rapid starting, loading and load changes
- On-line transfer between different fuel types
- Used in a variety of sub-systems:-
  - Electrical power generation
  - Compressor boosting of gas
  - Refrigerant compression for gas cooling
  - Waste gas compression of well re-injection
## Example Spectrum of Fuel Types

<table>
<thead>
<tr>
<th>Description</th>
<th>Normal Operation</th>
<th>Normal Start</th>
<th>Fault Start 1</th>
<th>Fault Start 2</th>
<th>Fault Start 3</th>
<th>Compressor Trip</th>
<th>Booster Trip</th>
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<tbody>
<tr>
<td>CO2</td>
<td>0.00 mol%</td>
<td>3.00</td>
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<td>0.00</td>
<td>0.00</td>
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<td>Nitrogen</td>
<td>9.16 mol%</td>
<td>0.91</td>
<td>0.94</td>
<td>1.05</td>
<td>20.30</td>
<td>1.02</td>
<td>9.05</td>
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<tr>
<td>Methane</td>
<td>82.38 mol%</td>
<td>76.55</td>
<td>78.91</td>
<td>88.45</td>
<td>79.69</td>
<td>85.84</td>
<td>84.77</td>
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<tr>
<td>Ethane</td>
<td>8.32 mol%</td>
<td>9.83</td>
<td>10.13</td>
<td>10.26</td>
<td>0.01</td>
<td>12.91</td>
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<tr>
<td>Propane</td>
<td>0.13 mol%</td>
<td>6.65</td>
<td>6.86</td>
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<td>i-Butane</td>
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<td>0.89</td>
<td>0.92</td>
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<tr>
<td>n-Butane</td>
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<td>1.49</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>i-Pentane</td>
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<td>0.24</td>
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<tr>
<td>n-Pentane</td>
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<td>0.40</td>
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<tr>
<td>n-Heptane</td>
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<tr>
<td>H2O</td>
<td>0.00 mol%</td>
<td>Max 5 ppmv</td>
<td>Max 2ppmv</td>
<td>Max 2 ppmv</td>
<td>Max 2 ppmv</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>H2S</td>
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<td>Max 5 ppmv</td>
<td>Max 2ppmv</td>
<td>Max 2 ppmv</td>
<td>Max 2 ppmv</td>
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<td>0.00</td>
</tr>
<tr>
<td>Total</td>
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<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

| C1          | 82.38            | 76.55        | 78.91         | 88.45         | 79.69         | 85.84          | 84.77        |
| C2+         | 8.45             | 19.54        | 20.14         | 10.50         | 0.01          | 13.14          | 6.18         |
| Inerts      | 9.16             | 3.91         | 0.94          | 1.05          | 20.30         | 1.02           | 9.05         |
Key Operational Considerations

• Fuel ignition and flame stability
• Burner Injection Velocity
• Combustion Rumble
• Delivery System Pressure Limits
• Liquid Condensates
• Compressor Working Lines
DLE Operational Considerations

- Autoignition/flashback
- Emissions Control
- Combustion Noise
- In 2004, Rolls-Royce launched a rig initiative to understand the DLE effect with increasing C2+ and inert.
Test Set-up

- Combustor premixers
- Combustion chamber, primary zone
- Combustion chamber, secondary zone
- Discharge nozzle
- Exhaust pipe and exhaust cooling
- Water cooled emissions sampling
Test Outcome
Test Outcome

• Zone A - Universally acceptable
• Zone B - Highly likely acceptable for all operational & power requirements
• Zone C - Case-by-Case fuel and application assessment required.
• Zone D - Likely to only be acceptable for limited operational requirements
Zone B Summary

- Highly likely acceptable for all operational & power requirements
- Some operational experience
- Approaching ① sees increasing fuel delivery pressures, particularly on high CO2 on higher power engine marks.
- Approaching ② sees combustion noise signature beginning to change when high concentrations of butane are present, requiring adjustment in primary zone temperatures.
Zone C Summary

- Case-by-Case fuel and application assessment required.
- Limited operational experience
- Approaching 3 sees combustion noise signature beginning to change even on lighter species of C2+ (propane and ethane)
- Approaching 4 sees increasing fuel delivery pressures, even on N2. In addition, fuel ignition repeatability during start-up begins to decline when C2+ elements are limited.
Zone D Summary

- Likely to only be acceptable for limited operational requirements without some changes to hardware (e.g. fuel delivery pipe-work sizing).
- In Zone D1, on any C2+ fuel, the operational window between lean blow out and noise control becomes impractical without allowing emissions levels to begin to elevate.
- In zone D2, fuel manifold conditions begin to limit achievable power. Fuel ignition repeatability during start-up is poor in zone D2 when C2+ elements are limited.
Conclusions

• Rig testing, analytical assessment and service experience read-across has shown that the RB211 DLE machine has the ability to satisfy the operational requirements of a significantly wider inert and C2+ envelope than originally standarised, without hardware change.

• Due to permutations of inert, C2+, site conditions and required operational maneuvers, the significant number of acceptability criteria a gas turbine manufacturer must consider make it difficult to draw lines of absolute unacceptability and case-by-case analysis is often required.